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Sustainable and profitable crop and livestock systems in south-central coastal Vietnam

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Sustainable and profitable crop and livestock systems in south-central coastal Vietnam

Proceedings of the final workshop held in Quy Nhon, Vietnam, 5–6 March 2013

Editors: Surender Mann, Mary C. Webb and Richard W. Bell

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Cover: Smallholder crop and livestock management systems and their implications in south-central coastal Vietnam. (Photo: Richard W. Bell)

Foreword

Vietnam is a key partner of the Australian Centre for International Agricultural Research (ACIAR) in tackling issues of rural poverty. Productivity on either a land or labour basis is low in Vietnam, and there is limited availability of arable land. An increasing population and competition from urban and industrial uses are pushing more smallholder farmers onto marginal lands, including the sandy soils of the south-central coast. Overexploitation of land, water and soil resources, together with inappropriate farming approaches, is resulting in land degradation in these systems.

South-central coastal Vietnam is a region where research to underpin profitable but sustainable crop and livestock production systems benefits from Australian–Vietnamese collaboration. The research described in these proceedings was designed as a multidisciplinary venture linked with national research institutes, including provincially based research and extension departments. Its aim was to identify and facilitate adoption of promising resource management practices, for sustainable and profitable agricultural systems best suited to local conditions that enable improved market engagement.

At a workshop held in Quy Nhon, Vietnam, in March 2013, Vietnamese and Australian researchers shared their findings across the wide range of disciplines required to improve crop and livestock production integration. These included dealing with crop and livestock systems and available resources; the limitations to crop production on the infertile sandy soils, such as macronutrient and micronutrient deficiencies; value-chain analysis of crops with suggestions to improve farmers' incomes; forage and cattle production; and risks of groundwater pollution from agriculture. The integration of these disciplines is a major achievement of the workshop.

The research described in these proceedings is relevant to other regions that are adjacent to the coast within Vietnam and other countries (such as Thailand, Cambodia, Lao PDR, Indonesia, Malaysia, Australia, Sri Lanka and India) where farmers have small landholdings and are dealing with sandy soils. ACIAR will look for opportunities to promote the lessons learned in these proceedings to other regions.

Nick Austin
Chief Executive Officer
ACIAR

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- SMCN/2007/109—*Sustainable and profitable crop and livestock systems for south-central coastal Vietnam*
- SMCN/2003/035—*Improving the utilisation of water and soil for tree crop production in coastal areas.*

Abbreviations

ACIAR	Australian Centre for International Agricultural Research
ADF	acid detergent fibre
Al	aluminium
ASISOV	Agricultural Science Institute for Southern Central Coast of Vietnam
B	boron
C	carbon
CEC	cation exchange capacity
CF	composite fertiliser
CP	crude protein
Cu	copper
CWRPI	Centre for Water Resources Planning and Investigation
DARD	Department of Agriculture and Rural Development (provincial)
DONRE	Department of Natural Resources and Environment (provincial)
DM	dry matter
EC	electrical conductivity
ET_c	evapotranspiration of a crop
FUE	fertiliser use efficiency
FYM	farmyard manure
GSO	Government Statistic Office
ha	hectare
IMC	irrigation management company
INM	integrated nutrient management
IWRP	Institute for Water Resources and Planning
K	potassium
ka	thousands of years before present
KCl	potassium chloride
LW	liveweight
MARD	Ministry of Agriculture and Rural Development
m asl	metres above sea level
Mha	million hectares
Mn	manganese
Mo	molybdenum
MONRE	Ministry of Natural Resources and Environment
Mt	million tonnes
N	nitrogen
NDF	neutral detergent fibre
OM	organic matter
P	phosphorus
S	sulfur
SCAMP	Soil Constraints and Management Package
SCC	south-central coastal (Vietnam)
t	tonne
UNESCO	United Nations Educational, Scientific and Cultural Organization
VAWR	Vietnam Academy of Water Resources
VND	Vietnamese dong (currency)
VR	variable rate
WUE	water use efficiency
Zn	zinc

Section 1: Crop and livestock systems and available resources

This section presents an overall view of the farming practices including crops, trees, livestock, and available organic resources as a result of farming systems and their impact on nutrient balances. Water resources, soil types, properties and limitations to crop production and management options are also discussed.

Crop and cattle production systems in south-central coastal Vietnam

Hoang Thi Thai Hoa[1], Nguyen Xuan Ba[1] and Robert Summers[2]

Abstract

Sandy soils make up more than 233,000 hectares in the coastal zone of the south-central coastal (SCC) region of Vietnam. Most of the population live on the inherently poor sandy soils and their livelihoods are largely dependent on cropping and livestock. The objective of this study was to better understand the local farming systems of the sandy areas. To assess sustainability of current farming systems, study sites were chosen in one commune each from the SCC provinces of Binh Dinh, Ninh Thuan and Phu Yen, which are mainly rainfed and subject to drought.

The region is dependent on agriculture, with rice, peanut and cassava crops being the most popular. Most households also raised pigs, buffalo and cattle. Typical tree crops included mango, cashew and custard apple. The crop productivity was relatively low due to the unfavourable growing conditions (infertile sandy soil and lack of water) combined with poor animal productivity. Application of fertilisers depended on household circumstances and access to manure from household livestock. Rice received relatively high nitrogen compared with other nutrients, with little use of manure, while legumes and vegetables received application of other macronutrients with high rates of manure.

Farm sizes were relatively small in Binh Dinh and Phu Yen compared with Ninh Thuan. Larger landholdings and lower rainfall in Ninh Thuan prompted the farmers to up-scale raising of cattle, with sheep and goats being twice that of the other two provinces. Households in Binh Dinh and Phu Yen had greater numbers of pigs and poultry. In Binh Dinh and Phu Yen, 41% of households primarily utilised intensive stall-feeding in comparison to only 6% in Ninh Thuan.

Not many options exist to improve incomes, other than increasing productivity from limited agricultural landholdings. Improvement of soil fertility based on better use of available on-farm resources to improve crop and animal nutrition were identified as the main opportunities. These constraints combined with other economic difficulties in the region, such as lack of credit, capital for investment, inputs, market information and market access, further impede farmers' incomes. Although agricultural technical support is available through research and extension agencies, the complex and significant interactions of options require greater capacity and development of assessment and extension tools.

Introduction

Agriculture has played an important role in Vietnam due to its significant contribution to the national economy. Although its share of gross domestic product (GDP) has declined during the process of industrialisation and modernisation, agriculture still remains the backbone of the Vietnamese economy. It contributes approximately 17% of the country's GDP and 30% of total export value. The role of agriculture is significant for employment where 70% of the population live in rural areas and two-thirds of the labour force of the rural population are engaged in agriculture (Nguyen Dang Hao 2007).

Economic reform to a more market-oriented economy has resulted in a steady improvement in

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the rural household sector with a rapid increase in agricultural output which has not only met domestic demand, but also increased exports to world markets. For example, during the past 10 years, production of paddy has grown at over 5% per year, moving Vietnam from chronic food deficit to being the world's second-largest rice exporter.

Despite the dynamic development of Vietnam's household economy, the incidence of poverty and inequality is still relatively high in some regions. This study focuses on the coastal zone of the south-central region which is dominated by sandy infertile soils and a long dry season (6–9 months), especially in the southern provinces of Ninh Thuan and Binh Thuan (400–700 mm annual rainfall). Natural resource constraints and less-developed marketing systems and transport of crop and livestock products impede further development and poverty alleviation in this region.

Cattle production plays a very important role in farming systems and Vietnamese life. Demand for beef is increasing, particularly in the major urban centres, due to both tourism and increasing disposable income of the local population. Increasing cattle production is seen as an opportunity to help alleviate poverty in central Vietnam.

Cattle numbers increased rapidly during 2004–07 (Table 1) and then tended to decrease after that, due to price fluctuations and foot-and-mouth disease, among other reasons. Central Vietnam is a potential area for further cattle development. About 40% of the total number of cattle in the country are kept in the central region.

Growth in cattle numbers was led primarily through domestic demand, with an estimated 95% of beef consumed by Vietnamese, particularly in Ho Chi Minh City, which is the market for an estimated 70–80% of cattle from the south-central coastal (SCC) region Although this presents an attractive opportunity for smallholder farmers, there are a number of problems that need to be tackled before the opportunity can be exploited, especially in relation to feed quantity and quality.

The overall aim of the crop and livestock project integration was to identify and facilitate adoption of promising resource-management practices for sustainable and profitable production systems best suited to local conditions and also to enable improved market engagement.

As a first step, a farm survey was conducted in selected communes of the focus provinces of Binh Dinh, Phu Yen and Ninh Thuan. This survey aimed to achieve better understanding of the local farming systems and of resource use and management in the sandy areas of SCC Vietnam.

Farm survey sampling method

Selection of target districts and communes

The survey was conducted in sites selected as areas representing sandy soils of the SCC region. One commune from each of three districts was chosen:

- Cat Trinh commune, Phu Cat district, Binh Dinh province
- An Chan commune, Tuy An district, Phu Yen province
- Phuoc Dinh commune, Thuan Nam district, Ninh Thuan province.

After an analysis using a participatory rural approach (PRA), the following villages from the three communes were selected: Phu Kim and An Duc (Cat Trinh commune), Phu Qui, Phu Thanh and Phu Phong (An Chan) and Son Hai 1, Son Hai 2, Bau Ngu and Tu Thien (Phuoc Dinh).

Using a targeted sampling method, 180 households (60 from each of the study communes) were chosen to represent the main characteristics of their respective groups as recorded in the household socioeconomic classification annually certified by the Ministry of Labour and Invalid Social Affairs (MOLISA). This report distinguishes four categories of farm households: poor and non-poor, and with and without beef-cattle raising. The welfare indicator of the non-poor household category is defined as a monthly income per capita over Vietnamese dong

Table 1. Cattle population and growth rates in Vietnam from 2004 to 2009

Year	2004	2005	2006	2007	2008	2009
Population (million)	4.91	5.54	6.51	6.72	6.33	6.10
Herd growth rate (%)		12.8	17.5	3.3	–5.8	–3.7

Source: Vietnamese Statistics Department data, 2009

(VND)200,000 (i.e. about A$13) and the poor group, which is under this poverty line, is defined in terms of the value of a certain volume of rice at local prices.

Survey data source and collection

The primary data were collected from 88 households with cattle and 92 households without cattle. The household interview was conducted using a questionnaire developed by the project team led by Hue University of Agriculture and Forestry. A training course was also conducted at the Agricultural Science Institute for Southern Central Coast of Vietnam (ASISOV) to interview farmers. The questionnaires explored the following information:

- farm and household characteristics, including family size, age, education, sex, occupation, farm size, number of land parcels etc.
- household cropping and livestock production system
- main constraints to household production.

Secondary data were collected from yearly statistical reference books published by the General Statistics Office (GSO) based in Binh Dinh, Phu Yen and Ninh Thuan and from the data supplied by local authorities at village, commune, district and the provincial levels. The study also involved gathering information on farming systems, natural conditions, infrastructure, rural institutions and organisations from local partners at various levels that played a major role in the region, such as the Department of Agriculture and Rural Development (DARD) in each province, Extension Stations, District Sections of DARD and Commune People's Committees.

Study site characteristics

Of the three study communes, Cat Trinh has the largest area, number of households and population (Table 2). It also has comparatively well-developed infrastructure, mainly because half of the commune is located along National Road No. 1 and a provincial road. The inter-village roads have been upgraded in recent years. Apart from the commune's local market, there is a regional market where farmers can sell the bulk of their products and purchase the bulk of their inputs. As a result, local people have more access to exchange goods and to travel to other places.

The infrastructure of An Chan commune is less developed than others in the coastal zone. In the rainy season, it is sometimes isolated by flooding. The commune and village roads are in very poor condition. The main water source for An Chan is Ky Lo River, but it is often dry during summer.

The three study communes are mainly dependent on agriculture. Although cropping patterns have seen more diversification over time, rice still remains the dominant crop, except in Phuoc Dinh commune, where scarcity of water due to low rainfall impedes rice production. Farming systems in Cat Trinh and An Chan communes are rather similar, while Phuoc Dinh commune has a higher proportion of cash crops, such as watermelon, hot pepper, tomato and peanut.

On average, in the sandy zone there are 4.8–5.6 persons per household (Table 3) compared with the whole-country average of 5.0 persons (Nguyen Dang Hao, unpublished report 2009). Half of the total population is between 15 and 55 years old, i.e. there

Table 2. General characteristics of the three study communes

	Commune		
	Cat Trinh	An Chan	Phuoc Dinh
District	Phu Cat	Tuy An	Thuan Nam
Province	Binh Dinh	Phu Yen	Ninh Thuan
Households	2,616	1,888	1,959
Population	14,250	9,200	NA
Area (ha)	4,755	1,353	615
Agricultural land	1,410	547	183
Cattle	3,672	1,092	2,500
Pigs	5,500	1,000	146
Sheep and goats	843	NA	2,200
Poultry	28,000	17,800	NA

Note: NA = not available

is potential for a large labour force. Consequently, demand for employment is high. If an alternative source of employment is not created, the pressure on agricultural industries to create further employment locally will increase substantially in the coming years. The gender balance is skewed, with males making up 53.4–62.5% of the population.

The farm area of surveyed households in Ninh Thuan was 15.5 times larger than households in Phu Yen and 6.0 times larger than households in Binh Dinh province, which had the highest proportion of agricultural land (65–97%). The difference between total and agricultural land in Ninh Thuan suggests that households have the opportunity to raise cattle extensively. The other two provinces lack available natural resources, so the potential for improving extensive animal husbandry production is limited, leaving them with the option of intensifying crop and animal production.

A higher level of education leads to increased capacity for adopting advanced techniques, with the reverse also true (Le Thi Hoa Sen 2005). In all provinces, education among the population was relatively limited, although the majority of household heads had graduated from secondary (grades 6–9) or high school (grades 10–12). About 3–10% of the working-age population were illiterate. Less than half (40%) had education to secondary and high school level (Table 4). The average grade level attained by the workforce in the region was just beyond grade 7, and over 90% of the working-age people had no formal skills or training.

In rural areas, land is the main resource available to households to generate income. Statistically, most farms were small, but farm size across the study sites varied greatly (Table 5). The survey data revealed that, in general, the larger the landholding, the greater the wellbeing of the household.

Crop production

In general, the cropping systems in the sandy region were diverse. The main cropping system revolved around food crops such as rice, peanut and cassava, with some perennial tree crops such as mango, cashew and custard apple. Most households (around 90%) in Cat Trinh and An Chan produce rice. In contrast, in Phuoc Dinh, only 3% produce rice (Table 6), due to lack of irrigation and a prolonged dry season.

Table 3. Population, labour and cultivated land of surveyed households in the three study provinces

Indicator per household	Province		
	Binh Dinh (*n* = 60)	Phu Yen (*n* = 60)	Ninh Thuan (*n* = 60)
Total population[a]	4.8 ± 2.1	4.6 ± 1.6	5.6 ± 2.1
Labour units[a]	2.4 ± 1.6	2.9 ± 1.5	3.0 ± 1.6
Male (labour units)[a]	1.3 ± 1.0	1.5 ± 1.2	1.6 ± 1.0
Female (labour units)[a]	1.1 ± 0.8	1.4 ± 1.0	1.43 ± 1.0
Total area (m^2)[b]	8,166–10,970	3,163–4,473	49,310–192,932
Area of agricultural land (m^2)[b]	6,085–7,374	3,069–3,448	32,070–42,234

[a] Average ± standard deviation
[b] Range

Table 4. Literacy of the working-age population in the surveyed households

Commune	Illiterate		Primary		Secondary + High		University	
	N	%	*n*	%	*n*	%	*n*	%
Cat Trinh	5	8.3	30	50.0	24	40.0	1	1.7
An Chan	6	10.0	33	55.0	20	33.3	1	1.7
Phuoc Dinh	2	3.3	35	58.3	21	35.0	2	3.3

Note: data relate to the survey respondent from each household

Table 5. Agricultural land area (ha/household) of the survey respondents by welfare indicator

Category	Cat Trinh commune		An Chan commune		Phuoc Dinh commune	
	Average	SE[a]	Average	SE[a]	Average	SE[a]
Household type						
Poor	0.58	0.02	0.29	0.02	2.54	0.88
Non-poor	0.71	0.04	0.28	0.01	5.92	0.43
Beef-cattle raising						
With cattle	0.64	0.02	0.36	0.02	4.10	0.14
Without cattle	0.71	0.04	0.23	0.01	1.41	0.08

[a] SE = standard error

Table 6. Proportion (%) of surveyed households growing various crops in the three study communes of the sandy region

Crop	Commune		
	Cat Trinh	An Chan	Phuoc Dinh
Rice	86.7	91.7	3.3
Cassava	50.0	11.7	5.0
Peanut	26.7	–	25.0
Maize	–	6.7	13.3
Watermelon (fruit, seed)	–	–	35.0
Cashew	21.7	1.7	3.3
Mango	10.0	3.3	15.0
Custard apple	–	–	15.0
Hot pepper	–	–	13.3
Grass	8.3	30.0	18.3
Leafy vegetables, eggplant, tomato, water spinach	1.7	11.7	6.7

Note: Data in each column are number of households growing each crop compared with total households in each commune (n = 60)

The cropping systems in the three communes are closely associated with food self-sufficiency or food security, the second priority being to grow cash crops that generate higher income. Households that grow cash crops that are less vulnerable to failure that may affect their income. Grass was grown by 30% of households in An Chan, comprising only small areas in the household garden, whereas in Phuoc Dinh pasture was grown by 18% of households, as cattle feed or for grazing.

Crop rotation and yield of main crops

Growing rice is the main focus of most households as it provides them with their most favoured staple food. Farmers grow three rice crops a year in Cat Trinh, two rice crops in An Chan but only one rice crop in Phuoc Dinh, covering 0.14, 0.09–0.19 and 0.14–0.70 hectares (ha), respectively. Crops such as cassava also provide supplementary food for people and feed for animals. On average, the area under cassava cultivation in the spring season was highest in Cat Trinh commune (0.27 ha) and lowest in Phuoc Dinh commune (0.10 ha). In contrast, cassava cultivation was highest in Phuoc Dinh in the summer season (0.55 ha). Peanut was also found to be increasingly grown on inland sandy areas. But the distribution of peanut area was skewed toward Phuoc Dinh, where the average area of peanut was 0.48 ha—larger than that of Cat Trinh (0.28 ha). Vegetables were were grown mainly in Phuoc Dinh in both main (spring and summer) seasons.

The yield of the crops was generally low in the study zones, with the rice yield varying from 2.7 to 4.9 tonnes (t)/ha in the spring season, and from

2.4 to 4.0 t/ha in summer. Peanut yield was about 3.0 t/ha in Cat Trinh and Phuoc Dinh. Cassava yield varied greatly between 2.6 and 12.7 t/ha.

Mango, cashew and custard apple were the main tree crops. The number of mango trees under 4 years old per household ranged from 12 in An Chan to 14 in Cat Trinh and 40 in Phuoc Dinh. Custard apple occurred only in Phuoc Dinh commune with 131 trees per household. Yield of tree crops varied between communes due to different management practices and tree age.

Nutrient use from fertiliser and livestock manure

Farmers applied farmyard manure (FYM) combined with chemical fertilisers to all the main crops in the three communes. For rice production in the SCC region, the recommended rates of fertiliser per ha per season are 100 kg nitrogen (N), 26 kg phosphorus (P), 50 kg potassium (K) and 10 t of FYM. Actual fertiliser application rates for rice were higher for N than the recommended rates. K and P and especially FYM applications were lower than the recommended rates, mainly due to lack of knowledge and poor fertiliser-application techniques (Truong Van Tuyen et al. 2003). A low response to P application as a result of residual soil P may have also contributed to lesser use of P fertilisers. The main source of nutrients for most of the crops grown in these regions is from inorganic fertilisers and to a lesser extent from FYM.

Most farmers applied higher amounts of FYM to vegetables and legumes than rice mainly because of the higher price of the harvested products. Another reason was the convenience of transporting it only a short distance, as vegetables were normally grown close to the household. In addition, FYM may be also more effective in aerobic soils (for vegetable cultivation) compared with rice that is usually grown in anaerobic (flooded) soils. Use of chemical fertilisers was unbalanced for crops like peanut as farmers use the same recommended rates (100 kg N, 26 kg P, 50 kg K) in addition to 8 t of manure per ha rather than the 40 kg N, 26 kg P and 50 kg K with 8 t of manure that would have met crop nutrient requirements.

Most of non-poor households applied more FYM to crops than did poor households, and rates of chemical fertiliser application were lower and more balanced than on farms without cattle (Tables 7 and 8). Non-poor households may have been responding better to advice or poor households may have simply been limited by economics. In general, households raising cattle applied higher amounts of FYM than those without cattle (Table 7).

Fertilisers applied to tree crops depended on the type of tree, age and commune. FYM was applied mainly to tree crops such as mango, cashew and custard apple in combination with chemical fertilisers, with the exception of cashew in Cat Trinh which was not fertilised much as the price of cashew was low in 2009 when the survey was conducted.

Constraints identified through the farm survey

Production activities of the households in the region were constrained for many reasons. The main constraints to current cropping practices were as outlined below.

Low quality of land

Low soil fertility was found to be a major constraint to agricultural productivity. Most of the soils are acidic, have low organic matter and low clay content, leading to low water and nutrient retention capacity (Phan Thi Cong, unpublished data 2009).

Lack of water and irrigation

More than 50% of the households lacked irrigation infrastructure and had limited water availability.

Widespread pests and animal diseases

Pest and animal diseases were considered as a serious constraint, with about 21% of households reporting that they had difficulties in controlling pests.

High input prices and lack of high-quality inputs

Poor households with low financial capacity had difficulty in purchasing new technologies (machinery/tractor), seeds for improved crop varieties and new animal breeds, due to their high cost. In addition, the high costs of fertilisers for improved crops and animal feed for new animal breeds further restricted poor farmers.

Lack of knowledge

Training and education in the households was very low. This limited their ability to take advantage of new technologies, such as introducing new varieties and changing cultivation techniques. Poor households were less educated than more prosperous households.

Lack of information

Lack of access to market information limited the potential for poor farmers to adopt profitable agricultural and agriculturally based activities, with the result that they often sold their products at a low farm-gate price and bought inputs at a high price.

Table 7. Average use (kg/ha) of fertiliser and farmyard manure (FYM) for main annual crops by surveyed households in the study communes with and without cattle raising

Fertiliser	Spring season (December–May)		Summer season (May–August)		Third season (August–October)	
	With cattle	Without cattle	With cattle	Without cattle	With cattle	Without cattle
Cat Trinh commune						
FYM	7,836	6,248	6,260	5,422	6,074	7,916
Urea	108	204	108	216	202	230
Superphosphate	200	176	74	36	182	226
KCl	90	46	58	62	46	106
NPK (16:16:8)	180	258	216	252	268	210
An Chan commune						
FYM	6,612	4,266	6,250	5,800	8,222	2,614
Urea	334	326	288	310	220	138
Superphosphate	50	100	130	82	0	150
KCl	62	100	112	140	50	0
NPK (16:16:8)	328	298	366	366	584	162
Phuoc Dinh commune						
FYM	10,000	7,878	–	–	10,326	–
Urea	100	106	–	–	394	–
Superphosphate	0	208	–	–	594	–
KCl	0	78	–	–	154	–
NPK (16:16:8)	10	304	–	–	532	–

Note: FYM = farmyard manure; KCl = potassium chloride; NPK = nitrogen–phosphorus–potassium

Table 8. Average total application (kg/ha) of nitrogen (N), phosphorus (P) and potassium (K) for main annual crops by households in the study communes with and without cattle raising

Nutrient source	Nutrient applied (kg/ha)					
	With cattle			Without cattle		
	N	P	P	N	P	K
Cat Trinh commune						
FYM[a]	32	6	15	31	5	14
Inorganic fertiliser	100	26	47	138	27	51
An Chan commune						
FYM[a]	34	6	15	20	4	9
Inorganic fertiliser	197	34	65	163	27	58
Phuoc Dinh commune						
FYM[a]	49	10	20	38	8	16
Inorganic fertiliser	172	45	63	97	35	59

[a] Estimated nutrient content only: 1 t farmyard manure (FYM) has 4.8 kg N, 1 kg P and 2 kg K

Difficult market access and infrastructure

A major constraint to production and profit was limited transport infrastructure, which leaves the farming communities isolated and without access to markets and high cost of transport of inputs with periodic isolation due to inclement weather.

Scale and structure of animal husbandry

Cattle, pigs and poultry were the main animal husbandry enterprises for households in SCC Vietnam. Of those surveyed, the proportion of households with cattle production ranged from 48% to 55%, of which those in Phuoc Dinh commune had the highest proportion. The total number of animals per household in Phuoc Dinh was approximately four times larger than An Chan and Cat Trinh communes (Table 9). This result reflects the availability of land resources for households, as Cat Trinh and An Chan have constraints in land availability that restrict the scale of cattle production.

Phuoc Dinh predominantly had extensive cattle production systems, with only 33% crossbred animals, whereas Cat Trinh and An Chan had 50% crossbred animals, suggesting a greater incidence of semi-intensive cattle production. The structure of the herd in each province differed and represented a different strategy for animal production and use.

Pig and poultry production were popular in the three surveyed communes (Table 10). The scale of pig and chicken production in Cat Trinh and An Chan was larger than Phuoc Dinh ($p < 0.05$). Conversely, Phuoc Dinh had more sheep and goats per household than Cat Trinh and An Chan ($p < 0.05$). This possibly reflects the competitiveness of these industries in the different provinces or government priorities for their production.

Table 9. Scale and structure of cattle production in the survey communes based on age and breed (animals per cattle-raising household)

	Cat Trinh (*n* = 31)		An Chan (*n* = 29)		Phuoc Dinh (*n* = 33)	
	Yellow cattle	Crossbred	Yellow cattle	Crossbred	Yellow cattle	Crossbred
Breeding cow	0.19	0.42	0.97	0.41	3.52	2.15
Female calf, <12 months	0.35	0.26	0.38	0.21	1.12	0.27
Male calf, <12 months	0.19	0.26	0.17	0.28	0.58	0.33
Female calf, 12–24 months	0.16	0.06	0.10	0.07	2.09	0.27
Male calf, 12–24 months	0.03	0.10	0.24	0.10	0.48	0.48
Female calf, >24 months	0.39	0.52	–	–	1.55	0.33
Bull, > 24 months	0.29	0.35	0.28	0.28	0.76	1.12
Total[a]	1.61 ± 1.76	1.97 ± 2.48	2.14 ± 2.45	1.41 ± 1.62	9.39 ± 10.37	4.73 ± 7.43
Draught-power cattle[a]	0.87 ± 0.81		0.41 ± 0.82		1.27 ± 1.86	
Fattening cattle[a]	2.71 ± 1.75		1.38 ± 1.52		7.18 ± 6.85	

[a] Average number per household ± standard deviation

Table 10. Scale of livestock and poultry production of surveyed households

Type of animal[a]	Commune		
	Cat Trinh (*n* = 60)	An Chan (*n* = 60)	Phuoc Dinh (*n* = 60)
Pig	2.4 ± 6.26	0.8 ± 1.91	0.1 ± 0.52
Chicken	20.2 ± 33.89	9.2 ± 10.63	5.8 ± 14.12
Duck and goose	0.2 ± 1.19	1.2 ± 3.72	3.1 ± 13.41
Buffalo	0.07 ± 0.36	0.03 ± 0.26	–
Goat	–	0.05 ± 0.39	2.37 ± 13.43
Sheep	–	–	2.68 ± 13.65

[a] Average number per household ± standard deviation

Mode of cattle production

The three modes of cattle production in the three SCC provinces were grazing, supplementation and stall-feeding in order of increasing intensity. Grazing is the most extensive form of production, but can be intensified through supplementation. Stall-feeding is the most intensive and is based on feeding rice straw, crop residues, concentrates and grass.

In Cat Trinh and An Chan communes, around 41% of households primarily utilised intensive stall-feeding in comparison to only 6% in Phuoc Dinh (Table 11). Only 4% and 16% of farmers utilised grazing without supplementation in An Chan and Cat Trinh, respectively, whereas 24% of Phuoc Dinh households grazed cattle. In Phuoc Dinh, the cattle production is more extensive, relying on grazing and some supplementation, whereas the other two communes are primarily semi-intensive and intensive. Additionally, the mode of cattle production is related to scale, as grazing is more practical for larger herds rather than cut and carry.

Managing cattle production

Grazing cattle in Phuoc Dinh takes two to four times longer due to grazing land being larger and further from households, whereas in Cat Trinh and An Chan stall-feeding is more common. Bathing cattle and supplementing diets with vitamins and salt are common practices in Cat Trinh and An Chan.

Artificial insemination is an additional indicator for assessing the intensity level of cattle production. All households in Phuoc Dinh used uncontrolled natural insemination, reflecting the extensive production system, compared with only 31% and 22% of households in Cat Trinh and An Chan, respectively. In Cat Trinh and An Chan, the majority of households used controlled natural insemination with a minority using artificial insemination. The source of semen was Zebu purebred or crossbred, such as Brahman and Red Sindhi. This contributed to the high percentage of crossbred cattle in Cat Trinh and An Chan.

Yellow cattle bulls are predominantly used in Phuoc Dinhfor extensive grazing (69%) but crossbred bulls predominate in Cat Trinh and An Chan (Table 12) and are better suited as stall-feeding animals.

In all communes, the specific purpose for which the animal was being raised was the most common criterion for whether they were fed supplements, consequently affecting efficiency of production. In Phuoc, lower rainfall and the predominance of grazing based on the season was also an important criterion for offering concentrates (Table 13). Cows and fattening cattle were the priority cattle classes for receiving concentrate. However, the number of households that offered concentrate to cattle was low, and cattle production relied mostly on other available feed resources, including grazing, crop residues, and cut and carry.

Conclusions

This survey has provided general information on cropping and cattle production in three communes representing the sandy landscapes of SCC Vietnam.

The household survey showed farm size measured by land area was relatively small in Binh Dinh and Phu Yen provinces and very large in Ninh Thuan province, but farm size varied considerably with the income level of households.

Food crops including rice, peanut and cassava were the most popular in Cat Trinh and An Chan communes, while popular crops in Phuoc Dinh commune included hot pepper and watermelon. The main tree crops in the three communes were mango, cashew and custard apple. Crop yields in the three communes were low compared with the whole country due to the main constraints of low soil fertility and climatic conditions.

Use of fertilisers for crops depended upon crop type, household condition and number of animals raised. In general, farmers applied FYM to crops considered high value, such as legumes and vegetables. Chemical fertilisers were the main source of nutrients; however, rates of fertiliser application varied and were unbalanced for crops such as rice, which received too much N, indequate K and P, and less FYM. But other crops like legumes and vegetables received fertiliser at appropriate, and usually higher, rates. Non-poor farmers and farmers raising cattle used chemical fertilisers in combination with FYM for crops more often than poor farmers and those not raising cattle.

Two-thirds of surveyed households stated that lack of capital was the most important constraint to agricultural production. Variable rainfall pattern was also thought to be either important or very important by two-thirds of households.

For animal production, capital was identified by 69% of farmers as the main factor limiting cattle production. Other constraints, such as lack of feed, diseases, and lack of labour, were listed as important or very important by just under half of surveyed households.

Table 11. Mode of cattle production (% of surveyed households) in the study communes

Mode of cattle production	Commune		
	Cat Trinh (n = 31)	An Chan (n = 29)	Phuoc Dinh (n = 33)
Grazing	16.1	3.5	24.2
Grazing and supplementation	41.9	55.2	69.7
Stall-feeding	41.9	41.4	6.1

Table 12. Type of bull genotype (% of surveyed households) used in the study communes

Type of bull	Commune		
	Cat Trinh (n = 25)	An Chan (n = 23)	Phuoc Dinh (n = 16)
Yellow cattle	32.0	34.8	68.8
Red Sindhi	4.0	–	6.3
Red Sindhi crossbred	20.0	60.9	25.0
Brahman	4.0	0.0	–
Brahman crossbred	16.0	4.3	–
Others (Limousine, Simmental etc.)	24.0	–	–

Table 13. Top-four criteria upon which cattle are offered supplement (% of surveyed households) in the study communees

Criterion	Commune		
	Cat Trinh (n = 31)	An Chan (n = 29)	Phuoc Dinh (n = 33)
Age	12.9	13.8	–
Sex	3.2	13.8	3.0
Season	3.2	6.9	24.2
Purpose for raising	19.4	55.2	39.4

Feed for cattle production in SCC Vietnam is dependent on the season and can be constrained during the dry season, leading to its shortage. To overcome this problem, farmers opted to plant grasses, store crop residues, feed concentrates, cut and feed natural grass and perhaps reduce numbers of cattle. Depending on the province, 41–77% of surveyed householders reported storing by-products. In all provinces, approximately 60% of farmers reported cutting natural grass. Supplying concentrates was most common (55%) among the farmers in Binh Dinh, while in Phu Yen, planting grass was more common (59%). Reducing cattle numbers was uncommon but 15–20% of farmers sold cattle at a lower price during the feed shortage period, which resulted in greater influx of cattle to the market.

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Natural organic resources and nutrient balance in the farming systems of south-central coastal Vietnam

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Abstract

The availability and recycling of organic resources in sandy soils plays an important role in nutrient balance and nutrient availability for crops. The current utilisation of organic materials on farms in south-central coastal (SCC) Vietnam and its implications for nutrient balance on farms in this sandy terrain are not known. In 2009, after a survey of households in three communes (An Chan commune, Phu Yen province; Cat Trinh, Binh Dinh province; and Ninh Phuoc, Ninh Thuan province) located in the sandy region of SCC Vietnam, 91 samples of organic materials were collected to examine the existing use of organic resources, their nutrient composition and their potential contribution in supplying nutrients to crops. The samples included six kinds of materials: cattle manure, buffalo manure, pig manure, sheep manure, plant residues (peanut stem, cassava leaf, maize leaf, straw) and ash from burning crop residues in the field. Farmers in the selected communes utilised different kinds of organic material for various purposes, such as fuel for cooking, soil amendment and animal feed. There were no significant differences in total carbon (C) and total phosphorus (P) content of the organic samples except for the lower C in ash. However, each kind of manure or other organic material had different composition depending on the animal type and amount of added materials, method of preparation and time of storage. Among different kinds of farmyard manure (FYM), pig and cattle manure had higher nitrogen (N) than sheep manure, but P and potassium (K) concentrations were not different among manures, while among crop residues, cassava had lower N and K than other plant residues.

Partial nutrient balance at the field-plot level in farming systems of SCC provinces was developed to quantify inputs and outputs of macronutrients (NPK) in fields over 1 year's duration. Nitrogen balance was positive for rice–rice fields; however, N imports were less than exports in the other cropping patterns. Phosphorus imports exceeded P exports in all studied fields except for forages, whereas K exports always exceeded K imports regardless of whether one crop or two per year were grown. These results suggest that noticeable macronutrient losses occur out of fields, in managing crop residues, in FYM processing and in animal manure recycling but these are not necessarily losses from the farm. Further studies are needed to optimise nutrient cycling, and especially organic resources, in local farming systems. In the particular case of K, negative balances at the field level suggest a likely impact of this element in limiting crop yield.

Introduction

Soil organic matter (OM) is important in crop production because of its effect on soil physical condition and its role in supplying nutrients to plants. It is especially important in sands due to the lack of reactive surface area and microporosity from clay materials. Organic matter plays a critical role in soil structure formation and stability, which in turn increases resistance to wind erosion on sands. In addition, not only does soil OM increase available nitrogen (N), sulfur and phosphorus (P) levels in sands, it also improves the nutrient use efficiency of

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applied mineral fertilisers (Pinitpaitoon et al. 2011). It promotes the soil ecosystem health and stimulates micro-organisms that recycle carbon (C) and protect plants from diseases. An increase of soil OM can counteract the ill effects of high sand content, reduce the soil's total porosity and bulk density and increase microporosity and water-holding capacity (Rasmussen and Collins 1991).

Repeated applications of mature compost made from farmyard manure (FYM) or rice straw and crop residues (roots, chaff, stems and leaves that are left after crop harvest) are often recommended in Vietnam in order to maintain soil fertility (Hoang Thi Thai Hoa et al. 2015a). However, the use of composted organic materials has been gradually decreasing in Vietnam over the past few decades, because of labour shortages and a decline in animal production as well as recognition of the convenience and reliable composition of chemical fertilisers (Pham Quang Ha and Tran Thuc Son 2002). In some areas of south-central coastal (SCC) Vietnam, the direct application of crop residues has been maintained (Hoang Thi Thai Hoa et al. 2015a). Some of the manure produced on intensive livestock farms is used in a raw form, while some of it is mixed with a little bedding or straw. Various kinds of compost made from FYM and diverse organic materials—such as rice straw, peanut stem and aquatic plants—are being made. The ability of organic materials to supply balanced plant nutrition, increase soil fertility and build up the level of soil OM is strongly influenced by their decomposition process in the soil, as well as their nutrient content. However, the behaviour of various organic materials in soils is not yet clear, because of the diversity of composition, variable rates of application and varying levels of compost maturity.

Nutrient-balance exercises may provide indicators for the sustainability of agricultural systems. Nutrient-budget and nutrient-balance approaches have been applied widely in recent years. Studies have been undertaken at different levels, such as plot, farm, regional, national and continental. Widespread occurrence of nutrient mining and soil-fertility decline has been reported (Roy et al. 2003). In terms of nutrient cycling, a sustainable agroecosystem can be defined as a system that is capable of achieving maximum recycling of mineral nutrients while minimising losses through leaching, denitrification and run-off, and for erosion to be sufficiently low that it can be ignored. Thus, external nutrient inputs are needed only to offset the amounts removed by harvest and gaseous losses.

The aim of the present study was to determine at farm and field level the balance between N, P and potassium (K) inputs and outputs using a partial nutrient budget. While broadly the study examined aspects of the C cycle in local farming systems, it involved collecting a diverse range of organic materials used on farm, determining their chemical characteristics (C, N, P and K) and their potential contribution in supplying nutrients to crops.

Materials and methods

Survey on the use of organic resources for crop production

A survey was conducted in three provinces of SCC Vietnam in 2009. One commune was selected in each of three districts representing three provinces and covering the agroecological diversity of the SCC sandy zone. The communes were Cat Trinh (Phu Cat district, Binh Dinh province), An Chan (Tuy An district, Phu Yen province) and Phuoc Dinh (Thuan Nam district, Ninh Thuan province). The soils of these communes are described in more detail elsewhere in these proceedings (Bell et al. 2015). In total, 180 households from the three communes were chosen. Information related to the use of organic materials for crop production was collected through questionnaires. More details of the surveys and on data collection are presented in Hoang Thi Thai Hoa et al. (2015b).

Collection and preparation of organic samples

Based on the survey results, 91 samples of organic materials were collected. The number of samples was based on the following criteria: (1) representative types of organic material; (2) processing methods used on the organic material; and (3) types of animals raised (Table 1). Ash was included in the selected samples because straw and other crop residues are sometimes burned after harvest.

All samples were analysed at the Soil Science Department of Hue University of Agriculture and Forestry, in central Vietnam. The characteristics measured were: dry matter (DM) content, total N (Kjeldahl method), total P and K (nitric acid–perchoric acid (HNO_3:$HClO_4$) digestion). Approximate organic C was estimated by loss to ignition at 550 °C (Richard and Trautmann 1992).

Table 1. Type and number of organic samples collected

Province	Commune	Total no. of organic samples	No. of representative organic samples				
			Sheep manure	Cattle manure	Pig manure	Ash	Crop residues
Binh Dinh	Cat Trinh	38	0	10	5	1	22
Phu Yen	An Chan	33	0	11	7	1	14
Ninh Thuan	Phuoc Dinh	20	5	9	0	0	6
Total		91	5	30	12	2	42

Partial nutrient budget study

Sites chosen for implementing a partial nutrient budget were based on the findings of the general survey as mentioned above and came from the three representative communes.

To assess partial nutrient balance under different cropping systems at the field level, nutrient gains and losses were monitored and referred to as input and output data, respectively (Figure 1). The total partial nutrient balance of a given element (M) in an agroecosystem at its steady state at equilibrium is shown in equation (1):

$$M_{input} - M_{output} = 0 \quad (1)$$

Fifty-five representative crop fields with crop-rotation systems in Cat Trinh commune (rice–rice, rice–fallow, peanut–cassava and peanut–fallow), An Chan commune (rice–rice, rice–watermelon, mungbean–fallow, eggplant–fallow, and forage) and Phuoc Dinh commune (rice–rice, peanut–fallow, hot pepper–fallow, eggplant–fallow, and forage) were assessed for partial nutrient balance at the field level over the course of 1 year.

Usually N, P and K fertilisers were applied in the form of urea (46% N), thermophosphate (7.3% P) and potassium choride (KCl; 50% K). For all cropping systems, input data included: concentration of N, P and K in the fertiliser used (including FYM); rate of fertiliser application; volume and concentration of N, P and K in irrigation water and in rainfall; total crop residues remaining in the field after harvest (in rice systems, some crop residues are removed from the field for purposes such as cooking fuel, animal raising or mixing with manure); and N, P and K concentrations in any added crop residues. Output data comprised: quantity of marketable products; biomass of crop residues; and N, P and K concentrations in marketable products and crop residues. Losses of N via leaching and volatilisation were not considered in this study; however, they can be significant under some circumstances and may affect the output and the nutrient balance. All input and output parameters were recorded in both the field and laboratory.

All the chemical analyses on soil, water and plant nutrients were carried out at Hue University of Agriculture and Forestry. The international standard methods used to test soil, water and plants followed Page et al. (1996).

Statistical analysis

Analysis of variance and determinations of significant differences were performed using the least significant difference (LSD) test (0.05) in the Statistix 9.0 program.

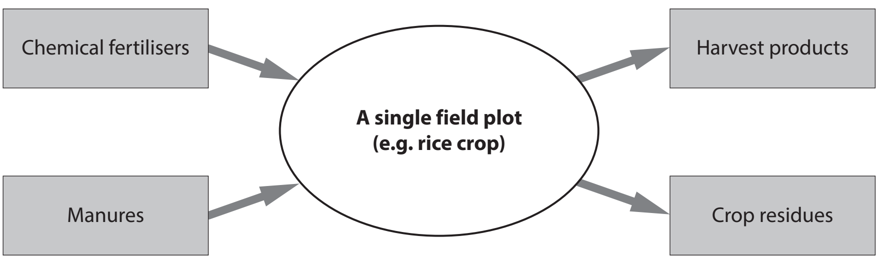

Figure 1. Partial nutrient budget at a single field-plot level

Results and discussion

Utilisation of plant residues for crop production

As in many traditional systems, farmers in the SCC region try to exploit all organic products. Results from 180 surveyed households in the three study commumes revealed that farmers utilised different kinds of crop residues, including rice straw and stems and leaves from peanut, cassava, maize and watermelon. Crop residues from maize and watermelon were not used by farmers in Cat Trinh and An Chan because they grew little or none of those crops. Farmers used crop residues for various purposes, such as fuel for cooking, animal fodder, crop mulching, bedding and litter with manure. However, the types and usage patterns of organic materials were different among the surveyed communes. Peanut stems and leaves were rated as 'medium use' for some purposes but not for fuel. Most crop residues were used as animal feed—most commonly maize leaf and stem (75.0%), followed by peanut and rice straw (67.5 and 58.3%, respectively) (Table 2).

Overall, only a few farmers from the surveyed communes used rice straw as litter with animal manure (3.9% of households; Table 2). Rice straw has a high C/N ratio and silicon content, and it can absorb urine and reduce N loss by volatilisation and leaching from manures and hence enhance the nutrient content of FYM (Le Van Can 1976). However, a large amount of rice crop residue is used for animal feed (Table 2). The principal uses of all crop residues in the different communes are presented in Table 3.

A high proportion of crop residues was used as animal feed (64% of households in Phuoc Dinh and 52% in Cat Trinh) correlated with those communes with a largest numbers of buffalo and cattle (3,672 cattle and 837 buffalo in Cat Trinh and 2,500 cattle in Phuoc Dinh, compared with 1,092 cattle in An Chan). Rice straw and cassava were also used for mulching purposes, but this practice varied to a large extent between communes. Rice straw and other residues were also sold or donated to other families, especially in Cat Trinh and An Chan (15 and 35%, respectively). Although adding to farm income, this means that part of the organic resource is lost from the field and the farm and, hence, nutrients from the residues are lost and not returned to the soil.

Characterisation of organic materials

Organic resources constitute a major source of nutrient inputs for both crop and livestock production in smallholder tropical farming systems. Therefore, the quality of FYM and crop residues is an important factor to be considered in OM management. The mean values of the C, N, P and K concentrations of collected samples are shown in Table 4 for each type of organic material.

Carbon content of different organic samples ranged from 3.8 to 51.6% (Table 4). C is considered to represent 55% of dry matter of organic materials (Richard and Trautmann 1992). Nitrogen content varied from 0.2 to 1.4% (Table 4). This rather large variation was attributed to numerous factors, such as animal type and age, type of feed, amount of straw, method of preparation and length of manure storage—which varied between 1 and 6 months, depending on the crop season. Sheep manure had the highest C:N ratio (68), followed by cassava leaf with 51 (Table 4). This stresses the need to combine plant residues (depending on plant species) with other organic amendments and/or inorganic N fertilisers to obtain a good C:N ratio (between 20 and 30) to

Table 2. Percentage of surveyed households utilising crop residues for different purposes

Residue use	Rice straw (n = 103)	Peanut (n = 40)	Cassava (n = 34)	Maize (n = 16)	Watermelon (n = 18)
Burned in the field	0.9	–	11.8	6.3	27.8
Mulch	0.9	–	8.8	–	–
Returned to soil	1.9	15.0	14.7	0	44.4
Animal feed	58.3	67.5	23.5	75.0	27.8
Litter	3.9	12.5	5.9	6.3	–
Fertiliser	0.9	10.0	8.8	–	5.6
Domestic fuel	0.9	–	44.1	–	–
Sale, donations	33.9	10.0	8.8	18.8	–

be effective for crop production (Khalil et al. 2005). Cattle and pig manure was higher in P (0.2%) compared with sheep manure. The K content varied according to the type of organic material. Potassium from organic amendments is considered an effective fertiliser because the K^+ cation is not tightly bound to organic molecules.

The contribution of organic amendments to the required amount of these elements/nutrients over one cropping season is of utmost importance in sandy soils, due to their low retention capacity and limited content of nutrients. The concentrations of nutrients in different manures as calculated from the average values in Table 4 are presented in Table 5. Although large variations occur, depending on the source and processing of manures, the order of magnitude of elements contained in 1 tonne (t) of fresh FYM is about 4.80 kg N, 0.82 kg P and 2.16 kg K. This is similar with other studies carried out at the country level in Vietnam (Nguyen Van Bo 2001) in which 1 t of FYM contained 3.50 kg N, 0.74 kg P and 2.91 kg K.

Based on the nutrients from different FYM (Table 5) and rates of manure application (2, 5 and 10 t/hectare (ha)) as per the household survey in SCC Vietnam, application of 2 t of FYM can supply only 9.7 kg of N, 1.5 kg of P and 3.2 kg of K (Table 6). However, one improved rice crop requires about 120 kg N, 26 kg P and 50 kg K for a yield of about 6 t/ha (Dierolf et al. 2001). Hence, other nutrient sources like crop residues and inorganic fertilisers should be applied to deliver the rest of the crop needs. For most of the farmers in this region, inorganic fertilisers or soil reserves were used to supply nutrients to crops. For root crops, farmers applied 4–6 t/ha of FYM, supplying 40–60 kg N, 6–9 kg P and 12–18 kg K per ha, which is still well under the total requirement (Dierolf et al. 2001). Survey results indicated that amounts of manure applied to peanut (4.5–7.0 t/ha) and cassava (3.2–7.5 t/ha) were common across sites and seasons.

Table 3. Percentage of surveyed households utilising crop residues in each of the three study communes

Residue use	Commune		
	Cat Trinh	An Chan	Phuoc Dinh
Burned in the field	4.1	16.7	15.0
Mulch	2.5	–	–
Returned to soil	7.1	9.2	18.8
Animal feed	52.0	28.6	64.2
Litter	1.9	6.4	12.5
Fertiliser	9.7	5.0	10.6
Domestic fuel	14.4	18.8	–
Sale, donation	14.9	34.9	2.1

Note: data in each column was calculated using the average of each crop residue utilised for the different purposes

Partial nutrient budget

Net surpluses or deficits of nutrients were calculated by measuring and summing up all the imports and exports of resources into and from a given plot. The balance of nutrients for field plots representing the cropping systems of the SCC region varied between negative or positive, as reported in Table 7.

Table 4. Chemical characteristics of organic materials collected in three communes of south-central coastal Vietnam

Organic material	No. of samples	DM (%)	C (%)	N (%)	C:N ratio	P (%)	K (%)
Farmyard manure							
Cattle manure	30	52.3 ± 7	21.9 ± 8.4	1.1 ± 0.4	19.5	0.2 ± 0.09	0.5 ± 0.17
Pig manure	12	46.2 ± 7	18.8 ± 7.5	1.3 ± 0.2	14.8	0.2 ± 0.04	0.3 ± 0.17
Sheep manure	5	45.9 ± 3	37.3 ± 1.3	0.6 ± 0.1	67.6	0.1 ± 0.04	0.5 ± 0.08
Crop residues							
Rice straw	19	60.8 ± 17	51.6 ± 7.4	1.3 ± 0.3	38.5	0.1 ± 0.04	1.0 ± 0.17
Cassava leaf	8	61.3 ± 15	45.4 ± 3.8	0.9 ± 0.3	50.9	0.1 ± 0.04	0.4 ± 0.08
Peanut stem	9	63.3 ± 13	43.1 ± 2.5	1.4 ± 0.3	29.9	0.1 ± 0.04	0.6 ± 0.17
Maize leaf	6	70.45 ± 3	48.6 ± 3.7	1.4 ± 0.2	34.5	0.1 ± 0.04	1.3 ± 0.08
Ash	2	62.13 ± 4	3.8 ± 0.4	0.2 ± 0.0	21.3	0.1 ± 0.00	1.2 ± 0.08

Note: DM = dry matter; C = carbon; N = nitrogen; P = phosphorus; K = potassium; chemical characteristics given as average ± standard deviation

All cropping systems had positive balances for N, except for peanut–cassava, hot pepper–fallow, eggplant–fallow (An Chan only) and forage that had negative N balances and rice-based fields in Cat Trinh that had balanced N input and output (Table 7). The data suggest that the rates of N used for the cropping systems with positive N balances could possibly be reduced. Nitrogen added in excess of the crop requirement accumulates in inorganic forms, predominantly as nitrate N (NO_3-N) and is prone to leaching and/or denitrification when the field is flooded for the next rice season (Buresh et al. 1989). Leaching losses during double rice cropping are usually small in the lowlands but can be high when a single rice crop is followed by other crops (Alam and Ladha 1997). There is an obvious need to determine the magnitude of N losses, especially under cropping systems that have N surpluses, and, if necessary, develop strategies to reduce or overcome losses.

The average P inputs were always higher than the outputs, except for forage (Table 7). The excess ranged from 4–16 kg/ha/year, suggesting that unrecovered P will accumulate in soils where fertiliser is applied. Phosphorus dynamics are determined largely by factors that govern sorption and desorption to and from soil particles. However, pale sands are prone to P leaching where high fertiliser P rates are applied, as observed under peanut or vegetable production systems (Bell et al. 2015). Hence, P surpluses may be lower than calculated where significant leaching loss of P is occurring. Flooding during the rice crop drastically increases the solubility of P as a result of chemical reduction to ferric oxy-hydroxides, thereby releasing the adsorbed and occluded P fraction of the minerals (Roy and De Datta 1986). In addition, under submerged rice cultivation, acid soil increases P solubility as reduction of ferric oxy-hydroxides elevates the pH towards neutrality. However, prolonged flooding and increased addition of P in soils have the tendency to increase P adsorption, due mainly to the increased surface area as a result of amorphous iron oxy-hydroxides (Patrick and Khalid 1974). This indicates that there is scope for reduced rates of P for rice-based cropping.

The resulting K balances on single field plots were negative for all cropping systems, which confirmed the results presented above at the farm scale. Omission of K has shown it to be a limiting nutrient for crops in the SCC region (Hoang Minh Tam et al. 2015). Hence, management practices are required to reduce K losses and/or enhance K fertilisation if sustainable yields are to be achieved in this region. Rice straw and other crop residues are often removed by farmers and used as fodder or other purposes and only a small amount of K is returned to soils through the use of manure. Farmers tend to apply chemical fertilisers to supply K due to their convenience. There is always the risk of K loss by leaching from manures before it can reach the field and be used by the crops. In addition, organic nutrient sources are rarely applied to land for crop production, due mainly to either (i) animal manures are not readily available or (ii) lack of transport facilities over long distances between fields and where animals are raised (Kornegay 1996).

Table 5. Calculated supply of nutrients from different farmyard manures applied (kg/t of fresh manure)

Type of manure	N	P	K
Pig manure	6.00	0.77	1.49
Cattle manure	5.80	1.12	2.57
Sheep manure	2.80	0.60	2.32
Average	4.80	0.82	2.16

Note: N = nitrogen; P = phosphorus; K = potassium; data in each column were calculated based on dry matter of nutrient contents as shown in Table 4

Table 6. Calculated supply of nutrients (kg/ha) for three rates of farmyard manure application.

Type of manure	2 t/ha			5 t/ha			10 t/ha		
	N	P	K	N	P	K	N	P	K
Pig manure	5.4	0.7	1.4	13.5	2.1	3.9	27.0	3.7	7.1
Cattle manure	12.0	1.6	3.0	30.0	3.9	7.5	60.0	7.7	14.9
Sheep manure	11.6	2.2	5.2	29.0	5.6	12.9	58.0	11.2	25.7
Average	9.7	1.5	3.2	24.2	3.8	8.1	48.3	7.5	15.9

Note: N = nitrogen; P = phosphorus; K = potassium; data in each column were calculated from Table 4 with amount of manure applied in 1 ha

Table 7. Average nutrient balances in the main cropping systems at field-plot level in communes of south-central coastal Vietnam

Cropping system	Commune	Nutrient (kg/ha/year)		
		N	P	K
Rice–rice (*n* = 19)	*Cat Trinh*			
	Input	188	32	120
	Output	187	19	146
	Balance	1	13	–26
	An Chan			
	Input	185	27	115
	Output	160	20	140
	Balance	25	7	–25
	Phuoc Dinh			
	Input	228	24	43
	Output	174	9	100
	Balance	54	15	–57
Rice–fallow (*n* = 4)	*Cat Trinh*			
	Input	123	18	66
	Output	120	12	104
	Balance	3	6	–38
Rice–melon (*n* = 3)	*An Chan*			
	Input	178	33	90
	Output	180	21	177
	Balance	–2	12	–87
Peanut–fallow (*n* = 6)	*Cat Trinh*			
	Input	193	12	56
	Output	133	8	45
	Balance	60	4	–11
	Phuoc Dinh			
	Input	187	25	19
	Output	186	9	60
	Balance	1	16	–41
Peanut–cassava (*n* = 5)	*Cat Trinh*			
	Input	241	43	83
	Output	288	27	212
	Balance	–47	16	–129
Mungbean–fallow (*n* = 3)	*An Chan*			
	Input	105	11	19
	Output	86	5	70
	Balance	19	6	–51
Hot pepper–fallow (*n* = 6)	*Phuoc Dinh*			
	Input	126	23	52
	Output	145	15	134
	Balance	–19	8	–82

continued

Table 7. (cont'd) Average nutrient balances in the main cropping systems at field-plot level in communes of south-central coastal Vietnam

Cropping system	Commune	Nutrient (kg/ha/year)		
		N	P	K
Eggplant–fallow (*n* = 4)	*An Chan*			
	Input	102	20	42
	Output	140	8	82
	Balance	–38	12	–40
	Phuoc Dinh			
	Input	112	28	24
	Output	82	13	127
	Balance	30	15	–103
Forage crop (*n* = 5)	*An Chan*			
	Input	149	7	24
	Output	186	11	134
	Balance	–37	–4	–110
	Phuoc Dinh			
	Input	86	0	16
	Output	149	8	70
	Balance	–63	–8	–54

Note: N = nitrogen; P = phosphorus; K = potassium

Conclusion

The different types of organic materials (crop residues and manures) available in the three study communes of SCC Vietnam and their use by farmers for various purposes (fuel for cooking, crop mulching, bedding or littering with manure, direct application to crops and as animal feed) were the main focus of this study. The elements C, N, P and K were measured, with significant differences observed for only N and K in these communes. Peanut and maize residues had the highest N content (up to 1.4%) compared with other plant residues. The quality of FYM depended on the type of animal, the amount of added material and the processing method. Pig and cattle manure had higher N content than manures. Manures that were not processed and stored properly had lower N, P and K compared with manure that was composted with crop residues. One tonne of fresh manure had mean nutrient contents of about 4.8 kg N, 0.8 kg P and 2.2 kg K.

Nutrient-balance assessments at field level showed that there were most often positive balances for N and P and excessive applications may result in loss of these nutrients, especially N, and may cause pollution of the groundwater and surface water (Ho Le Phi Khanh et al. 2015). Negative K balances are indicative of declining levels in the soil and are associated with the management practices for different crops. This suggests that detailed understanding of nutrient management is needed for individual fields and crops for a sustainable production system.

Future research is required to enhance nutrient use efficiency by managing on-farm organic resources in combination with inorganic fertilisation. Secondly, farm-gate budgets are unable to reveal whether surplus nutrients have accumulated in soil or are lost to the environment. The surpluses of N and deficits of K on some farms are of concern and warrant further investigation. Long-term studies and monitoring of soil nutrient pools are critical to understand and sustainably manage nutrients in farming systems of SCC Vietnam.

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Water resources in south-central coastal Vietnam: knowledge, management and research opportunities

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Abstract

The south-central coastal (SCC) region of Vietnam extends from Binh Thuan province in the south to Da Nang city in the north. Up to 70% of the region's population derive the majority of their income from agriculture. With a long dry season and cyclical droughts, water resources are vital to irrigated cropping in the region. Floodplain crops, predominantly rice, consume the majority of stored surface water. Outside the flood plains, agriculture is mostly groundwater dependent. Overexploitation, eutrophication and increasing salinity due to seawater intrusion are emerging problems affecting the sustainability of groundwater-dependent farming in SCC Vietnam. Under current institutional arrangements, management of water resources for irrigated agriculture are surface water and supply focused. There are no agencies working with groundwater-dependent farmers to assist them in utilising groundwater sustainably. The current status of water resources and their management in the SCC region indicate that there is considerable scope for international donors and water resource professionals to assist Vietnamese agencies and farmers to improve the sustainable use and management of water resources; groundwater in particular. However, to provide appropriately prioritised assistance to improve outcomes for water resources in SCC Vietnam, stakeholders need ready access to local water resources knowledge. This knowledge is mostly documented in Vietnamese and limits its accessibility to non-Vietnamese readers. In this mini-review, we aim to assist non-Vietnamese readers in understanding institutional arrangements for water resources management in SCC Vietnam and the current status of water resources knowledge, and we also highlight opportunities for research to improve policy and fill knowledge gaps.

Introduction

The south-central coastal region (SCC) of Vietnam covers 44,367 km^2, extending from Binh Thuan province in the south to Da Nang city in the north. Around 60–70% of an estimated population of 9 million earn the majority of their income from agriculture and the region is subject to a high incidence of rural poverty (General Statistics Office 2009, 2012).

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Agricultural production in the SCC region is challenged by biophysical constraints, including >330,000 hectares (ha) of low-productivity sandy soils and climatic extremes. Average annual rainfall varies from 600 mm along the coastal fringe of the southern province of Ninh Thuan to more than 1,800 mm in the central province of Binh Dinh. The region experiences frequent and severe flooding in the 3–5-month wet season and soil water deficits in the 7–9-month dry season. Rainfall across SCC Vietnam is influenced by the El Niño Southern Oscillation (ENSO) effect, resulting in wetter than average La Niña years and drier than average El Niño years (Sano et al. 2012). In El Niño periods, the availability of water can be very limited. For example, in 2004, water shortages in Ninh Thuan resulted in a 60% reduction in rice, cassava and maize yields (Oxfam 2005).

Irrigation water for floodplain crops, predominantly paddy rice, is mostly diverted from coastal rivers, with lowland agriculture consuming 80–90% of stored surface water released into rivers and irrigation channels (Strategy of Management and Protection of Water Resource in Vietnam, Water Resource and Hydraulic Works Department 6/96, cited in CIEM–Danida 2012; Dao Ngoc Tuan, Deputy Director, Institute for Water Resources Planning, pers. comm. 13 November 2012). By contrast, 70–80% of water used for rural domestic purposes is sourced from groundwater (Dang Dinh Phuc 2008). Outside the river flood plains, crops are rainfed or, especially on the sands, are groundwater dependent. Predominant crops are cashew (60,000 ha), mango (12,100 ha), peanut (32,100 ha), cassava (108,900 ha) and vegetables (66,500 ha), worth a total of US$623 million/year (MARD 2011). Overexploitation of groundwater, leaching of nutrients to groundwater and increasing groundwater salinity are emerging problems affecting the sustainability of groundwater-dependent farming in SCC Vietnam (Keen et al. 2013).

There is considerable scope for providing technical, institutional and funding support for Vietnamese agencies and farmers to improve outcomes for water resource utilisation and management in the SCC region. However, to provide appropriately prioritised assistance, international donors, investors and agricultural and water resource professionals need access to water resources knowledge, which is mostly documented in Vietnamese. In the following discussion, we aim to assist non-Vietnamese readers by summarising the contents of a larger report published by the Australian Centre for International Agricultural Research (ACIAR; Keen et al. 2013). The report provides a detailed overview of the institutional arrangements for water resources management and water resources knowledge and research in SCC Vietnam. The report also highlights opportunities for research to improve policies and fill knowledge gaps.

Key water resource institutes

Historically, institutional arrangements for water resources management in Vietnam have been complex and fragmented, with responsibilities for surface water under the Ministry of Agriculture and Rural Development (MARD) and groundwater under the Ministry of Natural Resources and Environment (MONRE).

Key water resource agencies under MARD

National Institute for Agricultural Planning and Projection (NIAPP)

NIAPP is a national-level planning institute headquartered in Hanoi with considerable influence over policy and planning decisions for agricultural land use in Vietnam.

Vietnam Academy of Water Resources (VAWR)

VAWR functions as a national-level water resources research institute. VAWR operates mostly out of Hanoi but has offices in the central highlands and southern Vietnam.

Institute for Water Resources Planning (IWRP)

IWRP specialises in national-level investigation and planning for water resources development with a primary focus on surface water resources for irrigated agriculture. IWRP has institutes located in the north and south of Vietnam.

Department of Agriculture and Rural Development (DARD)

DARD is a provincial-level agency with the primary role of implementing national policies, strategies and plans pertaining to rural extension and development, agriculture, fisheries, aquaculture, forestry, salt production, irrigation water supply schemes and flood mitigation within their respective province.

Key water resource agencies under MONRE

Centre for Water Resources Planning and Investigation (CWRPI)

CWRPI is mandated to plan and implement investigations for water resources, especially groundwater resources, across Vietnam. Southern and Central Vietnam CWRPI divisions are known as Division 8 and Division 7, respectively.

National Centre for Hydro-meteorological Forecasting (NCHMF)

NCHMF is primarily responsible for monitoring and forecasting climate and river conditions and for issuing weather and flood warnings. NCHMF conducts climate research and maintains the national monitoring network for climate and river basin and reservoir hydrology.

Department of Natural Resources and Environment (DONRE)

DONRE is a provincial agency with the main function of implementing MONRE's national environmental management and protection policies and regulations within their respective province. The DONREs regulate abstraction of groundwater for municipal and industrial purposes through licensing, and monitor water quality and groundwater levels, mainly in urban areas.

Institutional arrangements for water resources

Water resources policy in Vietnam is developed at the national level within a national legislative framework. The Law on Water Resources (LWR 08/1996/QH10), Decree 179/1999/ND-CP and, more recently, the 2012 revised Law on Water Resources and Decree 21/2013/ND-CP provide the primary legislative framework for water resource management in Vietnam. A complexity of sub-law and secondary legislation with implications for water resource management has also been created within the different ministries. Subordinate divisions typically adopt legislation pertaining to their respective ministry and functions. A number of reviews (Hirsch et al. 2005; Kellogg Brown & Root Pty Ltd 2009; Can Tho University 2011) have commented on overlaps, duplication and gaps within the legal framework, leading to contradictions and conflict among government agencies responsible for implementing water resources law.

Water resource planning and research for agriculture and aquaculture predominantly occur at a national level and through subordinate national and regional divisions under MARD and MONRE (Figures 1 and 2). The key national and regional institutions and their functions were described above. However, at the time of writing, these arrangements were in transition under the revised Law on Water Resources (21 June 2012), which delegates planning and management of water resources at the river-basin level to MONRE. The implications of these changes remain unclear and may be complicated further by the draft 'Law on Irrigation', introduced for public comment in early 2013 by MARD.

Under existing arrangements, the physical supply of surface water for agriculture, forestry and aquaculture in the SCC provinces (Figure 1) is initially controlled by irrigation management companies (IMCs). IMCs are either solely state owned or private–public partnership entities. IMCs are supervised by Provincial and District People's Committees (PPCs and DPCs) and are advised by DARDs and DONREs. With water user fees abolished in 2007, IMCs are heavily subsidised by national and provincial governments.

Water Boards operate as committees under PPCs. Not all provinces have Water Boards because the Law on Water Resources does not require each province to form a Water Board. One of the Water Board's primary purposes is to determine water supply requirements and allocation to districts within the province.

River basin organisations (RBOs) are also established at different levels; international river, inter-province basin and provincial basin. Inter-provincial RBOs engage in participatory management of inter-province catchment issues with representation from each province within a catchment. However, the process of establishing RBOs has been slow, and they have been established in only a few basins, mostly in the north and south of Vietnam.

IMCs release reservoir water into rivers and the irrigation channel system, and they are also responsible for controlling distribution to communes on the irrigation channel network. IMC and DARD responsibilities extend to maintaining irrigation channel infrastructure within the province up to the commune boundary. Beyond the commune boundary, farmer water user groups are responsible for maintaining, mostly at their own cost, irrigation water distribution systems (channels and pumps). Not all communes have a water user group and those that do predominantly grow lowland rice.

Farmers in SCC Vietnam engaged in production of upland crops have a high dependency on groundwater for irrigation. Despite DARD having responsibilities for agricultural resources, groundwater is not a focus for their activities. Implementation of groundwater management falls under DONRE (Figure 2). However, DONRE does not regulate or work directly with groundwater-dependent farmers. Licences are not required by farmers (crop, livestock, forestry and aquaculture) to extract groundwater but farmers are required to register their wells. In reality, few farmers register their wells, unless they have accessed government subsidies for well construction, and DONRE does not monitor groundwater extracted for agriculture.

The brackish-water aquaculture industry is also a significant user of location-specific groundwater resources near the coastal fringe. Estimates for water use by aquaculture range between 20,000 m^3/ha/year (CRP and World Bank 2003) and 35,000 m^3/ha/year (Verdegem and Bosma 2009). Water use by shrimp farmers increases significantly in the dry season

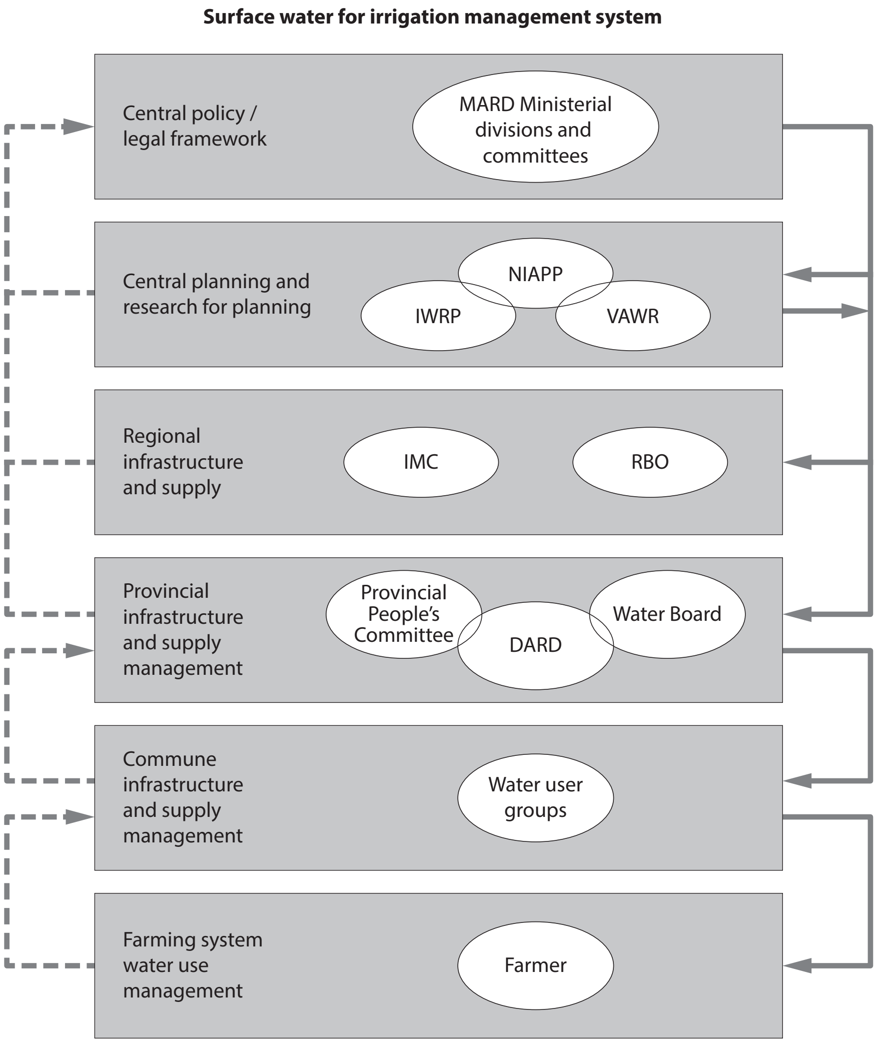

Figure 1. Simplified schematic diagram of the primary components for surface water supply management systems for irrigation relevant to south-central coastal Vietnam. Note: solid lines indicate principal pathways of influence and dashed lines indicate feedback pathways; MARD = Ministry of Agriculture and Rural Development; IWRP = Institute for Water Resources Planning; NIAPP = National Institute for Agriculture Planning and Projection; VAWR = Vietnam Academy of Water Resources; IMC = irrigation management company; RBO = river basin organisation; DARD = Department of Agriculture and Rural Development

when accelerated evaporation from shrimp ponds requires input of fresh water to dilute increased salt concentration. DONRE regulates shrimp hatchery companies via licensing but the law does not require licences for individual shrimp farmers. Consequently, no organisation regulates or monitors groundwater extraction by shrimp farmers.

Under these arrangements, it is apparent that systems for managing water resources for irrigated agriculture are focused on surface water and its

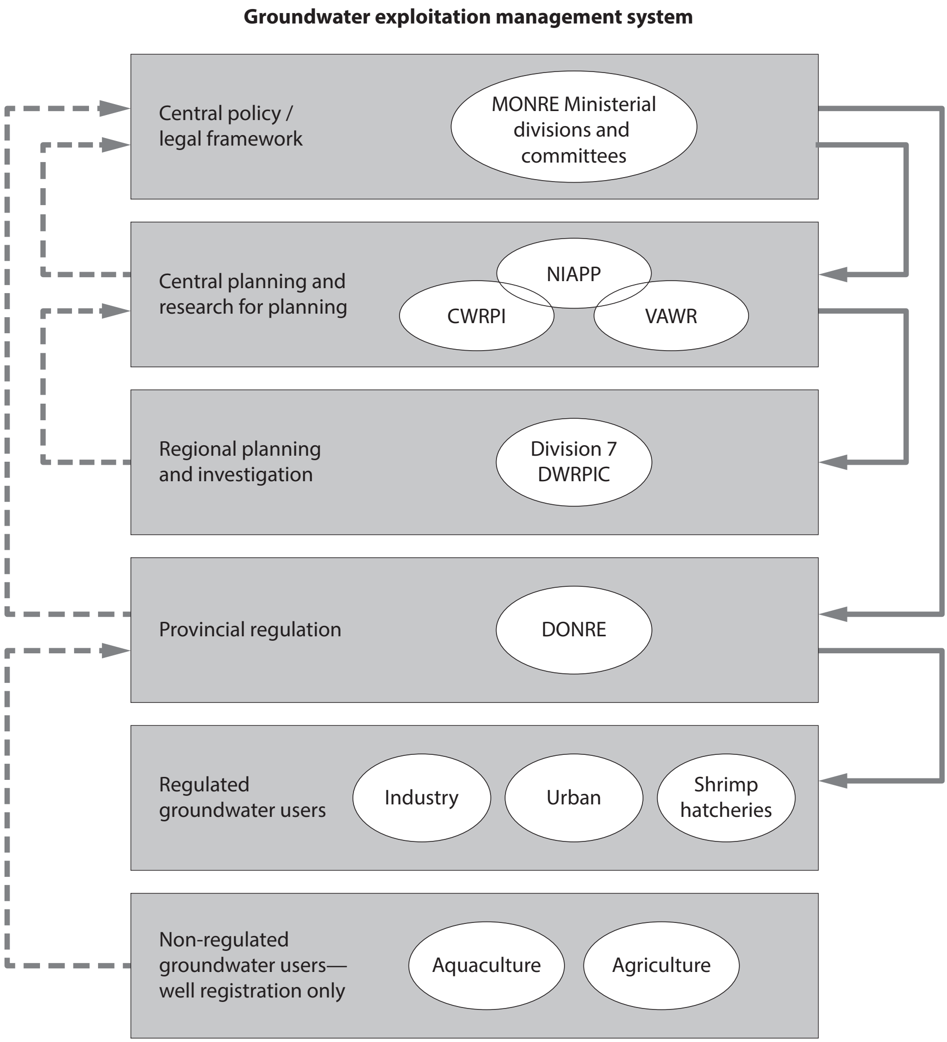

Figure 2. Simplified schematic diagram of the primary components for groundwater exploitation management systems relevant to south-central coastal Vietnam. Note: solid lines indicate principal pathways of influence and dashed lines indicate feedback pathways; MONRE = Ministry of Natural Resources and Environment; CWRPI = Centre for Water Resources Planning and Investigation; NIAPP = National Institute for Agriculture Planning and Projection; VAWR = Vietnam Academy of Water Resources; DWRPIC = Division 7 of CWRPI; DONRE = Department of Natural Resources and the Environment

supply; almost solely established to support lowland rice production (Keen et al. 2013). Irrigation water supply and planning for groundwater exploitation dominate institutional arrangements with virtually no organisation working to assist farmers to utilise groundwater sustainably. Other than through land-use planning, few, if any, of the institutional arrangements for water resource management service upland crops, especially those dependent on groundwater for irrigation. This highlights a significant gap in water resource management in Vietnam.

Status of water resources knowledge

Surface water held in reservoirs and in irrigation scheme infrastructure is well documented in water plans produced by MARD agencies. Water plans are in place for all SCC provinces covering the period from 2012 to 2020. Given MARD's surface water mandate, these plans mostly focus on infrastructure for surface water irrigation schemes. For Quang Nam, Quang Ngai, Binh Dinh, Phu Yen and Khanh Hoa provinces, infrastructure upgrades are planned for 802 irrigation systems and construction is planned for 592 irrigation systems to service an additional 161,979 ha of crop land and 13,539 ha of aquaculture, and additional domestic water supply for 387,400 people. MARD has indicated a budget of Vietnamese dong (VND)140,770 billion (A$6.8 billion) to implement the 2012–2020 central coastal Vietnam water resources infrastructure plan. The 2012–15 budget indicated for the water resources science and technology program is VND120 billion (A$6 million).

Groundwater resources are mostly documented in groundwater-potential maps produced at 1:50,000 and 1:250,000 scale by CWRPI. Maps have been prepared for most SCC provinces but, to date, groundwater exploitation plans for SCC Vietnam have been prepared for only Phu Yen province. Plans for Ninh Thuan and Binh Dinh provinces are currently under development. The official total exploitable dynamic groundwater reserve for SCC Vietnam is estimated at 4.3 Mm^3/day. However, the accuracy of this estimate is uncertain. A Vietnamese MONRE Ministry-level Department of Water Resources Management report (Dang Dinh Phuc 2008) states that <3% of SCC groundwater systems have been investigated to a reliable level of detail. This same report estimates total dynamic reserves for SCC Vietnam at 18.2–34.5 Mm^3/day with a sustainable yield of around 2.4 Mm^3/day. Of this, only 0.35 Mm^3/day is based on accurate assessments, with the remainder based on less-reliable data.

Most component data required for water balance modelling are available for SCC Vietnam but there is a notable absence of reliable data on groundwater extracted for rural household consumption and irrigation. A coarse estimate for total groundwater abstraction in the SCC region is 261.8 Mm^3/year (Dang Dinh Phuc 2008). However, this estimate is based on an assumption of only 2,000 ha for groundwater-irrigated agriculture and 405 ha for aquaculture. This appears to be a critical error in calculating the estimate, since the official statistic for the total area used for regionally important upland crops in SCC Vietnam is 280,000 ha (MARD 2011), a significant proportion of which is likely irrigated from local aquifers.

Recent irrigation and groundwater resource research

The Agricultural Science Institute for Southern Central Coast of Vietnam (ASISOV) is the principal agricultural research institute for SCC Vietnam. ASISOV has been involved in irrigation and water resource research via previous ACIAR and Asian Development Bank projects but its Vietnamese government–funded research predominantly focuses on evaluating cultivars with tolerance to drought, acidic soil and salinity, and production technologies for rice, peanut, green pea, soybean, taro and cashew.

National government funding has supported the VAWR to undertake irrigation research in Ninh Thuan and Binh Thuan provinces. A project completed by VAWR in 2008 adapted irrigation scheduling and developed low-cost pressurised and filtered drip irrigation for dragon fruit in Binh Thuan and table grapes in Ninh Thuan (Trung 2008). Water requirements for dragon fruit were determined and evaluation of partial root-zone drying (PRD) indicated that application of PRD in periods of low water availability has potential to reduce water consumption for dragon fruit by 40% without a yield penalty. Outcomes from the project led to the development of a Vietnamese standard for irrigation of dragon fruit and table grapes.

VAWR also evaluated small-scale water-storage techniques to supply water for rural household consumption and irrigation in several drought-vulnerable hamlets in Ninh Thuan. The techniques mostly involved collecting and piping groundwater discharged from the base of sand dunes to 20–30 m^3 capacity storage tanks, some covered with plastic to reduce evaporation (Tuan 2011a, b). Vietnamese government funding is currently supporting VAWR to undertake research to evaluate irrigation hardware and scheduling for sugarcane crops in Quang Ngai province.

The primary focus for many international donor research projects in SCC VN has been Binh Thuan and Ninh Thuan and, more recently, Quang Ngai province. A large proportion of these focus on assessing groundwater for domestic consumption.

A project titled *Groundwater artificial recharge and salinisation prevention as a drought-fighting measure in central coastal areas of Vietnam* was completed in 2001 through collaboration between the German Government and the Vietnamese Ministry of Science, Technology and Environment (MOSTE). The project was located in the Luy River Delta of Binh Thuan province. Results from modelling indicated that a recharging trench covering a total area of 1 km^2 could potentially divert an additional 133–300 m^3/day of water to the local aquifer. Scenario-testing for seawater-intrusion mitigation indicated that the most effective, but also most expensive, option for preventing further seawater intrusion into the Luy Delta aquifer was to construct an underground slurry dyke system. After installation of the dyke, saline water would be pumped out to sea from wells installed near the dyke wall.

Between 2004 and 2010, a large project titled *Augmenting groundwater resources by artificial recharge in Binh Thuan province, Viet Nam* (IHP 2011) was completed by a consortium involving: the United Nations Educational, Scientific and Cultural Organization (UNESCO), the University La Sapienza, Italy, and Vietnamese institutes, including the Vietnamese Academy of Science and Technology, Binh Thuan DARD and DONRE, and CWRPI. Extensive field investigations, hydrogeological and geophysical surveys, installation of monitoring systems, and chemical and isotope analyses of groundwater were carried out. Capacity-building during the project extended to around 200 Vietnamese participants who gained competency in artificial aquifer recharge and in the use of stable isotopes in hydrology and hydrological methods. This project was the first to implement an artificial aquifer recharge pilot project in Vietnam. The pilot project was established in the Bau Noi well field with a 5 km pipe installed to supply about 220 m^3/day water to Hong Phong village.

A project titled *Improvement of groundwater protection in Vietnam—IGPVN* commenced in 2009, with phase 1 completed in 2010. Phase 2 of this project was ongoing until 2014. The project is funded by the German Ministry for Economic Cooperation. Primary partners for this project are the Institute for Geosciences and Natural Resources (BGR— Bundesanstalt für Geowissenschaften und Rohstoffe), Germany, and CWRPI (Division 7) with collaborative partners including DONREs from Nam Dinh, Ha Noi, Ha Nam, Soc Trang and Quang Ngai. Phase 1 of the project focused on the northern Vietnam province of Nam Dinh (BGR 2011). Phase 2 has extended to other parts of northern Vietnam, Quang Ngai province in the SCC region and Soc Trang province in southern Vietnam. Recommendations to emerge from phase 1 of this project included the following measures to reduce groundwater overexploitation and salinisation: enforcing regulation to control extraction; registration and extraction licensing; central water supply based on treated surface water; reducing extraction by identification of sources for groundwater loss or misuse; alternatives for groundwater usage and awareness campaigns; optimising extraction; conjunctive usage; and groundwater monitoring.

Ninh Thuan province has been the subject of recent groundwater salinity surveys under a project co-funded by UNESCO and Vietnamese and Italian governments. The project is titled *Impacts of sea level rise by climate change on coastal zone and islands in central part of Viet Nam* and commenced in 2006. Data collected to date indicate that increasing groundwater salinity in Ninh Thuan is primarily caused by: (1) overextraction, mostly for irrigation, of brackish water from shallow coastal sand-dune aquifers; and (2) industrial salt production in Ninh Thuan. The situation is expected to worsen and spread further inland.

Two previous ACIAR projects in SCC Vietnam (SMCN/2003/035—*Improving the utilisation of water and soil for tree crop production in coastal areas* and SMCN/2007/109—*Sustainable and profitable crop and livestock systems for south-central coastal Vietnam*) are the only known foreign donor projects to have conducted applied on-farm research related to water resources. Field experiments with cashew demonstrated productivity gains from extending the duration of irrigation from the standard practice of flowering only to irrigating from flowering through to nut set (Keen et al. 2011). In both Binh Dinh and Ninh Thuan, cashew yields increased significantly with mini-evaporation pan irrigation scheduling. Water use efficiency was improved with mangoes and the volume of water applied to grapes was halved without a yield penalty. Mini–evaporation pan irrigation scheduling also increased peanut yields with significant water savings (Phan Thi Giac Tam and McKay 2015).

While several reviews of water resource policy in Vietnam have been undertaken at a national level, none of these have specifically focused on examining the impacts of water resource policy on communities in SCC Vietnam. A study due to be completed in late 2013 titled *Linking increases in water use efficiency for food production at the farm scale to global projections* aimed to improve policy and instruments available to farmers and policymakers for increasing water use efficiency in agricultural food production. This study was funded by the German Government and implemented by the Leibniz Institute for Agricultural Engineering Potsdam-Bornim (ATB), the International Food Policy Research Institute (IFPRI) and Southern IWRP.

This project was focused mostly in Ninh Thuan province and combined a local farm-scale approach with a global modelling approach to further develop a methodology for estimating agricultural water flows, costs of production factors that affect them at the farm scale and to improve projections for agricultural water use. The study was based on a methodology for water flow balance at the farm scale using models (developed at ATB and IFPRI) which simulate both water supply and water demand for food production.

Water resource research priorities for SCC Vietnam

Surface water sustainability

Priorities raised in water sector reviews (Hirsch et al. 2005; Kellogg Brown & Root Pty Ltd 2009; Can Tho University 2011) indicate that the complex institutional arrangements for water resource governance are in need of further reform. Responsibility for implementing reforms is a matter for the Vietnamese Government and recent amendments to the Law on Water Resources indicate that progress is being made in this area. However, Vietnam would benefit from further water resource policy intervention.

Future efforts to improve the management of surface water resources for irrigation in SCC Vietnam would be necessarily placed in a rice-production setting. The reason for this is that irrigation from surface water is predominantly used for year-round lowland rice production. Opportunities to improve efficiencies in the use of surface water for rice production are mostly at the irrigation scheme level. Currently, excess water is released from reservoirs to allow for losses due to evaporation, leaking distribution channels and unused water released into fallow paddy land. These losses could be reduced by improving distribution networks. Vietnamese planning agencies are focused on increasing reservoir capacity to negate water shortage risks. This approach is supported by large development donors, such as the Asian Development Bank, providing loans and grants for developing and upgrading irrigation scheme infrastructure in Vietnam.

Downstream rice farmers located toward the end of irrigation channels would probably benefit most from water resource research. When irrigation water supply requirements are underestimated and water released from reservoirs is inadequate, rice famers at the end of irrigation networks or rivers are affected by water shortages. Seawater intrusion into flood plains adjacent to tidal zones of lower river catchments is also a problem when water released from reservoirs is inadequate to maintain hydraulic pressure. Rice-production issues are currently well supported by the International Rice Research Institute (IRRI) which conducts collaborative research in Vietnam and elsewhere to adapt rice-production systems to reduce water consumption and to increase tolerance to salinity. Outcomes from this and other research are available to SCC farmers but it is not clear whether DARD extension offices have been focused on scaling these out.

Research to improve prediction of water demand and distribution using models and to improve communication between water users, water resource managers and IMCs may benefit downstream rice farmers by identifying opportunities to improve the reliability of water supply. Evaluation of extension methodology, water distribution modelling and communication within the water sector are topics for which there appear to be opportunities for improvement.

Groundwater sustainability

As discussed above, there are no agencies in Vietnam working with groundwater-dependent irrigated farming systems to regulate extraction of groundwater or to build farmers' capacity in water and fertiliser use efficiency. SCC provincial agencies involved in groundwater resources at the implementation level are less resourced and have lower capacity than the national planning agencies. A significant structural shift in water governance and changes in allocation of responsibilities to relevant government agencies, distribution of human capacity and funding arrangements in Vietnam are required to remedy these problems. Improvements may arise as a result of the current migration of responsibilities for water resources to MONRE. However, MONRE and its agencies would benefit from assistance in developing appropriate policy, and regulatory and economic solutions, for sustainable groundwater utilisation that is more inclusive of groundwater-dependent agriculture. Such research would need to operate at national and provincial levels with strong support from the appropriate ministerial departments.

Spatial information, groundwater-potential estimates and planning documents and guidelines for exploitation of groundwater resources exist for much of SCC Vietnam. However, it has only been since 2008 that momentum has accelerated in developing groundwater monitoring networks, updating related spatial information and developing and implementing groundwater management plans for SCC provinces. While gaps remain, capacity is strong in this field, mainly at national and regional planning levels, and it appears that these gaps are being filled rapidly. In addition, UNESCO (in partnership with donors from the Netherlands and Italy) and donors from Germany (Institute for Geosciences and Natural Resources—BGR) are currently funding groundwater investigation projects in northern and southern provinces of SCC Vietnam. Despite the level of activity in this area, there remain opportunities to contribute to this field through supporting groundwater hydrology investigations in central provinces such as Binh Dinh, where groundwater is critical to upland agriculture and there are gaps in groundwater resource knowledge.

The volume of groundwater abstracted is known for major population centres in SCC Vietnam but the volume of groundwater abstracted for agriculture and aquaculture, which are likely to be the largest users of groundwater, is mostly unknown. In addition, there do not appear to be reliable demand estimates for groundwater-dependent agriculture, and areas where groundwater shortages occur are not identified on maps. Landscape-scale water balance studies would contribute to understanding whether current and projected groundwater utilisation for primary production is sustainable. As part of such studies, areas where groundwater shortages and degradation are occurring could be identified and mapped. This would enable strategic prioritisation for targeting locations for on-farm water management training, farming system adaptation and development of irrigation water supply infrastructure. Related research could also determine the agroeconomic value of groundwater-dependent irrigation to the SCC region and may assist in attracting central government and foreign donor resources towards improving groundwater management in SCC Vietnam.

Irrigation schemes in SCC Vietnam are predominantly established to service lowland paddy rice. There do not appear to have been documented studies that have assessed the feasibility of developing irrigation schemes to buffer against water shortages in groundwater-dependent areas or improve production and facilitate development of agriculture in areas with limited or no access to water for irrigation. There are opportunities for research to improve irrigation demand estimates and to estimate the economic value of developing irrigation schemes for upland agriculture.

Farmers dependent on groundwater for irrigation in SCC Vietnam are usually located in coastal and upland areas dominated by sandy soils. Contamination of groundwater used for irrigation is most likely in areas where there is intensive cropping on sands. High application rates of inorganic fertilisers, manures and pesticides, and high infiltration rates and low nutrient-holding capacity of the sandy soils, combine to increase risks of groundwater contamination. Declining groundwater quality is recognised as a significant problem in a number of coastal and midland districts. Preliminary results from groundwater sampling in Ninh Thuan and Phu Yen provinces under ACIAR projects revealed several cases of very high nitrate levels (>50 mg/L is common, with >500 mg/L in some areas), well in excess of World Health Organization (WHO) guidelines for drinking water (Keen et al. 2011; Summers et al. 2013).

Current monitoring of groundwater quality focuses on groundwater used for urban and peri-urban consumption. In rural areas, groundwater quality monitoring tends to be non-existent or rudimentary and ad hoc; for example, when a specific area is studied under an international donor project (e.g. Binh Thuan—Nguyen Thi Kim Thoa et al. 2008; Ninh Thuan—current UNESCO project *Impacts of sea level rise by climate change on coastal zone and islands in central part of Viet Nam*; Quang Ngai—current German donor project *Improvement of groundwater protection in Vietnam*). Some assessment and mapping of groundwater quality occurs as part of hydrogeological investigations by MONRE agencies. However, these data are mostly used for land-use and groundwater exploitation planning purposes whereby groundwater quality is assessed based on its fitness for purpose. It is not clear how identification of groundwater quality problems is acted upon.

The existence of water quality issues indicates that there is a need to prioritise research to adapt and scale out integrated nutrient and water use management technologies. There are also strong prospects for this research to achieve short to medium term impacts on farmer livelihoods and on the improvement and protection of groundwater quality. Such research should be coupled with capacity-building activities to support the development, testing and implementation of these technologies by research and extension personnel and groundwater-dependent farmers.

Seawater intrusion and salinisation of coastal aquifers

Seawater intrusion is closely related to groundwater sustainability but it is a complex and specific issue that justifies treatment as a stand-alone priority. Concerns about seawater intrusion into coastal aquifers is common among Vietnamese agencies, with a general belief that the problem is widespread in Vietnam and expected to worsen with increasing exploitation for domestic and industrial use, continued expansion of salt and shrimp farms and predicted sea-level rise (MONRE 2009; CIEM–Danida 2012).

CWRPI Division 7 hold maps that mark boundaries of areas affected by salinity. The existence of these maps indicates that some level of monitoring and reporting on groundwater salinity occurs; however, it appears that few of these data are published in Vietnamese or international research literature. Seawater intrusion is mentioned in IWRP and CWRPI Division 8 water resource plans but few details are given. An 80-page Vietnamese Ministry-level Department of Water Resource report (Dang Dinh Phuc 2008) states that seawater intrusion is a significant problem, but again little detail is provided. The only mention of seawater intrusion in SCC Vietnam is for Ninh Thuan, where it is thought that seawater intrusion is caused by exploitation of groundwater for aquaculture.

Cases of seawater intrusion are commonly reported in Vietnamese media. On 1 February 2007, the Thanh Nien newspaper quoted Mr Vo Anh Kiet, Director of the Provincial Centre for Meteorology and Hydrological Forecasting (CMHF) for SCC Vietnam, as saying that seawater intrusion into coastal aquifers, especially adjacent to river mouths, between Da Nang and Binh Thuan province, had been serious. Areas affected by seawater intrusion into coastal aquifers include: Da Nang, 30 km^2; Quang Nam, 100 km^2; Binh Dinh, 130 km^2; Khanh Hoa, 200 km^2 ; Ninh Thuan, 130 km^2. Seawater intrusion into Han (Da Nang), Ve (Quang Ngai) and Ca Ty (Binh Thuan) rivers was reported as being 10 km to 25 km inland.

Vietnamese media reports for Binh Dinh province are supported by a Division 7 report (Vu Ngoc Tran n.d.) which indicated an area of 150 km^2 affected between Quy Nhon and Ha Than river and 20 km^2 near the gulf of Nuoc Ngot. The location and size of affected areas for Binh Dinh were further supported by a Binh Dinh Department of Science and Technology (DOST) media release reporting on outcomes from a seawater intrusion assessment carried out by Mr Vo Ngoc Anh (Vice-Director of the CMHF for SCC Vietnam). The DOST media release indicates that, in addition to the areas mentioned in the Division 7 report, seawater intrusion also affects land adjacent to Tra O lagoon (28 km^2) and Lai Giang Delta (37.9 km^2).

There are a few specific areas under a UNESCO-funded project, in Ninh Hai to An Hai districts in Ninh Thuan province, for which there have been recent seawater intrusion/groundwater salinity surveys. Ninh Hai district was also the subject for basic groundwater salinity surveys under an ACIAR project in 2009 and 2010 (Keen et al. 2011) and electrical conductivity (EC) levels averaged 5.6 dS/m (n = 31) but were as high as 13 dS/m (Keen et al. 2011). The UNESCO project was due to be completed in 2014 and is expected to partially fill a gap in understanding the extent and causes of groundwater salinity in Ninh Thuan province. However, there remain opportunities to support ongoing monitoring, hydrological and salinity modelling and to conduct groundwater and community surveys to determine the status of coastal aquifer salinity in SCC provinces where data may not exist.

Adaptation to groundwater salinity is considered a key priority for affected districts within SCC Vietnam. Some of the most severely affected areas occur along the coastal fringe of Ninh Thuan province. Vegetables are grown on around 450 ha in Ninh Hai district, 140 ha in Van Hai district and 150 ha in An Hai district. Deep sands are dominant in these areas. Water and nutrient holding capacity are low while infiltration rates are high. Consequently, these areas also tend to have high rates of fertiliser applied, which further complicates the salinity problem by loading the groundwater with nitrates and other contaminants. The current situation presents challenges as seawater intrusion is not easily reversed, but there are prospects for research to adapt irrigation and fertiliser practices and cropping systems to reduce the impact of saline water and soil on farmer livelihoods. With seawater intrusion expected to worsen in the future, there is a clear need to develop adaptation strategies in preparation. Work undertaken in Ninh Thuan province would provide a case study for other areas affected by seawater intrusion and promote on-farm water use efficiency practices to prevent overexploitation of vulnerable coastal aquifers.

One such area is Phu Yen province, where there are 1,150 ha (25% of Phu Yen's vegetable production area) of vegetables produced on coastal sands. National and local governments currently have a plan in place, as part of a food security strategy, to double this area by 2020. There are opportunities to improve the income of smallholder farmers by growing higher value crops but there is also a need to improve the productivity of existing vegetable crops by developing solutions to overcome soil constraints and seasonal water availability. The status of groundwater salinity and quality is mostly unknown in areas where vegetables are grown on sandy soil in Phu Yen, and the extent to which groundwater quality issues may be affecting productivity is unknown.

Conclusions

A key observation to emerge during this review was that there are no agencies or groups working with groundwater-dependent farmers to assist them in utilising groundwater sustainably. There appears to be an opportunity for technical and policy interventions aimed at facilitating greater interaction between MARD and MONRE agencies and groundwater-dependent farmers in SCC Vietnam.

Information available on SCC water resources discovered during the review exceeded expectations. However, the most notable gap in water resource knowledge pertains to an absence of reliable data on groundwater abstraction and sustainable yield. This information is critical to evaluating the sustainability of groundwater-dependent agriculture in the SCC region.

Potential contamination of groundwater is a known issue in a number of rural locations but monitoring is rarely undertaken outside urban areas. There is an opportunity to facilitate greater recognition of the need for groundwater quality monitoring in rural areas. Improved knowledge of groundwater quality would enable targeting of areas where farmers need technologies and practices to improve on-farm irrigation and nutrient management.

Seawater intrusion into coastal aquifers in SCC Vietnam has occurred in a number of locations, with affected areas totalling 750 km^2. Solutions are needed to improve management of groundwater abstraction to reduce risks of seawater-intrusion events and to adapt farming systems to saline irrigation water where intrusion is already present and largely irreversible. A number of international donors are seeking solutions to seawater intrusion but none are seeking on-farm solutions.

In conclusion, key opportunities to improve water resource knowledge and management for SCC Vietnam include:

- policy intervention to improve regulation and funding for services provided to groundwater-dependent farmers
- water balance studies to improve understanding of whether current and projected groundwater utilisation for primary production in SCC Vietnam is sustainable
- coordinated programs for water quality monitoring, modelling and mapping in targeted rural areas within the SCC region
- hydrological and salinity modelling and groundwater and community surveys to determine the status of coastal aquifer salinity in SCC districts where data do not exist
- improved extension and communication to improve outcomes for groundwater-dependent farmers
- groundwater hydrology investigations in central provinces where there are gaps in groundwater resource knowledge

- economic modelling to determine the feasibility of developing irrigation schemes to buffer against water shortages in groundwater-dependent areas and improve production and facilitate development of agriculture in areas with limited or no access to water for irrigation
- research to adapt irrigation and fertiliser practices and cropping systems to reduce the impact of saline water and soil on farmer livelihoods
- improved prediction of water demand and distribution through modelling and improved communication between surface water users, water resource managers and IMCs.

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Soil types, properties and limiting factors in south-central coastal Vietnam

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Abstract

Sands occupy over 0.5 million hectares in Vietnam, with two-thirds of the area in the coastal zone of central Vietnam. Limited study of the sands of central coastal Vietnam has been conducted to identify crop productivity constraints or to develop methods of increasing productivity and sustainability of use of these soils. The aim of this study was to determine the diversity of sands in three study areas (Phu Cat district, Binh Dinh province; Tuy An district, Phu Yen province; Thuan Nam district, Ninh Thuan province) representing south-central coastal (SCC) Vietnam, their edaphic properties and the patterns of soil distribution. Profiles examined (22 in Binh Dinh, 13 in Phu Yen and 21 in Ninh Thuan) were analysed by horizon for texture, water holding capacity and chemical properties.

Sand profiles occurred on recent coastal barrier dunes and marine sands, late Pleistocene red dunes, alluvial plains, dissected sand plains and on granitic colluvium and in situ on granite parent rocks. The parent material and geomorphology appeared to best explain differences in edaphic properties. Profiles were broadly divided into deep sands (<5% clay), deep loamy sands and sandy loams (5–18% clay) and profiles where clay content increased with depth (ranging from <5% in topsoil to >15% at depth). Most sands were acid except where lime addition to peanut had raised surface pH or on sands of marine origin. Water holding capacity (–0.1 bar) was consistently lower except where clay was >10%. Organic carbon, cation exchange capacity and extractable nutrient levels were low except in peanut and vegetable fields where elevated extractable phosphorus levels were evident. In related studies (Hoang Minh Tam et al. 2015), multiple nutrient deficiencies were also present in all sands. In summary, there is a diverse range of sands in SCC Vietnam with multiple constraints for crop production. Management of these sands to increase productivity of crops will require packages based on detailed investigations of soil characteristics to combine inputs that are tailored to overcome each suite of constraints rather than blanket recommendations.

Introduction

Vietnam has about 0.5 million hectares (ha) of soils classed as sands (Vietnam Soil Association 1996). The Vietnamese definition of sands comprises all soils with sand content over 80% (Nguyen Van Toan 2004). Of these, about 339,000 ha (68%) occur in the central coastal region (Table 1). In Vietnam, sands are classified as Yellow and white sand dune soil, Red sand dune soil and Sandy marine soil (Vietnam Soil Association 1996). Sands of south-central coastal (SCC) Vietnam were derived from aeolian (Quang-Minh et al. 2010) and fluvial activity and in situ weathering processes (NISF 2001; Hoang Thi Thai Hoa et al. 2010). The transported parent materials are unconsolidated, deposited material of sand texture. The in situ weathered sandy profiles tend to be derived from granitic parent rocks and their colluvial products.

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Recent reviews of the properties of sands in Vietnam have been reported by Pham Quang Ha et al. (2007) and Hoang Thi Thai Hoa et al. (2010). However, there is still relatively limited detailed information on the properties and management of the sands of SCC Vietnam.

Table 1. Area of coastal sands in Vietnam

Local name	All of Vietnam (ha)	Coastal central Vietnam (ha)
Yellow and white sand dune soil	222,043	134,113
Red sand dune soil	76,886	75,000
Sandy marine soil	234,505	130,277
Total	533,434	339,390

Source: Vietnam Soil Association (1996)

The aim of the study was to identify major sand profile types in SCC Vietnam, their constraints for crop production, both instrinsic and modified, and relate the constraints to soil-landscape units and their land use. The intended outputs from this study, which is reported more fully in Phan Thi Cong et al. (unpublished project report 2013[3]), are to appropriately manage sandy soils and facilitate adoption of practices for sustainable and profitable crop production systems in the SCC region.

Materials and methods

Several reconnaissance surveys were carried out through field visits by the authors in each of the target communes: Cat Tuong, Cat Hanh and Cat Trinh communes, Phu Cat district, Binh Dinh province; An Chan commune, Tuy An district, Phu Yen province; and Phuoc Dinh commune, Thuan Nam district, Ninh Thuan province. Neighbouring communes in the same district were also included in the reconnaissance surveys to gain an understanding of landscape pattern and soil–landform relationships. Profiles were selected to represent the main soil-landscape units in the commune, and additional sites were described at the locations of field experiments.

At each profile, soil samples were collected for analysis from each horizon. The main soil survey and constraint determination by the Soil Constraints and Management Package (SCAMP) methodology (Moody and Cong 2008) was done for Binh Dinh and Ninh Thuan provinces in 2009–2010, while that in Phu Yen province was done mostly in 2010–11. In all provinces, it was necessary to return to describe profiles for new experiments, and for soil types that did not appear to be adequately represented in the initial survey. The SCAMP decision-support tool was used to define constraints to crop production of each site/soil profile and appropriate management practices for alleviating constraints were recommended.

Soils by horizon were analysed for: soil pH, measured in water (pH_{H_2O}) and in 1 M potassium chloride (pH_{KCl}); electrical conductivity (EC), both at a 1:5 soil–solution ratio and exchangeable acidity and aluminium (Al) extracted by 1 M KCl at a 1:2.5 soil–solution ratio; extractable phosphorus (P) (Olsen P) using 0.5 M sodium bicarbonate ($NaHCO_3$) at pH 8.5; organic carbon (C) by 1 N potassium dichromate ($K_2Cr_2O_7$) solution in 2.5 N sulfuric acid (H_2SO_4); cation exchange capacity (CEC) by 1 M ammonium acetate (NH_4OAc) at pH 7.0; soil particle size; and water holding capacity using a pressure plate apparatus to equilibrate soil samples to –0.1 and –0.33 bar matric potentials. Methods used are reported by Phan Thi Cong et al. (unpublished project report 2013).

Sands of Phu Cat district, Binh Dinh province

Geomorphology

The sands of Phu Cat district, Binh Dinh province, are diverse in properties (clay content, texture trend with depth, colour) and in landscape setting. They vary in texture from sand to sandy loam. From the similarities in profile descriptions and soil chemical properties, the 22 profiles can be simplified into nine soil types (Table 2).

Within the Gently undulating sand plain, profiles within 100 m from one another were identified with different soil colours, e.g. profiles numbered BD1–3, BD14–15 and BD41–43 in Phan Thi Cong et al. (unpublished project report 2013). This reflects, in part, the topographic variation in the Gently undulating sand plain. In addition, there was evidence of sand sheets overlying buried horizons, suggesting that the surface topography may also reflect aeolian re-working of sands and creation of low sandy rises. Augering indicated that there was another profile 1.5 m (i.e. a buried soil) beneath the described profile BD3. This could be the result of aeolian sand burying another land surface in the past. Geochronology

[3] A copy of this report can be obtained from RWB.

Table 2. Textural differences in soil types on different soil-landscape units in Phu Cat district, Binh Dinh province

Soil-landscape unit and soil type	Texture		
	Clay	Silt	Sand
Undulating sand plain			
Grey sandy loam (*n* = 3)	12.1	6.6	81.3
	13.6	5.6	80.8
	16.5	4.8	78.7
	17.7	6.2	76.1
Grey loamy sand (*n* = 2)	6.4	2.7	90.9
	9.1	2.0	88.9
	13.8	4.7	81.5
	15.8	4.3	79.9
Pale deep sand (*n* = 4)	2.2	5.3	92.5
	2.5	2.5	95.0
	2.9	3.9	93.2
	4.0	5.2	90.9
Footslopes of mountains			
Coarse granite sand (*n* = 3)	2.7	3.3	96.0
	8.0	5.3	89.0
	11.3	5.0	79.0
	10.0	5.0	80.0
Yellow-brown sandy loam (*n* = 2)	10.0	5.7	84.3
	13.0	6.6	80.4
	21.5	8.2	70.3
	21.6	8.7	69.7
Gently undulating sand plain			
Deep grey loamy soil (*n* = 1)	5.5	5.6	88.9
	6.7	8.8	84.5
	7.0	5.7	87.3
	7.5	4.6	88.0
Deep grey sand (*n* = 4)	2.0	3.2	94.4
	2.6	2.6	95.4
	2.8	2.8	94.8
	3.3	3.8	92.3
Brownish sand (*n* = 2)	3.0	2.0	95.5
	7.0	3.0	89.5
	10.5	3.5	85.5
	10.5	3.0	86.5
Pale brownish sand (*n* = 1)	1.0	3.0	96.0
	4.0	2.0	94.0
	6.0	2.0	92.0
	6.0	3.0	91.0
	6.0	2.0	92.0

Note: values are averages for successive horizons down the profile for different patterns of soil texture; values are averages as a percentage (*n* = number of profiles); the sum of sand + silt + clay may not add to 100 % due to analytical errors studies in SCC Vietnam (Quang-Minh et al. 2010) suggest active aeolian activity since the last sea-level maximum which might be responsible for such sand deposition in Phu Cat district. Deposition ages ranging from 8,300 ± 600 to 6,200 ± 300 thousand years before present (ka) were obtained for the stratigraphically oldest exposed barrier sands. Further periods of sand accumulation took place between 2,700 and 2,500 ka and between 700 and 500 ka. The sandy rises on the Gently undulating sand plain possibly date from one of these periods but further research is needed to date them accurately.

Most of the soil profiles in Phu Cat district had a common feature of containing >80% sand in the top soil layers with increasing clay with depth, in some cases with >20% clay (Table 2).

The Undulating sand plain was well dissected by streams flowing southwards off the mountains. Between the sandy rises, the low-lying areas form surface drainage where rice fields predominate (e.g. profile BD43). In addition, along the larger streams there is some outcrop of the basement granite. In the Undulating sand plain, profiles in low-lying areas where rice is grown tended to have higher clay than on the sandy rises (Table 2). This may reflect closer proximity to the weathered granite bedrock for the lowland paddy soils but deeper excavation at these sites is needed to verify this. There was greater relief between the highest and lowest parts of the Undulating sand plain than in the Gently undulating sand plain. Maximum elevation was lower than the Gently undulating sand plain (33 compared with 42 metres above sea level (m asl), respectively) (Table 3).

At the base of the mountain there were two distinctive soil-landscape units identified. On the toe slope of the mountain, at about 20–35 m asl, coarse sand occurred on deeply weathered granitic regolith (BD4, BD5, BD6). The coarse sand grains distinguished this sand from the sand plains. There appeared to be shallow groundwater within 2–4 m depth in the regolith, possibly derived from throughflow from the mountains. This shallow groundwater appears to be accessed by the cashew roots.

A second soil-landscape unit at the base of the mountain had similar elevation to the toe slope but differed in slope and soil properties. The gentler slope gave a terraced appearance and the soils were yellow-brown sandy loams (BD12, BD44).

Table 3. Sand profile types in Phu Cat district, Binh Dinh province, by soil-landscape unit, soil type and land use

Soil-landscape unit	Soil type	Profiles[a]	Land form and main land use
Undulating sand plain	Grey loamy sand, increasing clay with depth	BD8, BD9	18–33 m above sea level (asl), cassava–peanut crops
	Grey sandy loam	BD10, BD11, BD7	18–33 m asl, rice fields at 22–23 m asl
	Pale deep sand	BD13, BD45, BD46, BD48	16–33 m asl, prone to stagnant water in lower areas, cassava–peanut crops
Footslopes of mountains	Yellow-brown sandy loam	BD12, BD44	29–32 m asl, dissected terrace, cashew plantations, grazing and eucalyptus
	Coarse granite sand	BD4, BD5, BD6	22–33 m asl, weathered on granite bedrock or its colluvium, relatively shallow groundwater, cashew crops
Gently undulating sand plain	Brownish sand with increasing clay over depth	BD2, BD3	Very gently undulating sand plain, above flood level, 39–40 m asl, mango crops with or without peanut intercrop
	Pale brownish sand with increasing clay	BD1	Very gently undulating sand plain, 34 m asl, mango with peanut intercropping
	Deep grey loamy sand	BD43	Very gently undulating sand plain, above flood level, 35–42 m asl, rice in low-lying drainage connected to main stream
	Deep grey sand	BD14, BD15, BD41, BD42	Very gently undulating sand plain, on a sandy rise, 34–42 m asl, mango, grasses

[a] A full description of profiles is provided in Phan Thi Cong et al. (unpublished project report 2013)

Properties of soils

Most of the profiles were uniformly acid down the profile with pH_{KCl} in the range 4–5. However, in the surface 10–30 cm, eight of the profiles had pH elevated to 5–8 and these were in peanut fields or fields where peanut had been intercropped with mango. Despite the low pH, levels of exchangeable Al were generally low. The Al saturation (% of CEC) was always <34% and where values exceeded 20% they were generally encountered below 50 cm depth in the profile. Only profile BD2 had an Al saturation value of >20% (26%) in the topsoil layer (Table 4). Such levels of Al saturation are not likely to limit crop production, even in sensitive crops (Dierolf et al. 2001).

The EC was below 0.18 mS/cm in all profiles and generally <0.1 mS/cm. Hence, salinity would not be a constraint on these sands except perhaps in cases involving sensitive crops.

Organic C values were uniformly low, with most profiles having <0.5% organic C in the surface horizon and only two profiles having between 0.5 and 1.0% organic C. Values generally declined further with depth although when the topsoil was low in organic C, values often were fairly constant with depth.

Water holding at –0.1 bars was 3–9% in most horizons of the sands. In those profiles with higher clay (10–20%) in the subsoil, higher water content at –0.1 bars was recorded. The differences between water content at –0.1 and –0.33 bars were small, generally in the range 1–5% except in the Granite sands on the footslopes of the mountain, where subsoil horizons had 5–9% water stored at this range of water potentials.

Texture

The proportion of sand in profiles ranged from 70 to 96%. In general, there were similar percentages of clay and silt except in the profiles with higher clay where clay tended to be more abundant than the silt. The patterns in soil texture down the profile are discussed in more detail below.

Clay ranged from 12–18% on the low-lying rice soils of the Undulating sand plain to 2–4% on the deep sands on rises (Table 2). There were three broad patterns of profile texture: the uniform sandy loam textures (6–18% clay) associated with low-lying land used mostly for rice; uniform deep sands (2–4% clay); and profiles with increasing clay with depth. The paddy soils on the Undulating sand plain were close to the borderline between sandy loam and sandy clay loam textures. However, in general, the profiles examined would have met the criteria for Arenosols; that is, >65% sand and <18% clay to 1 m depth or more (FAO et al. 1998).

Main constraints of sands

There was greater diversity of landforms on which sands occur in Phu Cat than in Thuan Nam and An Chan study areas. Most of the sands appear to be derived from granite, either from in situ weathering or after surface reworking of materials by slope processes, fluvial activity or aeolian activity. There was a greater abundance of profiles with sandy loam and loamy sand textures than in An Chan or Thuan Nam, and a greater prevalence of profiles with increasing clay content with depth.

Key constraints identified by the SCAMP methodology were the high sand content together with low organic matter, and low CEC (Phan Thi Cong et al., unpublished project report 2013). In addition, while low water retention at –0.1 and –0.33 bars is not assessed by SCAMP, levels were very low on most of the sands. These properties are probably all linked since lack of clay and organic C limits CEC and soil water retention, while low clay limits the accumulation of organic C in soils.

In peanut fields, liming results in cases of highly alkaline pH which in turn may induce nutritional disorders in crops. While pH was otherwise low, levels of exchangeable Al were generally not limiting except for very sensitive crops.

Many of the profiles had distinctive compact layers in the root zone. For sites with tree crops, this did not appear to restrict root abundance. For rice, the presence of a compacted layer may be attributed to a plough pan and can be considered a positive soil attribute for retention of standing water in the paddy field. In peanut fields, there were cases where compact soil close to the soil surface could limit peg penetration and pod development in the soil.

The present examination is based on a selective sampling of soils with particular emphasis on sands and hence does not represent a systematic soil survey of Phu Cat district. Even within the sand soil-landscape units, the number and location of profiles was directed by the location of experimental sites. In the Gently undulating sand plain, the profiles described were concentrated in a small part of the landscape unit and hence further sampling would be desirable.

Table 4. Properties of sands in Phu Cat district, Binh Dinh province

Horizon[a] (cm)	pH_{H_2O}	pH_{KCl}	EC (dS/m)	Org. C (%)	Olsen P (mg/kg)	Exch. Al^{3+} (cmol/kg)	CEC (cmol/kg)	Soil water, –0.1 bar (%)	Soil water, –0.33 bar (%)
Grey sandy loam (*n* = 3)									
0 –7	5.44	4.31	0.09	0.68	13.80	0.09	2.10	4.17	2.97
7–26	5.13	4.09	0.03	0.44	7.00	0.23	2.00	4.07	2.73
26–43	5.14	4.10	0.02	0.22	1.03	0.25	2.00	4.43	2.83
>43	5.12	4.11	0.02	0.18	0.83	0.26	2.17	5.23	3.43
Grey loamy sand (*n* = 2)									
0–9	7.38	6.90	0.10	0.14	13.6	0.00	1.75	4.25	2.85
9–18	6.43	5.34	0.05	0.21	23.8	0.04	2.15	4.80	3.25
18–45	5.82	4.70	0.04	0.28	21.4	0.28	2.80	5.85	3.65
>45	5.73	4.16	0.06	0.24	7.3	0.60	2.70	5.60	3.95
Pale deep sand (*n* = 4)									
0–11	5.71	5.05	0.07	0.23	38.8	0.02	2.20	5.00	2.75
11–26	5.28	4.60	0.03	0.19	16.2	0.13	2.13	4.98	2.55
26–46	5.06	4.43	0.06	0.20	20.3	0.24	2.53	5.60	2.90
>46	4.95	4.40	0.04	0.21	2.6	0.36	2.18	5.78	2.88
Coarse granite sand (*n* = 3)									
0–11	5.20	4.13	0.01	0.42	3.43	0.07	1.69	7.13	1.81
11–36	5.57	4.23	0.02	0.29	3.23	0.24	1.98	8.35	2.58
36–62	5.43	4.13	0.03	0.17	3.53	0.30	2.34	10.59	4.06
>62	5.30	4.17	0.02	0.16	3.33	0.28	2.33	10.91	3.84
Yellow-brown sandy loam (*n* = 2)									
0–13	5.23	4.17	0.02	0.43	2.35	0.39	3.74	6.95	4.70
13–23	5.12	4.19	0.03	0.38	1.45	0.34	3.81	7.10	4.95
23–64	4.74	4.11	0.01	0.40	1.54	0.35	4.00	7.45	5.45
>64	5.30	4.18	0.03	0.45	2.83	0.14	4.33	7.35	5.20
Deep grey loamy sand (*n* = 1)									
0–15	5.03	4.21	0.02	0.43	14.2	0.04	3.54	5.30	3.20
15–35	4.82	4.13	0.06	0.42	6.9	0.04	3.62	5.60	3.40
35–65	5.09	4.09	0.02	0.35	5.0	0.04	3.85	5.40	3.20
> 65	5.25	4.41	0.05	0.42	9.6	0.04	3.70	5.40	3.10
Deep grey sand (*n* = 4)									
0–14	6.15	5.61	0.03	0.31	17.6	0.05	2.07	4.53	2.70
14–33	5.88	5.05	0.04	0.36	7.9	0.06	2.14	4.53	2.63
33–51	5.66	4.84	0.02	0.35	5.9	0.08	2.18	4.50	2.65
>51	5.08	4.35	0.02	0.36	8.2	0.24	2.22	4.93	3.03
Brownish sand (*n* = 2)									
0–8	6.05	5.10	0.01	0.40	3.25	0.25	1.45	6.21	1.50
8–24	5.20	4.25	0.01	0.35	2.95	0.15	1.95	7.60	2.35
24–78	4.80	4.20	0.01	0.23	2.45	0.35	2.00	7.89	3.70
>78	4.75	4.05	0.01	0.22	1.75	0.54	2.15	7.76	3.37
Pale brownish sand (*n* = 1)									
0–17	5.50	4.50	0.01	0.23	2.00	0.04	1.30	4.23	1.01
17–27	5.40	4.40	0.01	0.21	1.00	0.12	1.36	5.45	1.99
27–95	5.40	4.30	0.01	0.21	1.40	0.24	1.40	5.26	2.57
95–102	5.00	4.30	0.01	0.22	1.20	0.21	1.45	6.76	2.83
102–150	5.10	4.30	0.01	0.20	1.20	0.17	1.40	5.86	2.59

[a] Variable thickness of horizon among profiles described

Note: pH_{H_2O} = pH measured in water; pH_{KCl} = pH measured in 1M potassium chloride; EC = electrical conductivity; Org. C = organic carbon; Olsen P = extractable phosphorus; Exch. Al^{3+} = exchangeable aluminium cations; CEC = cation exchange capacity; *n* = number of profiles

Soils of Thuan Nam district, Ninh Thuan province

Geomorphology

Aeolian sands are a major landform in the coastal zone of Ninh Thuan. Quang-Minh et al. (2010) presented evidence that the red sand dunes are in the order of 139,000 ± 15,000 to 276,000 ± 17,000 years old. The red sand dunes in Ninh Thuan are contiguous with those in Binh Thuan province and hence probably of the same age. They were not found in Phu Yen or Binh Dinh provinces.

Stratigraphy of the red dunes suggest that they comprise up to 60 m of red sand, overlying 10–20 m of grey-white sand with a 10 m base of white sand rich in carbonate (Quang-Minh et al. 2010). Exposures of the red sand in Phuoc Dinh commune reveal a remarkably uniform sand deposit, with little evidence of bedding layers within it. However, the stratigraphy reported by Quang-Minh et al. (2010) suggests that dissection of the red sand dunes could expose sands with quite different properties at lower elevations towards the base of the deposit.

The white sands studied by Quang-Minh et al. (2010) are 10–40 m deep with sequences of white, yellow and reddish yellow sand, which may sit on a basement of granite. The sands may be enriched in heavy minerals such as ilmenite, zircon and rutile. By contrast with the red dunal sands, the white-yellow coastal barrier sands are more recent. Dating suggests that they mostly formed around the time of the last sea-level high (6,000–9,000 years ago) and hence the basal sands of the white sand dunes were dated at 6,200 ± 300 to 8,300 ± 600 years old. Further periods of sand accumulation took place between 2,700 and 2,500 years and between 700 and 500 years ago. There is also evidence of sand remobilisation in the last 200 years, presumably linked to human disturbance.

Reconnaissance surveys in Ninh Thuan province identified five groups of sands: Red dunal sand; White coastal sand; Sand derived from granite in situ or on its colluvial sediments at the footslope of hills; Alluvial soils associated with small drainage systems; and Coastal marine sand. In Phuoc Dinh commune, the main soils are Granite sand, Red dunal sand and White sand (Table 5). White sand generally

Table 5. Landscape patterns, soils and land use of the portions of Phuoc Dinh commune, Ninh Thuan province, with most potential for agriculture

	Red dunal sand	Coastal white sand	Alluvial soils	Granite sand on gentle slopes
Landform	10–100 m above sea level (asl) with rolling topography	Recent barrier dunes, relatively unstable	Narrow valley, 10–30 m asl, increasing in elevation with distance from the discharge, comprising three distinctive terrace ages with current terrace being lowest	30–120 m asl, sloping land with variable granite outcrop and depth to bedrock
Soils	Deep uniform fine–medium red sand with occasional sub-horizontal aeolian bedding features. Bleached variations occur at the base or margins of the dunes. Seepage zones may also develop in depressions	Deep pale, poorly consolidated sand	Vary from brown sandy loam to loam depending on terrace age and proximity to stream	Generally coarse-to-medium sand of variable depth. Clay content generally increases with depth and proximity to bedrock
Land use	Extensive grazing of sheep and cattle, fruit trees, neem and acacia	Housing, aquaculture ponds for prawns and extensive grazing	Vegetables, fruit trees, pasture often using seepage water from the red dunes	Extensive grazing, cashew

occurs closest to the coast and in Phuoc Dinh commune is the site of most human settlement (Son Hai village) and shrimp aquaculture ponds. Hence, it is of limited significance for agriculture, and will receive less attention in this paper. The Red dunal sand is extensively used for grazing of sheep and cattle, and significant areas have been planted to neem and *Acacia mangium*. These areas are probably important recharge zones for local groundwater resources in Phuoc Dinh that are exploited for vegetable production and paddy rice where groundwater seepage occurs. The base and margins of the red dunes have yellow or white sand variations. These areas, while small in extent, are important because they often coincide with groundwater seepage which is used for vegetables, horticulture and rice production. Small areas of cashew and longan are grown on Red dunal sand. In the neighbouring commune, peanut is an important cash crop in years of high rainfall. The rocky hills of Phuoc Dinh are characterised by extensive granite outcrops. Sand-textured soils occur on these hills and surrounds. On the lower and gentler slopes of the granite hills, deep coarse sand and shallow sand on clay occur. In places, the basement of the profile has sufficient clay for an excavated reservoir to collect and retain run-off water. This may present additional opportunities for small-scale irrigation. The alluvial depositions in a narrow valley between granite hills and Red dunal sand comprise a relatively small portion of the commune area, but due to the availability of stream flow and groundwater have a high potential for intensive crop and horticultural production (vegetables, mango, custard apple).

Substantial areas of Coastal marine sand occur around Phan Rang city. Ninh Hai commune, north of Phan Rang, is an important vegetable production and grape growing area. There are concerns about saline water intrusion into shallow groundwater used in this commune for irrigation (Keen and Chu Thai Hoanh 2015). However, the Coastal marine sand is not found in Phuoc Dinh commune and profiles are not described in the present report.

Soils distribution

The soil-landscape pattern was determined from reconnaissance surveys in the Thuan Nam district, mini-pit examinations of 23 profiles using the SCAMP methodology (Moody and Cong 2008) and interpretations of Google Earth images of Phuoc Dinh and neighbouring communes (Phan Thi Cong et al., unpublished project report 2013). The landscape comprises the following soil-landscape units of particular relevance to agriculture (Table 6):

- Red brown sand
- Pinkish grey sand on the margin of the red sand dunes
- Alkaline grey sand in seepage zones in depressions and at the margins of red dunes
- Granite sand on gentle to moderate slope
- Rocky slopes with granite outcrop
- Coastal white sand dunes
- Narrow alluvial terraces with sand and loams on different terraces.

Red brown sand

The Red brown sand occurs mostly at 40–90 m elevation and is characterised by a distinctive red colour (7.5YR to 10YR on the Munsell colour charts). However, on the southern margin of the red dune, Red brown sand contacts with the upper alluvial terrace at about 10 m asl. The properties of the profile were quite uniform with depth in the upper 40–80 cm (Table 7). Red brown sand was strongly acid, but had little or no extractable Al and low levels of exchangeable acidity. Organic C levels were extremely low at the surface horizon and declined further with depth. Very low levels of Olsen extractable P were found in profiles (Table 7). The CEC was mostly less than 2 cmol/kg but increased slightly with depth. Water retention at –0.1 and –0.33 bars was very low and indicated limited available water storage. Red brown sand contained about 4% clay in the surface horizons, increasing with depth. Fine–medium sand comprised 94% of the surface horizon and decreased to 91% with depth. However, there was some variation in texture, with two profiles having 10% clay at 40 cm depth (profiles NT6, NT10).

From the profile characteristics described and physical and chemical properties determined for Red brown sand, a number of predictions can be made about its behaviour and management. The high permeability and low plant available water will be major constraints, especially in the low rainfall environment of Ninh Thuan. In general, nutrient supply is expected to be low on this sand. Based on the Olsen extractable P levels, P fertiliser will be necessary for crop production. The low organic C suggests that nitrogen (N) supply will also be low without fertiliser or manure application. Low CEC suggests that potassium (K) supply will also be limiting. The availability of micronutrients and sulfur (S) may also be limiting to crop production but this needs to be tested by soil and plant analysis and by field experiments that examine crop response to the addition of these elements (Hoang Minh Tam et al. 2015). While pH was low, there was insufficient exchangeable Al to cause toxicity for root growth, even in sensitive crops. However, manganese (Mn) toxicity at low pH cannot be ruled out. Sands tend to be poorly buffered; hence, there is a high acidification risk if ammonium-N fertilisers, especially ammonium sulfate, are used regularly.

Pinkish grey sand

Only one profile of the Pinkish grey sand was described (Table 7). This soil type occupies only a small area in Phuoc Dinh commune, being confined to the margins of the red sand dunes. It is not clear whether this soil represents a different sand deposit with lower iron (Fe) content, or whether weathering has depleted the sand of its Fe. Stratigraphy studies by Quang-Minh et al. (2010) suggest that a Pinkish grey sand strata underlies the Red brown sand and this may be the explanation for the occurrence of the Pinkish grey sand which tends to occur at elevations below the upper strata of the red sand dune (74 versus >90 m asl).

Apart from colour, the main difference between the Pinkish grey sand and Red brown sand was the lower clay and silt content in the former. Pinkish grey sand contained 98% sand with 1% clay and 1% silt. The CEC was correspondingly lower, as was organic C (Table 7). Pinkish grey sand had slightly lower pH than Red brown sand, but neither contained significant exchangeable Al.

Alkaline grey sand

Only one profile of the Alkaline grey sand was described, from a seepage zone in the narrow depression between a granite hillslope and red dune (Table 7). The cause of the alkaline pH may be pedogenic due to the accumulation of alkaline salts

Table 6. Sand profile types associated with soil-landscape units in Thuan Nam district in relation to landform and land use

Soil-landscape unit	Soil type	Profiles[a]	Land form and main land use
Red dune	Red brown sand	NT1, NT6, NT10, NT11, NT24, NT25, NT26, NT30, NT31	Deep, uniform, stable red dunes up to 100 m elevation with gentle to moderate slopes
	Pinkish grey sand	NT27	Lower elevation strata (70 m above sea level (asl)) underlying red sand occurring on the margins of the red dunes
	Alkaline grey sand	NT7	Occurs in lower elevation (70 m asl) seepage zones terraced and used for cropping including rice
Granite	Deep granite sand	NT9, NT28, NT29	The basement geology is granite and on hills and slopes; sandy soils have weathered on granite. The profile depth and form vary with slope and bedrock topography. Grazing land with some use for fruit trees (cashew) and crops
	Shallow granite sand	NT8	Shallow profile with weathered granite at 45 cm depth. Grazing land, prone to waterlogging
Alluvial	Alluvial sand	NT21, NT22, NT12, NT13	A narrow valley between Red dune to the north and granite hills to the south. Three terraces evident, with the current terrace the lowest. Irrigated vegetables and fruit trees grown on the upper terrace but grazing of pastures is the land use on the middle and lower terraces
	Alluvial loam	NT23, NT14	Middle terrace, loam horizon over sands similar in properties to Alluvial sand
White sand	White sand	Not described	Coastal barrier sand dunes, loose unconsolidated sands, mostly used for human settlement, aquaculture ponds and infrastructure

[a] A full description of profiles is provided in Phan Thi Cong et al. (unpublished project report 2013). Note that additional clay profiles were described in Ninh Thuan on volcanic rock and are not reported here.

from groundwater discharge, or a relic feature of a different parent material deposited at the base of the red dunes. The EC of this profile was higher than most other sands, especially at the surface, but still not excessive for plant growth (Table 7). The current land use for peanut production may also mean that lime application is exacerbating the high surface pH. However, based on previous stratigraphic studies, a calcareous sand strata occurs at the base of the red dunes and hence this is the most probable explanation (Quang-Minh et al. 2010).

The particle size distribution of the Alkaline grey sand was similar to that of the Red brown sand and its CEC higher but organic C was equally low. In the peanut field, the Olsen P concentration was high at 3–27 cm depth, reflecting perhaps P fertiliser addition, while the remaining layers of the profile had low levels of Olsen P, comparable to the level in the unfertilised Red brown sand.

Granite sands

The granite sands varied in profile depth from quite shallow (<50 cm) to over 1 m (Table 7). The variable depth reflects both variation in bedrock topography as well as erosional and depositional activity on slopes. The shallow profiles are prone to waterlogging in the monsoon season. The clay base to the profile appears to retain water. There is potential to excavate to the clay base of the deeper regolith and store run-off water in shallow reservoirs (3–5 m depth) for small-scale irrigation.

The Shallow granite sand was strongly acid, especially at depth, but negligible exchangeable Al was detected in the profile (Table 7). It had low organic C and a slightly higher CEC than Red brown sands. Very low Olsen P levels were determined. Clay content increased from 3% to 6% down the profile, while sand dropped from 94% to 92%. Water retention at –0.1 bars was up to double that in Red brown sand (Table 7).

The Deep granite sand had similar properties to those of the Shallow granite sand (Table 7). It had lower clay (2–3% compared with 3–6%, respectively) and sand, and hence higher silt (4–6% compared with 2–3%, respectively). Higher organic C in the surface horizons was associated with higher CEC and water retention at –0.1 bar relative to the Shallow granite sand. The clay content was similar to that in Red brown sand but, by contrast, the granite sands comprised medium–coarse grains rather than the fine–medium grains of the Red brown sand.

Alluvial soils

As is common for alluvial deposition, layers in profiles can vary greatly in clay and silt content. Two of the six alluvial profiles had a silty surface horizon, but the remainder of the profile contained 85–90% sand, like the entire profile for the two alluvial sands.

Alluvial sand contained only 4–6% clay and 5–7% silt (Table 7). The sand grains were medium- to coarse-grained, suggesting that erosion from the steep granitic slopes of the catchment contributed significantly to the alluvial sediments. pH_{KCl} was weakly acid in the range 6–7. The organic C concentration was extremely low as in most of the other sands. A high subsoil Olsen P concentration may reflect repeated P fertiliser applications for vegetables. The Alluvial sand had higher CEC than Red brown sand and higher water retention at –0.1 bars (5–6% compared with 4%, respectively).

The Alluvial loam, on account of its A horizon with 15% clay and 26% silt, was higher in organic C, CEC and water retention at –0.1 bars than the surface horizons of the Alluvial sand or indeed higher than the subsoil layers of the same profile (Table 7). However, because of its location on the middle and lower terraces, this soil was prone to river flooding and hence pasture was the primary land use.

Sands of An Chan commune, Phu Yen province

Geomorphology

The geology, and hence the soil distribution, within An Chan commune is rather complex. Several hills rise 30–50 m asl and emerge from the surrounding land. The geology is basalt in at least one of these hills, which is consistent with its abundance in the hills of this region, but has not been confirmed at others. A high barrier dune dominates the northern coastal strip of An Chan. It is fringed on the western boundary by both low-lying paddy fields and sand sheets. Within the paddy land, soil texture varied greatly, from soils with over 60% clay (profiles PY11–PY13) to only 3% clay, while pH varied from 7–8 (PY2, PY3) to <5.

The geomorphic origin of the An Chan commune landscape is probably strongly influenced by the episodes of sea-level rise and fall in the past 8,000–10,000 years along coastal Vietnam (Quang-Minh et al. 2010). The sand dune and sand sheets presumably formed due to intense aeolian activity during sea-level regression. Marine sediments that accumulated during recent sea-level incursions and clay sediments that accumulated in shallow estuarine or lacustrine (lagoonal) environments are likely to be expressed in soil properties of the plain.

Soil distribution

Given the episodes of sea-level rise and fall since the last major marine incursion 8,000 years ago (Quang-Minh et al. 2010), the An Chan commune landscape is postulated to be an estuary infilled with

Table 7. Properties of sands in Thuan Nam district, Ninh Thuan province

Horizon[a] (cm)	pH_{H_2O}	pH_{KCl}	EC (dS/m)	Org. C	Olsen P (mg/kg)	Exch. Al^{3+} (cmol/kg)	CEC (cmol/kg)	Clay (%)	Silt (%)	Sand (%)	Soil water, –0.1 bar (%)	Soil water, –0.33 bar (%)
Red brown sand (*n* = 7)												
0–10	6.17	4.99	0.02	0.25	3.4	–	1.82	4	2	94	3.86	2.13
10–30	6.11	4.63	0.02	0.16	2.5	0.05	1.94	4	2	94	4.03	2.26
35–75	6.13	4.55	0.03	0.16	2.1	0.05	2.15	7	2	91	4.25	2.51
Pinkish grey sand (*n* = 1)												
0–18	5.82	4.70	0.01	0.10	5.7	–	1.34	<1	<1	99	2.95	1.78
18–50	5.75	4.52	0.01	0.09	8.5	0.13	1.48	1	1	98	3.06	1.77
50–70	5.48	4.54	0.01	0.10	6.7	0.18	1.45	1	1	98	3.07	1.84
>70	5.15	4.56	0.01	0.09	4.6	0.20	1.32	1	1	98	3.02	1.72
Alkaline grey sand (*n* = 1)												
0–3	8.50	8.30	0.17	0.19	5.3	–	2.50	4	1	94	3.80	2.30
3–27	8.70	8.70	0.07	0.30	19.8	–	2.54	4	1	95	3.70	2.20
27–55	8.10	7.70	0.08	0.09	4.6	0.03	2.23	3	2	95	3.50	2.00
>55	7.60	7.20	0.03	0.08	4.8	–	2.34	5	1	94	4.00	2.50
Alluvial sand (*n* = 2)												
0–12	7.66	6.70	0.04	0.26	4.1	–	2.90	4	7	89	5.86	3.36
12–27	7.45	6.20	0.02	0.24	14.2	–	3.45	5	7	88	6.17	3.49
35–43												
43–82	7.12	6.05	0.09	0.16	3.2	–	2.95	6	5	89	5.15	2.95
Alluvial loam (*n* = 1)												
0–28	7.83	6.73	0.34	1.37	2.7	–	8.21	15	26	59	8.86	4.78
28–53	7.87	6.99	0.39	0.68	1.1	–	4.02	6	9	85	6.98	3.57
53–65	7.47	6.35	0.27	0.32	1.2	–	3.46	4	6	90	6.79	3.56
Shallow granite sand (*n* = 1)												
0–7	7.10	5.30	0.03	0.29	1.5	–	2.20	3	3	94	7.80	3.80
7–17	6.00	4.30	0.03	0.22	1.4	0.01	2.20	5	3	92	7.40	4.00
17–33	6.00	4.30	0.02	0.10	1.5	0.01	2.10	5	2	93	6.80	3.60
33–47	5.90	4.70	0.09	0.14	1.8	–	2.10	6	2	93	6.30	3.40
>47	5.30	3.50	0.08	0.32	2.0	–	2.10	6	2	92	5.30	3.00
Deep granite sand (*n* = 1)												
0–8	6.20	4.90	0.03	0.50	3.5	–	3.20	2	6	92	9.70	5.20
8–26	6.00	4.60	0.01	0.45	1.0	0.02	2.80	2	5	93	9.00	5.20
26–70	5.60	4.30	0.01	0.10	1.1	0.19	3.10	4	4	92	7.50	3.10
70–125	5.50	4.40	0.02	0.08	0.9	0.17	3.00	3	5	92	6.60	3.00

[a] Variable thickness of horizon among profiles described

Note: not all profiles listed in Table 6 were analysed; pH_{H_2O} = pH measured in water; pH_{KCl} = pH measured in 1M potassium chloride; EC = electrical conductivity; Org. C = organic carbon; Olsen P = extractable phosphorus; Exch. Al^{3+} = exchangeable aluminium cations; CEC = cation exchange capacity; *n* = number of profiles clay sediments and then more recently buried on the seaward section by aeolian sands. The clay-rich sediments were supplied by alluvial transport from hills in the hinterland plus local colluvium from out-cropping hills. Some of these hills have basalt rock outcrop which is consistent with the high clay content of the Heavy grey brown clays. The plains surrounding a lagoon in An My commune, immediately north of An Chan commune, comprise black cracking clays which are consistent with a basaltic origin. Indeed, the lagoon environment in An My may be a mimic of how infilling of An Chan occurred during an earlier period of sedimentation. The alkaline sediments that form sand and loam profile types may reflect marine influences on sedimentation in the estuary. The more recent sand deposition from the east has probably buried clay sediments but insufficient coring has been carried out to verify this. At the interface of the sand and clay deposition, there has probably been some mixing of materials either naturally by interlayering of sand and clay sediments, or by tillage for agriculture. The contrasting sources of sediments are reflected in the large range in clay contents of soils on the valley from over 60% to 3% clay.

Properties of soil-landscape units

Dunal sand

The dunal sand profiles, called Deep pale yellow brown sand, contain almost no clay or silt, although one of the profiles at depth had a horizon below 50 cm with 7% clay. Organic C, CEC and water retention at –0.1 and –0.33 bars were extremely low in this sand (Table 8). Where the sand has been used for vegetable production, Olsen P levels were uniformly high to >50 cm depth, suggesting easy leaching of P fertiliser (and probably other nutrients as well). While used for vegetable production in the dry season under irrigation, these sands are extremely infertile and difficult for water and nutrient management. Avoiding nutrient leaching, especially nitrate-N and phosphate, into groundwater is an important challenge to ensure good water quality for household consumers. The possibility of groundwater pollution from nutrients and pesticides used in vegetable production is reported in Do Thi Thanh Truc et al. (2015).

The Deep pale yellow brown sand is possibly best used for perennial crops, but for vegetables and annual crops soil amendments are required to improve its ability to retain water and nutrients. Organic matter, including manures, biochar and clays are all possible amendment materials worth consideration.

Sand sheet

The Grey brown sand of the extensive sand sheet is chemically similar to the Deep pale yellow brown sand with low organic C, CEC and water retention (Table 8). However, it contains 3% clay and 3% silt whereas both of these constituents were present in only trace amounts in Deep pale yellow brown sand. While the greater clay and silt content should improve its nutrient retention and properties for agriculture, P concentrations were elevated throughout the profile on the Grey brown sand, suggesting active leaching of added fertiliser P. The Grey brown sand was strongly acidic, more so than the Deep pale yellow brown sand, but little or no extractable Al was detected.

The Grey brown sand used for vegetables and annual crops requires soil amendments to improve its ability to retain water and nutrients. Organic matter, including manures, biochar and clays are all possible amendment materials worth consideration.

Alkaline soils

Two forms of alkaline soil profiles were identified: one with 20–27% clay and the other with only 4–10% clay. Both occurred at low elevation in the plain adjacent to the western margin of the barrier dune. The Alkaline sand had pH 8.3–8.8 throughout the profile. Clay content increased with depth from 4% to 10%, and silt also increased with depth. Organic C generally increased with depth and concentrations were much higher than other sands. The EC was higher than other sands but still below levels that might harm crop production (Table 8). Olsen extractable P concentrations were lower than other sands and declined sharply with depth, suggesting limited P movement by leaching, unlike the other sands in An Chan commune.

The Alkaline loam had generally lower pH than the Alkaline sand but much higher pH than other clay-rich profiles in An Chan commune. Organic C was relatively uniform with depth but concentrations were lower than the Alkaline sand. Olsen extractable P was high at the surface of the Aklaline loam but declined sharply with depth (Table 8).

Table 8. Properties of sands in An Chan commune, Tuy An district, Phu Yen province

Horizon[a] (cm)	pH H_2O	pH_{KCl}	EC (dS/m)	Org. C (%)	Olsen P (mg/kg)	Exch. Al^{3+} (cmol/kg)	CEC (cmol/kg)	Clay (%)	Silt (%)	Sand (%)	Soil water, –0.1 bar (%)	Soil water, –0.33 bar (%)
Deep pale yellow brown sand (*n* = 3)												
0–20	5.84	5.08	0.08	0.27	14.0	–	0.64	< 0.5	1	99	0.95	0.63
20–50	6.88	5.93	0.03	0.09	12.0	–	0.50	trace	trace	100	0.95	0.50
50–90	6.95	5.87	0.05	0.15	12.3	–	1.31	3	1	96	1.47	0.91
Grey brown sand (*n* = 8)												
0–7	5.90	4.87	0.08	0.27	22.9	–	0.46	3	3	94	0.64	0.41
7–28	6.14	4.84	0.04	0.18	26.8	–	0.19	3	3	94	0.41	0.19
28–62	6.02	4.83	0.03	0.23	54.8	0.01	0.19	3	3	94	0.44	0.19
>62	5.98	5.29	0.06	0.27	50.7	0.01	0.19	3	4	93	0.44	0.19
Alkaline sand (*n* = 1)												
0–20	8.29	7.88	0.22	0.97	10.8	–		4	1	95		
20–45	8.58	7.85	0.14	1.27	8.9	–		5	6	89		
45–65	8.61	7.53	0.12	1.89	3.5	–		10	8	83		
>65	8.83	8.09	0.10	1.41	6.5	–		10	13	77		
Alkaline loam (*n* = 1)												
0–17	7.81	6.64	0.19	0.77	24.9	–		24	5	67		
17–36	8.52	7.47	0.16	0.67	10.3	–		27	7	66		
36–57	8.56	7.49	0.17	0.70	1.9	–		20	17	63		

[a] Variable thickness of horizon among profiles described

Note: additional profiles were described and analysed for An Chan commune (Phan Thi Cong et al., unpublished project report 2013, available from RWB) but only the sands and related lowland soils are reported here; cation exchange capacity (CEC) and soil water contents were not determined in the alkaline soils; pH_{H_2O} = pH measured in water; pH_{KCl} = pH measured in 1M potassium chloride; EC = electrical conductivity; Org. C = organic carbon; Olsen P = extractable phosphorus; Exch. Al^{3+} = exchangeable aluminium cations; *n* = number of profiles

Management strategies for the identified constraints

Considering all three study areas in SCC Vietnam, the soil constraints identified were: acidity, Al toxicity, high pH, sand texture, low CEC, low organic C, compaction, low plant-available water content and high extractable P. The severity of constraints varies among crops (Moody and Cong 2008). In this chapter, only a general rating of constraints has been presented rather than crop-specific ratings. Moreover, the constraints are calibrated for aerobic soils and several (such as acidity, compaction) are less relevant to rice grown on the same soils when saturated. Saturation tends to increase soil pH so that acidity and Al toxicity cease to be constraints so long as the soil remains saturated (Seng et al. 1999, 2004). Compaction may improve soil suitability for rice on sands by retaining water and decreasing the risk of loss of soil saturation in the root zone.

In the SCAMP methodology, each constraint has a number of generic management or treatment options listed to ameliorate the limitation for crop production (Moody and Cong 2008). These are discussed below, although at this stage few of them have been specifically tested and validated for the sands of SCC Vietnam. Moreover, the effectiveness of the treatments for tree crops is less well tested than for field crops.

High sand content

The focus of soil investigation in the present study was on sands, although in An Chan commune, due to the complex pattern of soil distribution, a number of clay soils were also examined. All the soils examined in Binh Dinh province had high sand content and most would classify as Arensols if the soil profile descriptions had extended to 1 m depth (FAO et al. 1998). Even the rice soils had <20% clay and hence had a sandy loam texture. Most soils had 90% sand or more and the deep sands generally had about 95% sand. In Ninh Thuan province, Red dunal sand had 95% sand, as did the Granite sand, while Alluvial sand contained only 90%. The Pale yellow brown sand of An Chan had 99% sand and was the most extreme of the sands examined. The range of clay content in sands of SCC Vietnam (0–20%) implies major differences in properties for management. The sands of the SCC region need to be differentiated based on clay content, and on profile trends in clay. While the dunal sands, for example, in Ninh Thuan and Phu Yen tended to be uniform deep sands, trends for increased clay with depth were noted in some of the sands in Phu Cat district and in the Alkaline sand of An Chan. Moreover, among the Red brown sands, two profiles had distinct increases in clay with depth. Such differences in clay and clay trends down the profile need to be detected by land managers and recognised for their impact on soil management.

It is common for multiple nutrient deficiencies to occur on sands (e.g. Bell et al. 1990). A key to improving the productivity of sands is to diagnose all the limiting nutrients (Bell and Seng 2007). Failure to diagnose any one of the limiting nutrients or applying a corrective treatment for only one of the deficient elements will limit the response due to the remaining limitation of other elements. However, even after diagnosis and applying corrective treatments, it is necessary to monitor crops for nutrient deficiencies over time since many nutrients leach on sands and the inherent nutrient supply capacity is limited. Soil and plant analyses are the main tools that can be used for this purpose (Bell and Seng 2007; Bell and Dell 2008).

Sands are poorly buffered so there is a high risk of pH change due to management. As seen in the present study, pH of sands can be easily increased to over 7 even with modest lime rates. Hence, the risk of over-liming of sands is high. It is advisable to monitor soil pH regularly on these sands.

Another consequence of high sand content, especially if there is a predominance of fine sand, is wind erosion risk. Low soil cover at times of high wind speed gives rise to wind erosion risk. The SCC region of Vietnam is relatively windy and hence the wind erosion risk warrants further attention in maintaining productivity of sands. Managers should maintain surface plant or crop residue cover or increase surface roughness to reduce wind erosion risk. Those areas with a high density of mango and cashew trees on sands will have satisfactory cover and protection against wind erosion. Wind breaks, crop residue retention and the use of zero tillage are effective tools for reducing wind erosion risk.

Amendment of sands with clay is a treatment that may be worth further investigation. Clay addition to sands in north-eastern Thailand has been highly effective in increasing productivity (Noble et al. 2001, 2004). Clay additions to sands decrease wind erosion risk. The type of clay will influence soil properties, with high-activity clay application being most desirable, if available. In north-eastern Thailand, bentonite clay was effective at 50 tonnes (t)/hectare (ha).

However, local clays and subsoil clays may be more readily available and hence require lower cost to obtain and spread. Kaolinitic subsoil clays used in the south-coastal region of Western Australia are effective amendments of fine sands when added at 6% clay (Hall et al. 2010). This requires additions of 150–300 t of subsoil/ha, depending on the clay percentage of the material.

Aluminium toxicity

While many of the sands were acid, few contained significant levels of Al. Aluminium saturation in the range 20–33% was reported in some profiles, but generally such values were found at 50 cm depth or greater. Hence, the risk of Al toxicity was generally low (Dierolf et al. 2001; Moody and Cong 2008). The impact of acidity may be through Mn toxicity or low levels of available molybdenum or impaired nodulation and N mineralisation. Nevertheless, crops sensitive to acidity will require lime application to the soil at rates that do not increase soil pH (water) above 6.0 otherwise induced deficiencies of trace elements are likely. Overliming is most likely to induce boron, Mn or zinc deficiencies. In general, farmers should incorporate lime as deep as possible to encourage deep root activity. Dolomitic limestone would be preferred if soil magnesium status is considered marginal. Liming is already used for peanut production (although a recent survey of peanut farmers in Phu Cat by the Agricultural Science Institute for Southern Central Coast of Vietnam (ASISOV) suggested large variability among them in rates used). The rate recommended is 400 kg/ha, which is not high, but with repeated application could lead to overliming. Already some soils with pH up to 7.9 have been reported. Gypsum that supplies the soluble calcium needed for pod filling in peanut may be a suitable alternative to continued liming of sands that are already alkaline.

Organic matter

As is usual with sands, most of the profiles in the present study were low in organic matter (OM). Mulch and incorporation of ‘green manure’ crops, such as legumes or forage grasses, into the topsoil can help to maintain soil OM. Similarly, retaining all crop residues as surface cover, avoiding burning of crop residues and minimising cultivation should help to maintain soil OM levels. For this reason, the development of minimum tillage or zero tillage planters for sands of this region would be beneficial. Application of organic materials such as animal manures, composted material and locally available plant residues, and use of alley or strip cropping to increase on-site crop residue production can all help to maintain soil OM levels. However, it is difficult to increase soil OM on sands since clay is needed to stabilise and protect OM against mineralisation. Stable OM amendments, such as biochar, may be more effective in the long term as OM additions to sands. Alternatively, clay addition, as discussed above, may have a role in protecting soil OM on sands and helping levels to increase over time, as reported by Hall et al. (2010) for amended sands in Western Australia.

Phosphorus

As seen in the present study on sands that have been fertilised with P for peanut and vegetables, levels of Olsen extractable P in the topsoil can increase substantially. In addition, large increases in extractable P in the subsoil were evident, suggesting P leaching. Hence, there is merit in re-examining the rates of P needed for peanut and vegetables on sands that have a history of P application and already have high Olsen P levels in topsoil and subsoil layers. Moreover, the high rates of leaching suggest that application of water-soluble P fertilisers should be split. In very low P-sorbing soils, such as sands, overapplication of soluble P fertilisers may result in P leaching into local groundwater (Do Thi Thanh Truc et al. 2015). In these soils, citrate-soluble P fertilisers such as fused magnesium phosphate, rather than water-soluble P fertilisers, should be used.

Leaching

To minimise leaching losses of applied nutrients, farmers should apply soluble fertilisers in split applications (e.g. Sitthaphanit et al. 2009). Split applications minimise the risk of loss of nitrate-N, K, calcium and magnesium by leaching. Increase in the OM content of the soil as described above, clay additions and biochar additions may all help to reduce leaching. Where possible, use of organic amendments as nutrient sources should also diminish leaching of nutrients.

Nutrient disorders

Through other investigations, nutrient disorders have been diagnosed on a range of the sands described in the present study (Hoang Minh Tam et al. 2015). Evidence has been derived from field responses of yield in mango, cashew and peanut, from leaf analysis and from double-pot experiments in the glasshouse (Hoang Minh Tam et al. 2015). Deficiency of P depends on previous P fertiliser history. On sites that have been fertilised with P for peanut, vegetables or fruit trees, P was generally adequate, while on sites on Red sand, Granite sand and Grey sand that had not been fertilised, P deficiency was recorded. On the sands, K and S deficiency were recorded in all cases where these elements were applied. On Yellow brown sandy loam and Pale brown sand, no S treatments were applied, so the question of deficiency has not been tested. Of the micronutrients, copper and boron were deficient in all cases except Red sand, Grey sand and Granite sand (only boron was deficient). No clear evidence of zinc deficiency was diagnosed in the omission experiments with peanut. While omission of molybdenum did not depress peanut pod yield, shoot dry matter was depressed at two of three sites. In an unpublished leaf analysis study with forages, Mn concentrations in *Panicum maximum* (green panic) were high enough to cause toxicity.

Hence, on sands in Binh Dinh, Phu Yen and Ninh Thuan provinces, there is strong evidence that multiple nutrient disorders will limit crop production. In addition to the other constraints discussed, integrated nutrient management to correct deficiencies of all limiting nutrients, and strategies to ensure adequate supply of nutrients in relation to crop demand, will need to be developed for sands (Hoang Vinh et al. 2015).

Compaction

Compact layers in sands were common in Phu Cat district of Binh Dinh province but not reported for either Ninh Thuan or Phu Yen provinces. Except for the sands that were described in paddy fields, the cause of compaction is not clear. Tillage when the soil is above (wetter than) its plastic limit may exacerbate the compaction. In some cases, the compaction layer was shallow at 7–17 cm and would be relatively easy to break up by conventional tillage machinery. Where the compaction is at 15–30 cm, the effects on crop growth may be less, but the difficulty of treating it by tillage would be correspondingly greater. If possible, farmers could grow tap-rooted crops that have the capacity to penetrate and weaken the hard layer.

Anecdotal reports suggest that subsoil compaction is caused by cassava cultivation, but there is no known evidence to support this. The puddling of soil for rice cultivation may account for some instances of a shallow compaction layer (e.g. profiles BD7, BD10, BD11), but many of the soils have had no recent history of rice cultivation. Hence, the compaction observed may be a natural phenomenon. More detailed investigation is needed to quantify the levels of soil strength attained and to verify that such levels act detrimentally on root growth in various crops of interest in Phu Cat district.

Conclusion

Study areas were located in Phu Cat district, Binh Dinh province, Tuy An district, Phu Yen province, and Thuan Nam district, Ninh Thuan province, to capture the main variation in types of sands and climatic influence on land use. The sands were diverse in their clay content, colour, pH and texture trend with depth. Most of these difference can be attributed to parent material which comprised aeolian sands (from white and red dunes), alluvial terraces, marine sediments, colluvial sediments (mostly from granite) and in situ weathered granite with or without surface re-working of sands by aeolian, fluvial or slope processes. Most of the sands were acid, but even when strongly acid contained little extractable Al. Alkaline sands in small areas were also identified in Ninh Thuan and Phu Yen. Organic C, CEC and water retention at –0.1 bars were generally very low but clearly increased with clay content that varied from 0 to close to 20%. Management influences on sand properties were also evident. On acid sands that had been used for crop and vegetable production, there was evidence of P leaching down profiles. Peanut fields in Binh Dinh often had elevated pH from regular lime applications. Also in Binh Dinh, there was evidence of compaction of sands in the rooting zone for crops. Strategies for improved management of the sands including soil amendments and fertilisers are discussed.

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Section 2: Limitations to crop production on the infertile sandy soils, including a wide range of macro- and micronutrient deficiencies

Identification of a wide range of nutrient deficiencies in annual and tree crops and integrated nutrient management strategies are the main focus of this section. The contribution of organic amendments and the potential for variable-rate nutrient additions to minimise costs for farmers are also covered. Use of the mini-pan to improve water use efficiency is examined for peanut, mango and cashew.

Diagnosing multiple nutrient deficiencies that limit crop growth and yield on sands in south-central coastal Vietnam

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Abstract

Nutrient management for profitable and sustainable crop production depends on correct diagnosis of the full range of disorders that could potentially limit crop yield and grain or fruit quality. On sands, a suite of nutrient disorders can typically limit crop yield but the specific deficiencies can vary among types of sand. Hence, for site-specific nutrient management, there is a need for accurate diagnosis of the disorders. In the present study, the omission design—'All' nutrients, and without phosphorus (P), potassium (K), sulfur (S), boron (B), copper (Cu), zinc (Zn) and molybenum (Mo)—was used in five field experiments to determine limiting nutrients for peanut growth and yield on a range of the major sand types in south-central coastal (SCC) Vietnam. A modified double-pot experimental approach was also used to determine its accuracy in more rapid prediction of field nutrient deficiencies. In three field experiments in Phu Cat district, Binh Dinh province, irrigated peanut yield was depressed by K, S, B and Cu deficiency. In addition, omission of Zn depressed yield in one of those fields. Omission of Mo depressed shoot dry matter (DM) of peanut in the Cat Hanh site in 2011 but not seed yield. Double-pot experiments with maize as a test plant confirmed K, S, B and Cu deficiencies in Binh Dinh sands. By contrast, in sands in Ninh Thuan province, P, K, S, Cu and Zn were deficient for peanut yield at one field site while P, K, S, B, Cu and Zn were deficient at another. The results were supported by maize plant DM and shoot nutrient concentration responses in the double-pot experiment. We conclude that nutrient disorders vary among different sands, requiring careful diagnosis for each type of sand, but parent material best explains differences in the suite of nutrient deficiencies diagnosed in each. The modified double-pot experiment predicted the same deficiencies as the field experiments, suggesting it could be used as a diagnostic tool to assess the suite of nutrient limitations expected in different types of sands, whether in Vietnam or elsewhere. Multiple nutrient deficiencies in SCC Vietnam require further research to develop integrated nutrient management approaches to overcome these deficiencies and also minimise the cost of inputs.

Introduction

Sands in the coastal zone of Vietnam cover about 0.33 million hectares (ha) (Hoang Thi Thai Hoa et al. 2010), located mainly in the north and south-central regions. Only limited investigation of these soils has been carried out to develop evidence-based nutrient management practices for profitable and sustainable crop production. Present recommendations largely focus on balanced fertilisation with nitrogen (N), phosphorus (P) and potassium (K) which are applied to a range of field and tree crops common in the region (Hoang et al. 2009). However, multiple nutrient deficiencies, including micronutrients, are common on sands (Bell et al. 1990). Failure to diagnose the full range of deficiencies will limit the response to nutrients in fertilisers, produce low

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nutrient use efficiency of the supplied nutrients, and little or no profit from the fertiliser investment (Bell and Dell 2008). Moreover, in the coastal zone, where shallow aquifers occur under sands, there is a high risk of groundwater pollution from nutrients, such as nitrate-N (NO_3-N) and phosphate-P (PO_4-P) (Do Thi Thanh Truc et al. 2015) when there is low nutrient use efficiency for supplied fertiliser.

Low clay and high sand contents are the main defining characteristics of sands. Up to 18% clay is allowable in the Arenosols—the principal World Reference Base order for sand-rich profiles. Within the range 0–18% clay and 65–100% sand that occur in the Arenosols (FAO et al. 1998), large variation in soil properties is possible. Within sandy terrain, such as in Vietnam, significant variation in profile clay content can occur along topo-sequences (Bell et al. 2015). Differences in clay content and in clay mineral type can greatly alter the yield potential of rice and other crops. The parent material for sands can also vary and will undoubtedly influence the likelihood of particular nutrient deficiencies. The coastal sands in central Vietnam have been broadly divided into Red, Yellow and White dunal sands and Sandy marine soils (Vietnam Soil Association 1996). Within these geomorphic units, further subdivision of sands is recommended based on clay percentage, clay distribution with depth and pH of the soil (Bell et al. 2015). For example, the Red dunal sand has a basal strata of calcareous sands that is overlain by yellow sands with up to 60 m of red sand capping the dune (Bell et al. 2015). Soils associated with exposure of each of these strata will differ in their properties and accordingly may have distinctive influences on crop productivity.

Our investigations in Ninh Thuan, Phu Yen and Binh Dinh provinces of south-central coastal (SCC) Vietnam indicate that sands derive from in situ weathered granite, from colluvial sediments weathered from granite and from siliceous sediments reworked by aeolian and fluvial activity (Bell et al. 2015). Sandy alluvial deposits also occur in the coastal terrain of Ninh Thuan. In summary, sands comprise a diverse range of soils by variation in texture, parent material and pedological development, leading to considerable variation in physical and chemical properties. Hence, the type and severity of nutrient constraints need to be carefully defined for different types of sand profiles.

Nutrient management of sands is generally more complex than that of other soils because of the prevalence of multiple nutrient deficiencies. In addition, the low water holding capacity of the sands can limit root access to nutrients when topsoils dry out and with increased propensity of many nutrients to leach away (e.g. Bell and Seng 2007; Sitthaphanit et al. 2009). In north-eastern Thailand, apart from N and P deficiencies, K, sulfur (S), boron (B), molybdenum (Mo) and copper (Cu) are commonly deficient (Bell et al. 1990). However, not all these deficiencies occur on all sands and in all crops. For site-specific nutrient management of sands, accurate diagnosis is needed of the suite of disorders limiting crop production in a particular soil type.

Peanut (*Arachis hypogaea* L.) was chosen as the test crop for field studies to determine what range of nutrient disorders might limit yield and nut quality. Peanut is expanding as a cash crop in the SCC region, driven by market opportunities in China (Phan Thi Tam Giac and Mackay 2015). However, little research on its nutrient requirements in this region have been undertaken apart from a few studies on micronutrients and P deficiency (Nguyen Thi Dan and Thai Phien 1991; Le Thanh Bon 1996; Hoang Minh Tam et al. 2010; Nguyen Van Chien 2010). These studies tested only a few of the nutrients essential for peanut growth and doubt remains whether peanut crops achieved their potential yield on these sands.

The first aim of this study was to identify the nutrient constraints for yield of peanut on a range of sands in Phu Cat district, Binh Dinh province and Ninh Phuoc district, Ninh Thuan province. The second aim was to test the reliability of the double-pot technique developed by Janssen (1974, 1990) to rapidly assess nutrient constraints for plant growth of maize on a range of sands from Binh Dinh, Phu Yen and Ninh Thuan provinces. The ability to rapidly assess the nutrient supplying capacity of soils is an essential first step in developing a useful nutrient management system. The double-pot technique was assessed to confirm its reliability in predicting nutrient deficiencies found in peanut in the field experiments.

Materials and methods

Field experiments

Soil preparation and management

Omission experiments were conducted at five sites in Binh Dinh and Ninh Thuan provinces during 2010–12 on soils classified as sands or loamy sands based on surface texture (Table 1). Land was ploughed and later levelled by raking. All the experiments followed a complete randomised block design with four replicates. Each plot covered an area of 15 m^2. Dual Gold[R] 960EC (S-Metolachlor (min. 98.3%) herbicide was used to control weeds by spraying the field after ploughing. Peanut (variety LDH 01) was chosen as the test crop at all sites to diagnose nutrient disorders that could limit growth and yield using an omission design (Bell et al. 1990). Two seeds/hole were placed manually at a distance of 20 cm with a row spacing of 25 cm to give a target density of 40 plants/m^2. Seeds were sown at a depth of 3–5 cm. The crop was regularly irrigated with bore water using a hose—a normal farming practice in this region—aimed at avoiding water stress to allow optimal crop growth. Pests and diseases were managed using various pesticides (Topsinm 70 wp, Anvil 5 SC, Cofidor, Admitox 750 wDG, Alimec USA 36 EC and Map – permethrin 50EC).

The optimum rates of nutrients applied to soils were referred to as 'All' and included macro- (N, P, K and S) and micro- (Cu, B, zinc (Zn) and Mo) nutrients at rates, forms and methods of application outlined in Table 2. Rates of fertiliser application were based on recommendations for peanuts (Dierolf et al. 2001). The 'All' treatment was used as a benchmark to compare crop growth against other treatments in which specific elements were omitted.

All treatments received lime as calcium oxide (CaO) at 500 kg/ha, supplying 358 kg Ca/ha. Half of N, K and lime and all of P, S, Cu, Zn and Mo were broadcast on the soil surface and incorporated in the

Table 1. Location, year and physico-chemical properties of soils used for field experiments

Site no.	Location[a], year	Soil properties (0–10 cm)								
		Clay (%)	Silt (%)	Sand (%)	pH_{KCl}	Olsen P (mg/kg)	Org.C (%)	CEC (cmol/kg)	EC (dS/m)	Soil water, –0.1 bar (%)
1	Cat Hanh, 2010	9	3	88	4.30	5.2	0.45	1.80	0.008	7.1
2	Cat Hanh, 2011	2	3	95	6.98	33.1	0.43	1.80	0.041	4.7
3	Cat Trinh, 2011	2	4	94	4.40	35.9	0.51	2.4	0.024	6.5
4	An Hai, 2012	1	2	98	6.10	14.9	0.29	1.45	0.059	3.1
5	Phuoc Dinh, 2012	3	1	96	4.83	7.0	0.11	1.73	0.016	3.4

[a] Cat Hanh and Cat Trinh communes, Phu Cat district, Binh Dinh province; An Hai commune, Ninh Phuoc district, and Phuoc Dinh commune, Thuan Nam district, Ninh Thuan province

Note: pH_{KCl} = pH measured in 1M potassium chloride; Olsen P = extractable phosphorus; Org. C = organic carbon; CEC = cation exchange capacity; EC = electrical conductivity

Table 2. Fertiliser rates, forms and methods of application in the field experiments

Nutrient (element)	Amount applied (kg/ha)	Form of fertiliser	Method of application
Nitrogen	30 N	Urea: NH_2CONH_2	Broadcast
Phosphorus	40 P	Sodium dihydrogen phosphate: NaH_2PO_4	Broadcast
Potassium	50 K	Potassium choride: KCl	Broadcast
Sulfur	20 S	Calcium sulfate: $CaSO_4$	Broadcast
Boron	0.25 B	Boric acid: H_3BO_3	Foliar
Copper	2.39 Cu	Copper sulfate: $CuSO_4$	Broadcast
Molybdenum	0.543 Mo	Ammonium molybdate tetrahydrate: $(NH_4)_6Mo_7O_{24}.4H_2O$	Broadcast
Zinc	4.05 Zn	Zinc sulfate: $ZnSO_4$	Broadcast

soil to 8 cm depth before sowing: the remaining half of N, K and lime was broadcast at flowering stage. Boron was applied at 0.25 kg/ha as boric acid by dissolving in 500 litres (L) of water and sprayed on peanut foliage just before flowering.

Plant sampling and harvesting

Peanut shoots were harvested to measure dry matter (DM) at branching, flowering and maturity from a quadrat measuring 0.5 m^2 in an area representing 20 plants. Pod yield was measured at maturity by uprooting all the pods from the whole plot (15 m^2). Pods were sun-dried in the open and weighed to estimate pod yield. Other harvest data included number of pods/plant, number of well-rounded pods/plant, weight of 100 pods and weight of 100 nuts (kernels) from 10 plants/plot.

Soil and plant analysis

Soil pH was measured in 1 M potassium choride (KCl) in a soil to solution ratio of 1:5 using a pH meter (Mettle TOLEDO MP220). Electrical conductivity (EC) was measured in a soil to water ratio of 1:5 using a EC meter (Mettle TOLEDO FE30). Available P (Olsen P) was extracted using 0.5 M sodium bicarbonate ($NaHCO_3$) at pH 8.5 (Olsen et al. 1954). Organic carbon was determined by 1 N potassium dichromate ($K_2Cr_2O_7$) solution and 2.5 N sulfuric acid (H_2SO_4) (Walkley and Black 1934; Walkley 1947). Cation exchange capacity (CEC) was measured after extraction with 1 M ammonium acetate (NH_4OAc) at pH 7.0 (van Reeuwijk 2002). Soil particle size was measured according to Day (1965). Water holding capacity was determined using a pressure plate apparatus to de-saturate soil samples to –0.1 bar matric potential.

Plant samples, except N, were analysed for all the test nutrients using inductively coupled plasma (ICP) by an accredited laboratory (CSBP Limited, Western Australia). Nitrogen was analysed by the Kjeldahl method.

Double-pot experiment

Method, preparation and management

The double-pot method used here is a modified version of Janssen (1974, 1990) which involves growing the desired test plant (maize) in soil packed in a container and suspended above a pot containing nutrient solution, so that the plant roots can access nutrients from both the soil and from a nutrient solution. By selective omission of nutrients from the nutrient solution, the relative nutrient supply capacity of the soil can be easily assessed. This method differs from the original method of Janssen (1974) in the design of the apparatus and the nutrient solution used. Instead of the plant roots being able to grow through a gauze layer to the nutrient solution under the soil, the nutrient solution is supplied to the soil via a wick system.

The containers used were those used for food takeaway supplies. Dimensions of the upper container were 115 mm width × 40 mm height with a 6 mm hole pressed out in the centre of the base to accommodate the absorbent wick. The lower container was 115 mm width × 100 mm height. The cylindrical wicks were uncut cigarette filters measuring 7 mm × 125 mm. The wick was placed to touch the bottom of the lower container and to be approximately 5 mm below the surface of the soil placed in the upper container. Soils were collected in bulk from three sites representing field experimental sandy soils of Cat Hanh and Cat Trinh communes in Binh Dinh province (samples 1, 2 and 4), two soils from Ninh Thuan province, representing granite sand from An Hai (sample 3) and red sand from Phuoc Dinh (sample 5), and one representative sandy soil from Phu Yen province (sample 6). Soils used and their physico-chemical properties are presented in Table 3. Samples 1, 3, 4, 5 and 6 were collected at 0–20 cm depth, whereas sample 2 was taken from 20–40 cm depth from the same site as sample 1.

Each pot received 1 kg of the sandy soil as described in Table 3 after being passed through a 2 mm sieve. The pot was packed into the top container at a bulk density of 1.35 g/cm^3, and the lower container was filled with approximately 500 mL of distilled/deionised water. The wick absorbed nutrients and the water from the lower container via capillary action to supply to the soil in the upper container. Initially, the pot was left for several hours for the soil to moisten and equilibrate.

Six maize seedlings of similar size germinated earlier on wet tissue paper were planted in the pots containing soil placed above the container filled with water that was later replaced with the relevant nutrient solution. Nutrient solutions were topped up daily, or when required, and were replaced with fresh solution once per week. The nutrient solution treatments were randomised in replicate blocks and replicated three times.

Treatments

Seven treatments were tested for their impact on maize vegetative growth in the glasshouse (Table 4). These included a complete solution (All) and complete solution minus each of P, K, S, Cu, B and Zn+Mo. The pots were harvested 50 days after planting. Each plant top was cut at 3 mm above the soil surface to avoid contamination from the soil. The tops were dried at 70 °C for 48 hours and dry weights measured. The plant samples were ground to pass through a 2 mm sieve and total nutrient analysis was carried out for N, P, K, S, Cu, B, Zn and Mo.

Statistical analysis

Data were analysed using one-way analysis of variance (ANOVA) for each experiment. Treatment differences were examined by least significant differences at $p < 0.05$.

Table 3. Sampling location and physico-chemical properties of soils used for the double-pot experiment

Sample no.	Sampling site[a]	Clay (%)	Silt (%)	Sand (%)	pH $_{KCl}$	Olsen P (mg/kg)	Org. C (%)	CEC (cmol/kg)	EC (dS/m)	Soil water, –0.1 bar (%)
1	Cat Hanh	3	2	95	3.92	17.3	0.69	nd	0.08	4.4
2[b]	Cat Hanh	2	3	95	4.05	5.2	0.49	1.80	0.02	7.1
3	An Hai	3	3	94	5.30	1.5	0.30	2.20	0.03	7.8
4	Cat Trinh	2	4	94	4.40	35.9	0.51	2.40	0.02	6.5
5	Phuoc Dinh	2	3	95	5.04	3.8	0.12	1.88	0.01	3.4
6	Phu Yen	0	1	99	5.29	0.015	0.16	1.60	0.74	nd

[a] Cat Hanh and Cat Trinh communes, Binh Dinh province; An Hai and Phuoc Dinh communes, Ninh Thuan province; Phu Yen province (An Chan commune)
[b] This is the same site as sample 1, but taken at 20–40 cm depth
Note: pH_{KCl} = pH measured in 1M potassium chloride; Olsen P = extractable phosphorus; Org. C = organic carbon; CEC = cation exchange capacity; EC = electrical conductivity; nd = not detected

Table 4. Concentration of stock and nutrient solutions used in the double-pot experiment

Compound/salt used	Amount added (g/L stock solution)	Nutrient solution (mL/L)						
		All	–P	–K	–S	–Cu	–B	–Zn +Mo
Micronutrients								
Calcium nitrate tetrahydrate: $Ca(NO_3)_2.4H_2O$	236.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Potassium nitrate: KNO_3	101.1	1.0	2.0	–	2.0	2.0	2.0	2.0
Ammonium phosphate: $NH_4H_2PO_4$	115.0	2.0	–	2.0	–	2.0	2.0	2.0
Magnesium sulfate heptahydrate: $MgSO_4.7H_2O$	184.8	1.0	1.0	1.0	–	1.0	1.0	1.0
Potassium chloride: KCl	149.0	1.0	1.0	–	1.0	1.0	1.0	1.0
Potassium phosphate: KH_2PO_4	136.0	–	–	–	–	–	–	–
Calcium chloride: $CaCl_2.6H_2O$	109.5	–	–	–	–	–	–	–
Ammonium nitrate: NH_4NO_3	40.0	–	2.0	–	2.5	–	–	–
Ammonium chloride: NH_4Cl	106.8	–	–	1.0	–	–	–	–
Micronutrients								
Iron (Fe) sequestrene	64.360	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Manganese chloride: $MnCl_2.4H_2O$	2.969	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Zinc chloride: $ZnCl_2$	0.204	1.0	1.0	1.0	1.0	1.0	1.0	–
Copper chloride: $CuCl_2$	0.134	1.0	1.0	1.0	1.0	–	1.0	1.0
Boric acid: H_3BO_3	0.031	1.0	1.0	1.0	1.0	1.0	–	1.0
Ammonium molybdate tetrahydrate: $(NH_4)_6Mo_7O_{24}.4H_2O$	0.012	1.0	1.0	1.0	1.0	1.0	1.0	–

Note: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; Zn = zinc; B = boron; Mo = molybdenum

Results and discussion

Soil characteristics and effect of nutrient omission on peanut growth on farmers' fields

All the sites selected for nutrient omission field trials had >88% sand and low organic carbon (C) content. Most of the soils were acidic ($pH_{KCl} \leq 6.1$), except Cat Hanh–site 2 where the pH was neutral (Table 1). As a result of low clay and organic C content, the CEC and water holding capacity were also very low. Using the Soil Constraints and Management Practices (SCAMP) tool, lack of clay and organic C—common features of most sandy soils of SCC Vietnam—were identified to be the key constraints that limited crop productivity (Hoang Thi Thai Hoa et al. 2010; Bell et al. 2015). In addition, the acidic pH influences the availability of macro- and micronutrients to plants (Corey and Schulte 1973). Increase in soil pH reduces the availability of micronutrients, with the exception of Mo (under high pH conditions) (Gupta 1969). Legumes, such as peanuts, are especially sensitive and soil pH can greatly affect crop responses to Mo; however, there are genotypes and species that differ in their response to Mo (Gupta 1969; Adams 1997).

Micronutrient deficiencies in various crops have increased in prevalence principally because of intensive cropping, liming, leaching, modern high-yielding cultivars, and also due to loss of topsoil through erosion (Gupta et al. 2008). Decreased use of plant residues and animal manures that contain micronutrients (Bell and Dell 2008) and use of macronutrient fertilisers can also lead to micronutrient deficiencies.

Some of the levels of total micronutrients analysed in the soils used for double-pot omission experiments showed that the levels of nutrients in these soils were variable and very low (Table 5) compared with levels of these nutrients around the world (Gupta et. al. 2008). However, the total quantity of a micronutrient in a soil is generally not a good indicator of its availability to plants (McLaren et al. 1984), although total quantity does indicate the relative abundance of a particular element in a soil and its potential replenishing power (Bergeaux 1966).

Levels of Zn were lower than 10 mg/kg in these soils (Table 5), whereas most of the Zn levels reported by Gupta et al. (2008) ranged between 10 and 300 mg/kg. Levels of S were below the detection limit (Table 5). Lack of equipment capable of measuring nutrients at low levels is an impediment to appropriately analysing nutrients in the SCC region or elsewhere in Vietnam. Hence, building analytical capabilities and laboratory facilities to accurately measure low levels of these nutrients is fundamental to being able to make recommendations for crop production.

Effect of nutrient omission at different stages of peanut biomass and yield

Above-ground biomass at the flowering stage was highest (around 2 tonnes (t)/ha) at site 2 (Cat Hanh commune, 2011) compared with all the other sites, whereas site 5 (Phuoc Dinh commune, 2012) had the lowest (around 1 t/ha) biomass. Omission of K reduced biomass at flowering in all five locations. Omission of N and P decreased biomass on all sands except site 1 (Cat Hanh, 2010). Omission of S decreased biomass of all sands except site 1 and site 5. Among the micronutrients, omission of B depressed biomass in site 1 and site 4 (An Hai commune, 2012), omission of Cu depressed biomass on site 3 (Cat Trinh commune, 2011) and site 4, omission of Mo depressed biomass on site 1 and site 3 while omission of Zn depressed it on site 4 and site 5 (Figure 1).

Table 5. Total nutrient levels in some of the soil samples from south-central coastal Vietnam collected for the double-pot experiment

Sample no.	Sampling site	Copper (mg/kg)	Zinc (mg/kg)	Sulfur (mg/kg)	Boron (mg/kg)
1	Cat Hanh	2.53	8.58	bdl	7.05
2	Cat Hanh	3.25	5.63	bdl	2.89
3	An Hai	1.38	9.75	bdl	3.71
4	Cat Trinh	1.00	6.18	bdl	2.87
5	Phuoc Dinh	1.44	3.80	bdl	21.5
6	Phu Yen	1.45	4.63	bdl	7.97

Note: bdl = below detection limit; see Table 3 for other properties of these samples

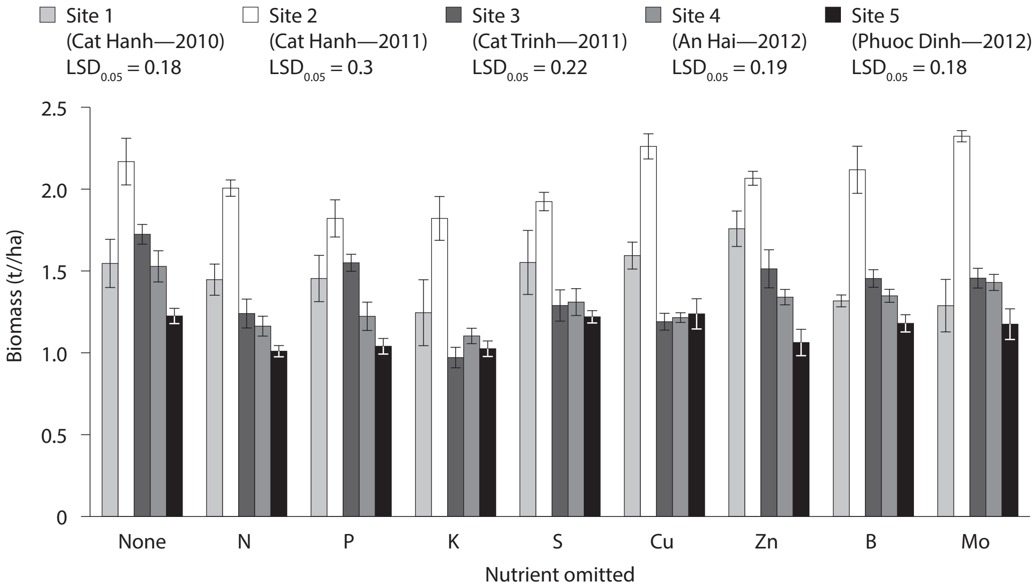

Figure 1. Effects of nutrient omission on above-ground biomass (t/ha) of peanut at the flowering stage. Note: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; Zn = zinc; B = boron; Mo = molybdenum; $LSD_{0.05}$ = least significant difference at $p < 0.05$

Biomass at the harvest stage more than doubled at all sites compared with biomass at flowering (Figure 2). Omission of N, P, K and S significantly decreased peanut growth at sites 2, 4 and 5. By contrast, at site 1, only Mo omission depressed above-ground biomass, and at site 3, N, P and K omission depressed above-ground biomass. While Zn omission depressed above-ground biomass in sites 2, 4 and 5, Cu omission depressed biomass at site 5 as did omission of Mo at site 2. At site 1, omission of Cu or B gave an increase in biomass which was significantly higher than all other sites and treatments, including where all nutrients (All) were applied (Figure 2). Plant residue, especially of peanut due to its high protein content, is used as feed for animals or as compost in the SCC region and hence is an important component of the peanut plant that contributes to farming income (Hoang Thi Thai Hoa et al. 2015). Hence, higher above-ground biomass in addition to higher pod yields would be an added advantage for farmers in this region.

With all the nutrients applied to peanut, the pod yield varied between 2.3 and 4.1 t/ha among the five field experimental sites (Figure 3), even though all the soils were sands or loamy sands and were sown during the main peanut-growing season. However, higher peanut yields of more than 6 t/ha are achievable (Middleton 1980). Differences in yields can be attributed to the type of parent material from which the soils were derived and their variable levels of total nutrients, which have the potential of replenishing a particular nutrient (Bergeaux 1966). Site 2 had the highest peanut pod yield of all the five sites (Figure 3), which may be attributed to the neutral pH and high levels of P in the soil (Table 1). In addition, the differential yield responses following fertiliser application can be attributed to differences in residual soil fertility status (Giller and Cadisch 1995; Palm et al. 2001; Koné et al. 2008).

Poor yield at site 1 was mainly because of the drought in 2010 that affected most of the crops in Binh Dinh province, even where all the nutrients were applied. Drought stress has an adverse influence on water relations, mineral nutrition, metabolism, growth and yield of peanut (Suther and Patel 1992). Levels of P were also low at this site and may have contributed to restricted yields.

Apart from different irrigation and rainfall regimes, distribution of clay with depth and other variable characteristics down the profile, as shown by Bell et al. (2015), could also have influenced the growth and yield of peanut. The rate of nutrient leaching, such as B, down the sandy profiles (e.g. Sitthaphanit et al. 2009) during field preparation and sowing may have also limited peanut growth later in the crop cycle. However, despite the differences in maximum yield at each site, strong responses of yield were obtained to omission of selected elements, including micronutrients. For example, omission of K and S depressed peanut pod yield at all sites (Figure 3). Omission of Cu and B decreased pod yield at the three sites in Binh Dinh (sites 1–3), while Cu, B and Zn deficiency reduced pod yield at Ninh Thuan (site 4/An Hai) and Cu and Zn deficiency reduced pod yield at Ninh Thuan (site 5/Phuoc Dinh). Deficiency of P limited pod yield at both sites in Ninh Thuan (sites 4 and 5), which can be attributed to low levels of P found in these soils (Table 1). Surprisingly, absence of Mo gave an increase in pod yield at site 1 which contrasts with the decrease in shoot above-ground biomass (Figure 2). One possible explanation is that 'All' produces excessive vegetative above-ground biomass that inhibits pod growth, while the reduced above-ground biomass in 'All – Mo' may decrease the sink strength of the shoots relative to pods. Lower levels of nutrients such as P and Mo can also affect nodulation and nitrogen fixation, especially when soils are acidic, particularly below pH 5.5 (Angelini et al. 2003).

Effect of nutrient omission on peanut pod quantity and quality

Hollow pods (known as 'pops') and/or a blackened plumule inside the seed or nut (known as 'black heart') are indications of poor quality resulting from calcium (Ca) deficiency (Singh and Basu 2005). Poor germination has also been observed where Ca concentration in peanut seeds is below 400 mg/kg. However, since lime was applied to all the experimental fields before sowing, it is assumed that the amount of Ca would have been sufficient to prevent internal defects in the seed and poor germination. Phosphorus and S both contribute to oil synthesis, nodulation and pod yield, all of which reflect peanut quality (Singh and Basu 2005); however, pod quality and quantity were both most affected in the absence of Zn (All – Zn) at site 1 (Table 6). The weight of nuts was depressed by the omission of most of the elements in comparison to the treatment where all nutrients were applied; in particular, Zn, P, Cu and S.

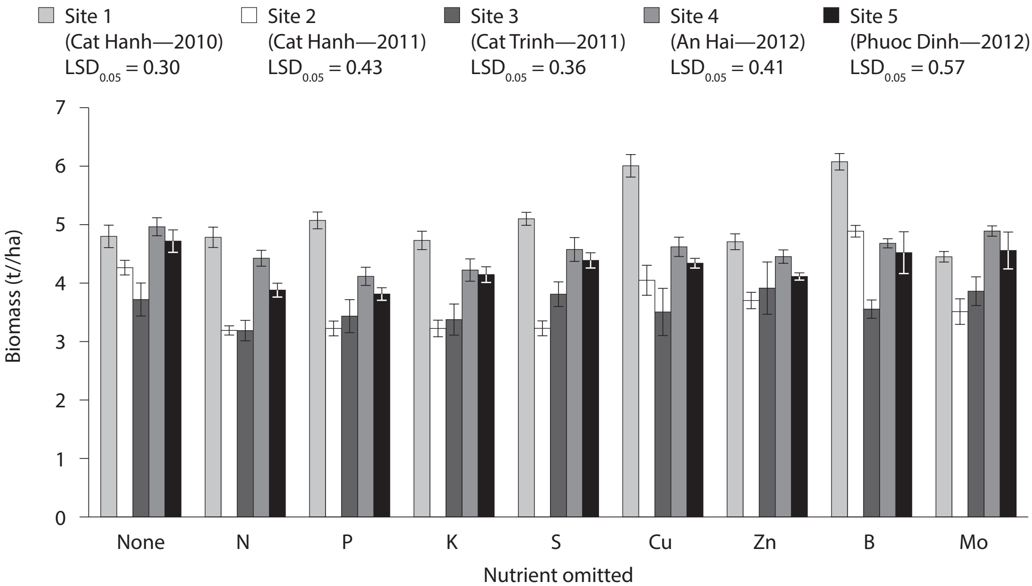

Figure 2. Effects of nutrient omission on above-ground biomass (t/ha) of peanut at the harvest stage.
Note: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; Zn = zinc; B = boron; Mo = molybdenum; $LSD_{0.05}$ = least significant difference at $p < 0.05$

Site 2 not only had a higher overall pod yield than other sands (Figure 3), but also had a higher number of well-rounded pods/plant and higher weight of nuts (Tables 6–10). Number of pods/plant and number of well-rounded pods/plant were most affected where K was omitted. Weight of nuts was highest where all nutrients were applied, reflecting the significance of balancing all the nutrients for optimum seed growth. Neutral pH of the soil at site 2 may have also enhanced nutrient uptake and, hence, peanut growth.

In general, site 3 had fewer pods/plant and well-rounded pods/plant compared with the other four

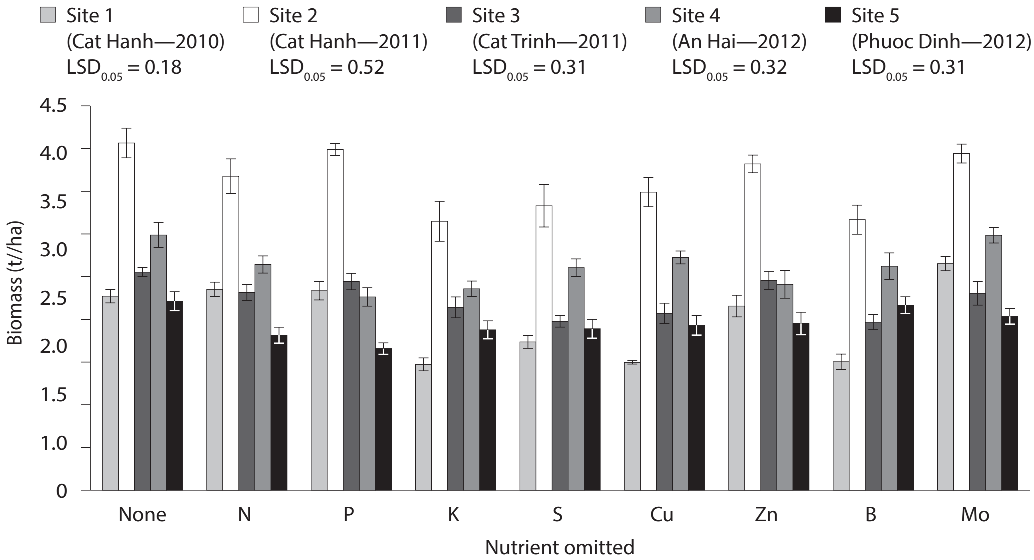

Figure 3. Effects of nutrient omission on pod yield (t/ha) of peanut at harvest. Note: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; Zn = zinc; B = boron; Mo = molybdenum; $LSD_{0.05}$ = least significant difference at $p < 0.05$

Table 6. Effects of nutrient omission on pod quantity and quality of peanut at site 1 (Cat Hanh commune, Binh Dinh province, 2010)

Treatment	No. of pods/ plant	No. of well-rounded pods/plant	Weight of 100 pods (g)	Weight of 100 nuts (g)
All	12.7	7.1	124	64.5
All minus N	13.1	6.3	119	60.3
All minus P	13.4	7.7	117	55.8
All minus K	11.2	6.0	103	63.6
All minus S	12.4	7.8	111	58.9
All minus Cu	13.4	6.6	104	57.0
All minus Zn	9.9	5.7	109	54.3
All minus B	12.0	6.8	106	61.1
All minus Mo	12.0	5.8	127	59.6
$LSD_{0.05}$	1.01	1.10	NS	3.32

Note: values are means of four replicates; N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; Zn = zinc; B = boron; Mo = molybdenum; $LSD_{0.05}$ = least significant difference at $p < 0.05$; NS = not significant sites, especially the other Binh Dinh location sites 1 and 2. Only omission of N and Cu decreased pods per plant (Table 8). The decrease in overall yield could be explained by the reduced numbers of well-rounded pods, where omission of K, S, Cu and B decreased these by 14–27% ($p < 0.05$). Omission of P had no impact on quality or quantity as the level of P in the soils at this site was more than adequate (Table 1).

Numbers of pods/plant and well-rounded pods/plant, and weight of pods and nuts were all higher at site 4 than at site 5. This is a reflection of the soil quality at site 4, where the pH is less acidic and there were higher P and organic C levels (Table 1). Omission of P and K decreased the number of pods/plant and well-rounded pods/plant at site 4 (Table 9), whereas at site 5, omission of N and P decreased both number of pods/plant and well-rounded pods/plant while omission of K depressed only well-rounded pods/plant (Table 10). Weights of pods and nuts were not significantly different among treatments at these sites with the exception of decreased 100 nut weight in the 'All minus K' treatment at site 4 (Table 9).

Table 7. Effects of nutrient omission on pod quantity and quality of peanut at site 2 (Cat Hanh commune, Binh Dinh province, 2011)

Treatment	No. of pods/ plant	No. of well-rounded pods/plant	Weight of 100 pods (g)	Weight of 100 nuts (g)
All	12.5	9.8	153	66.1
All minus N	12.7	9.1	160	62.2
All minus P	12.6	9.5	151	63.3
All minus K	9.9	7.5	159	63.7
All minus S	11.9	8.9	157	62.9
All minus Cu	11.1	9.0	155	60.1
All minus Zn	11.2	9.3	156	62.0
All minus B	11.8	8.6	153	59.3
All minus Mo	11.3	9.7	159	64.3
$LSD_{0.05}$	1.48	1.22	8.90	2.33

Note: values are means of four replicates; N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; Zn = zinc; B = boron; Mo = molybdenum; $LSD_{0.05}$ = least significant difference at $p < 0.05$

Table 8. Effects of nutrient omission on pod quantity and quality of peanut at site 3 (Cat Trinh commune, Binh Dinh province, 2011)

Treatment	No. of pods/ plant	No. of well-rounded pods/plant	Weight of 100 pods (g)	Weight of 100 nuts (g)
All	8.8	6.8	137	58.3
All minus N	7.5	5.8	143	58.6
All minus P	8.4	6.7	141	61.4
All minus K	9.2	5.7	142	61.2
All minus S	8.7	5.0	138	63.8
All minus Cu	7.8	5.2	138	59.3
All minus Zn	9.2	6.7	133	61.8
All minus B	8.7	5.5	139	56.3
All minus Mo	9.1	6.1	136	60.4
$LSD_{0.05}$	1.0	0.8	6.8	4.3

Note: values are means of four replicates; N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; Zn = zinc; B = boron; Mo = molybdenum; $LSD_{0.05}$ = least significant difference at $p < 0.05$

Table 9. Effects of nutrient omission on pod quantity and quality of peanut at site 4 (An Hai commune, Ninh Thuan province, 2012)

Treatment	No. of pods/ plant	No. of well-rounded pods/plant	Weight of 100 pods (g)	Weight of 100 nuts (g)
All	10.6	9.3	164	58.5
All minus N	9.6	8.3	162	57.6
All minus P	8.8	7.4	160	57.2
All minus K	8.9	7.2	159	55.8
All minus S	9.6	8.3	160	56.8
All minus Cu	9.7	8.4	161	58.6
All minus Zn	9.3	8.1	161	57.3
All minus B	10.1	8.6	163	57.7
All minus Mo	10.4	8.9	163	58.5
$LSD_{0.05}$	1.9	1.3	NS	2.7

Note: values are means of four replicates; N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; Zn = zinc; B = boron; Mo = molybdenum; $LSD_{0.05}$ = least significant difference at $p < 0.05$

Table 10. Effects of nutrient omission on pod quantity and quality of peanut at site 5 (Phuoc Dinh commune, Ninh Thuan province, 2012)

Treatment	No. of pods/ plant	No. of well-rounded pods/plant	Weight of 100 pods (g)	Weight of 100 nuts (g)
All	9.1	7.6	162	56.6
All minus N	6.9	5.7	162	56.2
All minus P	6.6	5.2	159	55.7
All minus K	7.9	6.3	157	54.1
All minus S	8.3	6.9	161	56.4
All minus Cu	7.7	6.4	161	56.8
All minus Zn	7.3	6.1	161	55.3
All minus B	8.2	6.9	161	56.8
All minus Mo	7.9	6.5	162	55.5
$LSD_{0.05}$	1.9	1.1	NS	NS

Note: values are means of four replicates; N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; Zn = zinc; B = boron; Mo = molybdenum; $LSD_{0.05}$ = least significant difference at $p < 0.05$

Soil characteristics and effect of nutrient omission on maize growth in double-pot trials

The double-pot experiment was carried out to assess its potential to identify nutrient deficiencies that could occur in sandy soils of SCC Vietnam. Maize was chosen as the test crop because of its responsiveness to nutrient deficiencies within a relatively short growing period.

Sandy soils for the double-pot experiment were collected to determine whether it could confirm the effects of nutrient omission from the peanut field trials and to examine additional sands not studied in the field (from Phu Yen province). All the soils were sandy, acidic and had low organic C, CEC and water holding capacity. Soil P levels varied between 0.02 and 36 mg/kg, which are considered low to adequate. Sample 6 (Phu Yen) had the lowest clay and P levels compared with the other soils (Table 3).

Dry matter yield of maize

Sample 6 had the highest DM yield per plant among all the soils, followed by samples 4 and 5 (Figure 4). All other soils had nearly half the biomass. In general, omission of K from the nutrient solution had the most significant effect on DM yield of maize compared with all other nutrients (Figure 4). All the sands assessed, due to low clay content, supplied limited K for crop growth (Bell et al. 2015). Omission of P depressed DM on all sands, except sample 2. Surprisingly, the P content of soils (Table 3) was not clearly related to the P limitation of maize growth in the 'All minus P' treatment. Omission of S depressed maize DM yield in all six sands. The most profound impact of S was observed in soils from Ninh Thuan and Phu Yen provinces—samples 3, 5 and 6.

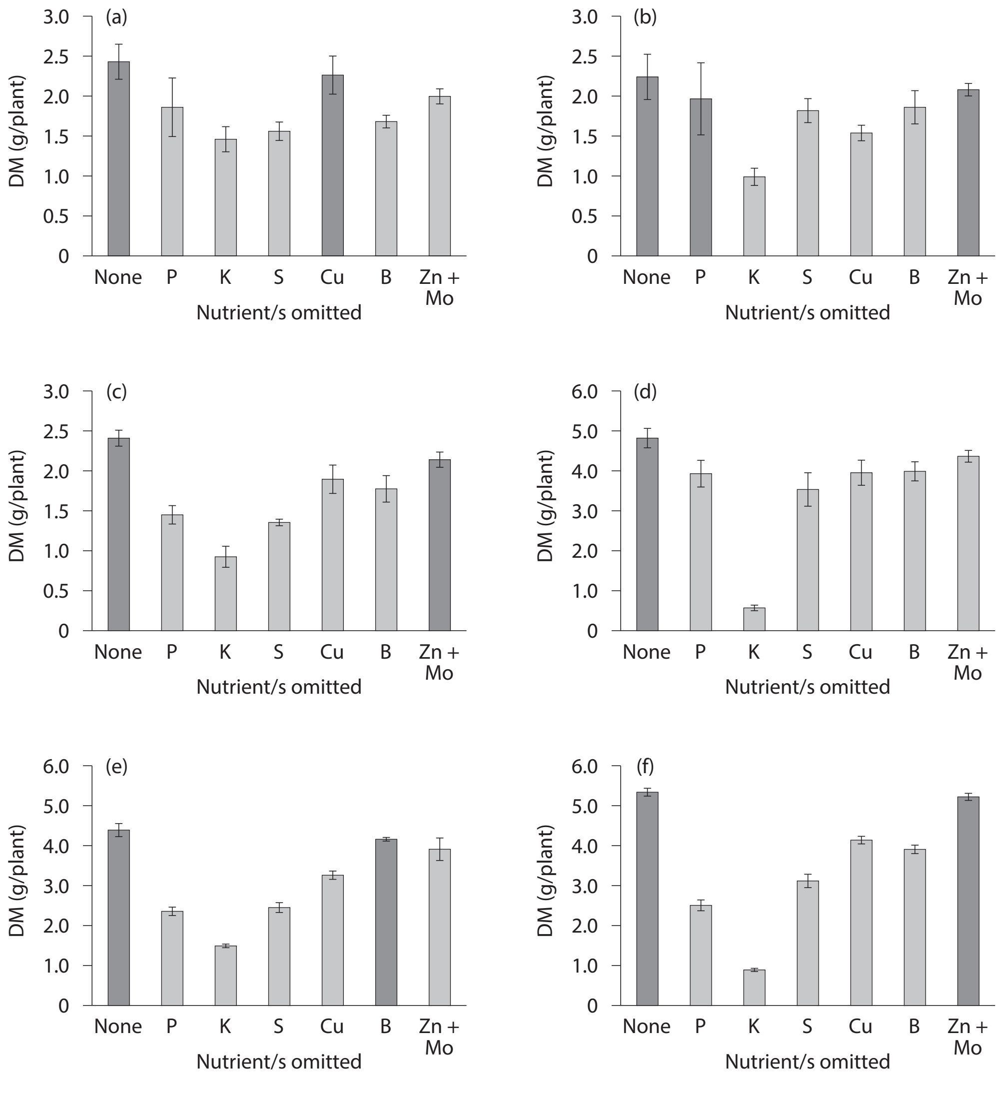

Figure 4. Effect of all nutrients or the omission of nutrients from solution on the dry matter (DM) of maize shoots harvested after 50 days using the double-pot technique with soil from (a) sample 1, Cat Hanh, 0–20 cm; (b) sample 2, Cat Hanh, 20–40 cm; (c) sample 3, An Hai; (d) sample 4, Cat Trinh; (e) sample 5, Phuoc Dinh; and (f) sample 6, Phu Yen. Note: for each sample, the bars with lighter shading were significantly ($p < 0.05$: least significant difference = 0.31) decreased relative to the 'All' treatment; P = phosphorus; K = potassium; S = sulfur; Cu = copper; B = boron; Zn+Mo = zinc + molybdenum

Omission of Cu depressed maize DM except in sample 1. By contrast, in sample 2, where soil had been collected from 20–40 cm depth from the same site as sample 1, maize DM was depressed by Cu omission (Figure 4b). Boron deficiency depressed maize DM on all sands except sample 5. In samples 1, 2, 4 and 5, omission of Zn+Mo depressed maize DM but the magnitude of the decrease was in the range 10–20% (Figure 4).

Nutrient concentration in maize shoots after treatment

In general, the lowest concentrations of each nutrient were found in the treatments where that particular nutrient was omitted and the highest in the treatment where all nutrients were applied (Table 11). However, there were substantially different concentrations among soils both with the 'All' treatment and those with the omission of specific elements from solutions applied in the double-pot experiment.

Table 11. Effect of all nutrients (All) and omission of selected elements on concentrations of macro- and micronutrients in shoots of maize

Soil type and treatment	Macronutrient (%)				Micronutrient (mg/kg)			
	N	P	K	S	Cu	B	Zn	Mo
Sample 1: sandy soil on granite from Cat Hanh commune (0–20 cm)								
All	1.33 g–l	0.15 a	1.83 kl	0.38 a	18.9 ef	17.8 hi	92.5 a	1.3 def
All minus P	1.27 h–m	**0.04 ijk**	2.51 bcd	0.27 bc	14.1 p–u	9.2 op	87.9 b	1.6 ab
All minus K	2.10 a	0.07 efg	**1.00 p**	0.30 b	15.1 k–p	6.5 rs	78.9 e	1.1 klm
All minus S	1.40 d–i	0.14 ab	2.51 bcd	**0.17 fgh**	14.6 m–r	8.5 pq	52.6 l	1.4 bcd
All minus Cu	1.43 c–h	0.14 abc	2.26 efg	0.18 efg	**12.8 tuv**	15.3 j	50.5 mn	1.2 jkl
All minus B	1.26 i–m	0.12 bcd	2.44 cd	0.18 efg	18.8 ef	**3.5 vw**	60.5 j	1.1 mno
All minus Zn+Mo	1.30 h–m	0.12 bcd	1.40 n	0.19 def	18.3 efg	11.6 lm	**40.9 rst**	**1.0 no**
Sample 2: sandy soil on granite from Cat Hanh commune (20–40 cm)								
All	1.29 h–m	0.08 ef	2.47 bcd	0.29 b	16.9 g–j	12.3 l	83.2 c	1.3 jkl
All minus P	1.21 klm	**0.03 jk**	2.53 bcd	0.20 def	12.1 v	7.7 qr	80.6 d	1.3 ghi
All minus K	1.25 i–m	0.06 ghi	**0.71 q**	0.23 cd	14.2 o–t	5.1 tu	77.5 f	1.2 hij
All minus S	1.26 i–m	0.09 e	1.61 m	**0.09 k**	13.3 r–v	6.6 rs	47.4 p	1.2 jkl
All minus Cu	1.37 f–k	0.11 d	1.98 ijk	0.11 jk	**10.1 w**	3.3 vw	56.0 k	1.1 mno
All minus B	1.20 lm	0.04 ijk	1.29 no	0.16 f–i	13.9 p–u	**1.9 x**	62.6 i	1.1 mno
All minus Zn+Mo	1.16 m	0.04 jk	2.49 bcd	0.13 h–k	12.7 uv	10.7 mn	**40.4 st**	**1.0 pq**
Sample 3: sandy soil on granite from An Hai commune, Ninh Thuan province (0–20 cm)								
All	1.33 g–l	0.12 bcd	2.48 bcd	0.18 efg	18.9 ef	17.8 hi	40.4 st	1.4 bcd
All minus P	1.25 i–m	**0.04 jk**	0.89 pq	0.17 efg	14.3 n–s	10.1 no	30.9 w	1.4 bcd
All minus K	1.21 klm	0.04 ijk	**0.87 pq**	0.20 def	13.8 p–u	6.6 rs	44.3 q	1.2 mno
All minus S	1.40 d–i	0.07 fg	0.73 q	**0.13 h–k**	15.9 i–m	11.9 l	30.1 w	1.1 mno
All minus Cu	1.18 lm	0.04 hij	0.87 pq	0.12 ijk	**12.9 s–v**	8.7 pq	37.8 u	1.6 a
All minus B	1.34 g–l	0.04 hij	2.18 gh	0.14 g–j	15.6 j–n	**6.0 st**	36.5 v	1.4 efg
All minus Zn+Mo	1.32 g–m	0.09 e	2.41 cde	0.16 f–i	17.2 ghi	14.4 jk	**23.6 y**	**1.0 klm**
Sample 4: sand from omission experiment on peanut in Cat Trinh commune (0–20 cm)								
All	1.65 b	0.12 cd	2.57 bc	0.14 g–j	18.6 ef	26.3 c	48.9 o	1.4 bcd
All minus P	1.48 c–g	**0.03 jk**	2.42 cde	0.13 h–k	15.7 j–n	21.2 e	45.3 q	1.3 ijk
All minus K	1.43 c–h	0.04 ijk	**0.98 p**	0.12 ijk	13.5 q–v	18.2 ghi	40.3 st	1.2 jkl
All minus S	1.26 i–m	0.04 ijk	2.63 b	**0.10 jk**	15.8 i–m	20.3 ef	48.9 o	1.1 mno
All minus Cu	1.23 j–m	0.04 ijk	2.47 bcd	0.13 h–k	**16.8 hij**	19.0 gh	41.5 rs	1.2 lmn
All minus B	1.55 bcd	0.04 hij	2.38 def	0.13 h–k	14.9 l–q	**10.2 no**	50.9 m	1.5 bc
All minus Zn+Mo	1.48 c–g	0.07 fg	2.43 cde	0.11 jk	16.1 i–l	17.2 i	**34.0 v**	**1.0 op**

continued

Table 11. (cont'd) Effect of all nutrients (All) and omission of selected elements on concentrations of macro- and micronutrients in shoots of maize

Soil type and treatment	Macronutrient (%)				Micronutrient (mg/kg)			
	N	P	K	S	Cu	B	Zn	Mo
Sample 5: red sandy soil from Phuoc Dinh commune, Ninh Thuan province (0–20 cm)								
All	1.67 b	0.06 ghi	2.49 bcd	0.23 cd	26.2 b	13.9 k	68.3 g	1.5 def
All minus P	1.65 b	**0.02 k**	1.92 jkl	0.12 ijk	13.3 r–v	4.3 uv	67.5 gh	1.5 cde
All minus K	1.41 d–i	0.04 hij	**0.84 pq**	0.22 de	15.5 j–o	2.4 wx	66.7 h	2.0 op
All minus S	1.43 c–h	0.04 ijk	1.22 o	**0.12 ijk**	16.3 ijk	4.9 tu	61.2 ij	1.4 fgh
All minus Cu	1.47 c–g	0.03 jk	2.03 hij	0.14 g–j	**13.1 s–v**	4.9 tu	61.6 ij	1.4 fgh
All minus B	1.59 bc	0.03 jk	2.22 fg	0.14 g–j	25.5 b	**1.9 x**	49.3 no	1.1 klm
All minus Zn+Mo	1.37 f–k	0.03 jk	2.14 ghi	0.13 h–k	19.6 de	5.4 stu	**41.9 r**	**1.1 mno**
Sample 6: sandy soil from Phu Yen province (0–20 cm)								
All	1.53 b–f	0.06 gh	2.95 a	0.17 fgh	28.5 a	32.4 a	60.3 j	1.2 jkl
All minus P	1.27 h–m	**0.02 k**	2.46 bcd	0.13 h–k	23.4 c	24.2 d	55.9 k	1.2 lmn
All minus K	1.41 d–i	0.04 jk	**0.85 pq**	0.11 jk	20.4 d	20.3 ef	50.1 mno	1.1 mno
All minus S	1.37 f–k	0.04 ijk	1.36 bc	**0.09 k**	22.3 c	19.4 fg	56.9 k	0.9 pq
All minus Cu	1.38 e–j	0.04 ijk	2.22 fg	0.10 jk	**18.1 fgh**	29.8 b	28.4 x	0.9 no
All minus B	1.54 b–e	0.03 jk	2.03 hij	0.16 f–i	22.5 c	**23.8 d**	39.6 t	1.2 jkl
All minus Zn+Mo	1.48 c–g	0.04 jk	1.79 l	0.11 jk	26.8 b	28.7 b	**23.2 y**	**0.9 q**
$LSD_{0.05}$	0.16	0.04	0.22	0.05	1.43	1.25	1.38	0.1

Note: values are the average of three replicates; averages followed by the same letter for an element are not significantly different; N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; B = boron; Zn = zinc; Mo = molybdenum; $LSD_{0.05}$ = least significant difference at $p < 0.05$

The leaf N concentrations in this study were ≤2.1% (Table 11), which is low. Sufficiency ranges of N for maize are 2.7–4.0 % (Steinhilber and Salak 2010). According to Reuter et al. (1997), critical shoot N concentrations at the eight-leaf stage could be as high as 3.7%. Plant analysis data (Table 11) show that the effects of the 'All' treatment and lack of P, K, Cu, Zn, B and Mo on the leaf N concentration were not large. The results in Table 11 also show very low P concentrations in maize. Self and Soltanpour (2010) classified P concentration in the whole plant from seedling to sixth leaf stage and fully expanded leaf prior to tasseling as: 0.22% (critical level), 0.22–0.25% (low), 0.25–0.50% (sufficient). From the data compiled by Reuter et al. (1997), the critical P concentration in shoots up to 45 days or 30 cm height is 0.29%. The shoot N and P concentrations indicate that the double-pot solutions did not supply adequate N and P for maize. Nevertheless, shoot P concentrations varied among the sands and highest P concentrations were in the 'All' treatment, with the exception of sample 2, and lowest without P application in all the soils tested. The growth responses to omitting P varied with individual soil types, signifying the importance of residual P levels in the sands which ranged between 0.02 and 35.9 mg/kg (Table 3).

The mean leaf K concentration in maize plants where K was omitted varied between 0.71 and 1.00% in the six soils investigated (Table 11). The range of sufficient K concentrations in cereals in young shoots, 5–8 cm above the soil surface, is 3.5–5.5% dry weight (Barker and Pilbeam 2007). According to other findings, the K sufficiency range for maize in the whole plant at seedling stage (<40 cm or six-leaf stage) is 1.5–4.0% (Reuter et al. 1997; Schwab et al. 2007). Based on these concentrations, maize in the 'All' treatment had marginal to adequate concentrations while omission of K in all sands induced a severe K deficiency.

Critical values of S in young maize shoots (<10-leaf or <45 days) range from 0.10 to 0.25% (Reuter et al. 1997; Osman 2013), indicating that the 'All' treatment supplied adequate S to maize in sands but was probably marginal in some, such as sample 4. When S was omitted in the double-pot experiment, shoot S concentrations were below the critical value for all the soils except sample 1), indicating deficiency. This is consistent with depressed shoot dry matter. However, even though maize in sample 1 had apparently adequate S, the concentrations were depressed compared to the 'All' treatment and growth was depressed.

Omission of Cu depressed maize growth in all sands except sample 1. However, Cu concentrations were above the critical range of 2.3–3.7 mg/kg (Osman 2013) when Cu was omitted (Table 11). In this case, the shoot growth response in the double-pot experiment was a more definitive indicator of Cu deficiency than shoot Cu analysis. In contrast, where B was omitted, B concentrations were within or below the critical range (3–5 mg/kg; Osman 2013) in samples 1, 2 and 5. However, in sample 5, shoot dry matter was not depressed, while in samples 4 and 6, it was depressed, despite having higher shoot B concentrations. Hence, the shoot B analysis was not always a reliable predictor of shoot DM response to omission of B.

Omission of Zn+Mo decreased both Zn and Mo concentrations in maize shoots but values remained well above critical concentrations for young maize shoots reported by Reuter et al. (1997). Moreover, there was no evidence of lower Zn or Mo concentrations in shoots on the samples where maize DM was depressed. However, in samples 4 and 5, omission of Mo+Zn depressed shoot N concentrations compared with the 'All' treatment. This is consistent with Mo deficiency which inhibits nitrate reductase enzyme and hence protein synthesis (Bell and Dell 2008).

General discussion

Multiple nutrient deficiencies were identified in all sands in field and double-pot experiments. This is a distinctive property of low fertility sands and requires a different approach to nutrient management than on other soils (Bell et al. 1990; Bell and Dell 2008). Whereas most other soils express one, two or three deficiencies of mostly macronutrients (generally N combined with P and/or K), on sands S and micronutrient deficiencies are also common.

The primary task for nutrient management in each sand type is to accurately predict the deficiencies that will limit crop production so that effective treatments can be developed. The double-pot experiment predicted deficiencies that were also identified in the field experiments. While correction of deficiency in the field is the most authoritative evidence, field experiments are costly and time consuming and hence only limited numbers can be afforded. Hence an accurate, low-cost approach such as the double-pot method can be used for screening large numbers of sands for potential deficiences. As shown in the present study, there would be merit in screening subsoils as well as topsoils since different deficiencies can be identified. Given the unreliable results from plant analysis in confirming deficiencies, and low reliability of soil testing in general for predicting micronutrient deficiencies (Bell and Dell 2008), the double-pot method is the recommended approach to follow.

When multiple nutrient deficiencies are diagnosed, the task of establishing suitable fertiliser programs can be time consuming. Recommended fertiliser practices involve a consideration of rate, timing, form and method of application (IPNI 2015). This experimentation needs to be conducted in the field, and repeated over several years and sites to establish reliable practices that can be recommended. Practices might need to be adjusted according to plant species, particularly between annual crops and perennial crops. However, some of this type of research has been conducted on sands in Thailand and could be assessed in SCC Vietnam as a first approximation of requirements for annual crops (Bell et al. 1990). Progress towards defining effective supply of S and micronutrients is reported by Hoang Vinh et al. (2015).

In addition to the supply of inorganic fertilisers to correct multiple nutrient deficiencies on sands, integrated nutrient management (INM) approaches are generally most effective. Organic resources such as manure or crop residues are presently used by farmers on sands in SCC Vietnam (Hoang Thi Thai Hoa et al. 2015). These could be used to increase the nutrient and moisture retention capacity of sands to enhance water and nutrient use efficiencies. Further evidence of the value of INM involving the use of biochar in addition to manure is reported by Hoang Vinh et al. (2015).

Conclusions

In field experiments in this study, multiple nutrient deficiencies were evident in each of the five sands examined. While the three sands in Phu Cat district of Binh Dinh province expressed deficiencies of K, S, B and Cu for peanut pod yield, a different suite of deficiencies was limiting peanut yield on each of the two sands in Ninh Thuan province (N, P, K, S, B, Cu, Zn at one site and N, P, K, S, Cu, Zn at the other). Parent material may be a predictor of which deficiencies will occur on particular types of sands; however, the DM response of the maize test crop using the double-pot experimental approach was a suitable predictor. The double-pot experiment also identified P, K, S, Cu, B, Zn and Mo deficiencies: the actual suite of deficiencies, however, varied among sands as in the field experiments.

The double-pot technique described and evaluated here appears to be a valuable diagnostic tool to predict the nutrient supplying capacity of a range of nutrients in sands, including micronutrients. Its simple design and low cost make it ideal for large-scale screening of soils, especially where access to analytical facilities for accurate soil and plant analysis, of micronutrients in particular, is limited.

Preliminary research on correction of multiple nutrient deficiencies in sands of SCC Vietnam, including INM practices, are reported by Hoang Vinh et al. (2015).

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Integrated nutrient management of annual and perennial crops on sandy coastal plains of south-central coastal Vietnam

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Abstract

Integrated nutrient management (INM) is the use of available organic resources (manure, crop residues, biochar etc.) together with inorganic fertilisers to optimise crop nutrition. In low fertility sands, INM needs to consider the balanced supply of all limiting nutrients, not just nitrogen and phosphorus. Three field experiments were conducted on typical sands in the south-central coastal (SCC) region of Vietnam on annual and perennial crops to assess the value of applying available organic resources (manure, biochar) with inorganic fertilisers (including nitrogen, phosphorus and potassium (NPK), sulfur (S) and micronutrients) to optimise crop nutrition. Peanut responded positively to addition of S and micronutrients in addition to NPK. However, application of organic resources (manure, biochar) in combination with inorganic fertilisers further increased peanut yield significantly. Application of biochar increased mango productivity by 16%. By contrast, in cashew, there was limited benefit from increased rate of inorganic fertiliser, with or without biochar, possibly because of micronutrient deficiencies that were not treated with the fertiliser applied. Therefore, balanced rates of nutrients as inorganic fertilisers are required to achieve optimal productivity and nutrient use efficiency on sands. The integrated use of manure or biochar with balanced inorganic fertilisers was most effective in increasing peanut yield and significantly increased profit compared with either organic amendments or inorganic fertiliser alone.

Introduction

To meet the rising demand for food production, agriculture in Vietnam needs to expand production area, increase productivity per unit land area and/or intensify cropping systems. Expansion of land area for agriculture is restricted due to higher demand for development of urbanised and industrialised areas which offer better investment options for some areas of the coastal zones. Increasing productivity and intensifying cropping systems both require the use of higher inputs of nutrients and higher nutrient use efficiency. Higher fertiliser use may be constrained by the recent increase in fertiliser prices (FAO 2012). Farmers have limited revenue or resources to invest in fertilisers but may be able to make efficient use of on-farm organic resources (Hoang Thi Thai Hoa et al. 2015a). Many studies show that the combination of organic materials with inorganic fertilisers

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increases nutrient use efficiency, especially on sands (Pinitpaitoon et al. 2011).

Farmers have the option of utilising on-farm organic resources generated from manure, crop residues and/or biochar. There are examples in Vietnam where farmers under rice cropping had integrated on-farm available organic resources with inorganic fertilisers to minimise the cost of inputs and maximise the outputs through increased yields (Mutert et al. 1999). In addition, application of organic resources not only maintains the inherent soil fertility and return nutrients (e.g. magnesium, sulfur (S), zinc (Zn) etc.) that are either not available or too expensive in commercially available fertilisers, but also helps improve the buffering capacity of soil to hold nutrients and water that could be lost through leaching or run-off (Rasmussen and Collins 1991). Most farmers primarily use nitrogen (N) and phosphorus (P) fertilisers and, to a lesser extent, potassium (K) fertilisers. While such nutrient management practices may result in short-term yield gains, there will be a net negative effect on soil nutrient balance in the long term, which will lower the sustainability of these systems (Hoang Thi Thai Hoa et al. 2015a). Maintaining soil organic matter (OM) will also help to maintain positive K balances.

Although nutrient concentrations in manures from animals vary with animal type and on their feed intake, an average application of 5 tonnes/hectare (t/ha) would supply approximately 23 kg N, 9.6 kg P, 12.4 kg K and 1,000 kg of carbon (C) (Dierolf et al. 2001). Even though the nutrient requirement for crops (depending on crop type) is 4–5 times higher than what can be supplied through 5 t of manure, nonetheless the repeated application of 1 t of C from manure can also significantly improve the physical and chemical characteristics of the soils. Livestock in farming systems of south-central coastal (SCC) Vietnam generate on-farm available organic resources such as manures, which can be applied to the field.

Residues from commonly grown crops in Vietnam also contain substantial amounts of C, N, P, K and other nutrients and if returned to the soils can supply a similar amount of nutrients as that from a comparable amount of manure (Hoang Thi Thai Hoa et al. 2015a, b).

Biochar, a product synthesised by pyrolysis of organic matter, contains varying concentrations of nutrients such as N, P, K and S, depending upon the source of organic material. Most biochars prepared from chicken manure have a very high concentration of these nutrients (Hall and Bell 2015). Farmers in the SCC region make their own biochar from rice husk; however, they do not have the right technology or the resources to convert crop residues to biochar consistently and the concentration of nutrients in biochars may vary according to the method of preparation and the crop material used. Application of biochar to soil helps to reduce losses of nutrients by minimising erosion, improve water holding capacity, enhance soil microbial activity, increase soil pH, improve availability of P and increase fertiliser use efficiency (Glaser et al. 2002; Lehmann et al. 2003).

Numerous studies on integrated nutrient management (INM) using organic and inorganic fertilisers have shown benefits that include: increased growth, development and yield of crops (Prativa and Bhattarai 2011); increased abundance of micro-organisms and development of mycorrhizas under soybean–wheat rotation (Khaddar and Yadav 2006); and an improved benefit:cost ratio in addition to making farming more sustainable under a potato–mungbean–rice crop rotation system (Mollah et al. 2011).

This chapter focuses on the effectiveness of the INM approach using biochars and manures along with inorganic fertilisers on peanut and the tree crops, mango and cashew. The research also reflects on the economic benefits of using this approach.

Material and methods

Three experiments were conducted on sandy soils of Binh Dinh province in the SCC region using manure, biochar and inorganic fertilisers to examine the effect of these materials on the growth of peanut (two sites), cashew (one site) and mango (one site). Designs for the experiments varied between the annual and perennial crops as did the method of application.

Effect of biochar on yield of an established cashew orchard

The experiment was located at Xuan An village, Cat Tuong commune, Phu Cat district, Binh Dinh province. Six-year-old cashew trees in an orchard planted with grafted plants had a density of 200 plants/ha when the INM trial with biochar and inorganic fertiliser treatments was carried out. The trees had been regularly pruned and fertilised. Biochar was prepared using rice husk (‘rice husk 1’ in Table 2). The experiment was designed with two factors (biochar and inorganic/organic fertiliser) arranged in a randomised complete block design.

Each main plot of 1,600 m^2 had 16 plants that were split into four subplots each containing four trees in an area of 400 m^2. Observations were carried out on four central trees, one from each subplot: the remaining 12 trees acted as buffers to prevent the influence of other treatments.

The treatments were:

- biochar
  - B1 = no biochar
  - B2 = biochar applied once in 2009 at a rate of 40 kg/tree
- inorganic fertiliser NPK 16:16:8:13S and manure (applied annually from 2009 to 2012)
  - F1 = (0.31 kg N + 0.16 kg phosphorus pentoxide (P_2O_5) + 0.80 kg dipotassium oxide (K_2O) + 0.13 kg S)/tree + 30 kg manure/tree
  - F2 = (0.47 kg N + 0.32 kg P_2O_5 + 1.60 kg K_2O + 0.26 kg S)/tree + 30 kg manure/tree.

The combinations of treatments were: B1F1; B1F2; B2F1; B2F2—each replicated three times.

Effect of integrated nutrient management on peanut yield

For this experiment in the spring–winter season of 2012, two experimental sites were chosen on farmers' fields, both of which were located in Phu Kim village, Cat Trinh commune, Phu Cat district, Binh Dinh province. The soil was tilled and prepared at an appropriate moisture level before the plots were split for different treatments. At both sites, treatments were laid out following a split-plot randomised design and manure, biochar ('rice husk 2' in Table 2) and inorganic fertiliser were top-dressed, then incorporated to 10 cm depth. Each plot covered an area of 15 m^2. Peanut variety LDH 01 was used and seeds were planted 10 cm apart with one seed per hole inserted by hand at a depth of 2–3 cm. The distance between the rows was kept at 30 cm to give a plant density equivalent to 330,000 plants/ha.

The treatments were:

- organic fertiliser
  - N = none
  - B = 11.1 t biochar/ha
  - M = 10 t manure /ha
- inorganic fertilisers
  - T1 = NPK (30 N kg/ha + 90 P_2O_5 kg/ha + 60 K_2O kg/ha)
  - T2 = NPK + S (20 kg/ha)
  - T3 = NPK + S + micronutrients (2.4 kg/ha copper (Cu), 4.05 kg/ha zinc (Zn), 0.25 kg/ha boron (B), 0.54 kg/ha molybenum (Mo)).

The combinations of treatments were: MT1; MT2; MT3; BT1; BT2; BT3; NT1; NT2; NT3—each replicated four times.

Effect of biochar and inorganic fertilisers on mango yield and quality

The experimental site was located at Tan Hoa Nam village, Cat Hanh commune, Phu Cat district, Binh Dinh province. The experiment was laid out in a randomised complete block design. Each plot of approximately 680 m^2 consisted of 15–16 trees. The biochar used was 'rice husk 2' (Table 2). Observations and measurements of number of flowers, yield and fruit quality were carried out on the four central trees from each plot and the other 11–12 trees acted as a buffer to prevent the influence of other treatments on the measured trees.

The treatments were:

- organic fertiliser
  - N = no biochar
  - B = biochar applied at a rate of 50 kg/tree
- inorganic fertilisers
  - T1 = NPK (0.49 kg N + 0.25 kg P_2O_5 + 0.38 kg K_2O)/tree
  - T2 = NPK + S (0.49 kg N + 0.25 kg P_2O_5 + 0.38 kg K_2O + 0.16 kg S)/tree
  - T3 = NPK + S + micronutrients (0.49 kg N + 0.25 kg P_2O_5 + 0.38 kg K_2O + 0.16 kg S + 10.9 g Cu + 2.5 g Mo + 18.4 g Zn + 1.1 g B)/tree

The combinations of treatments were: NT1, NT2, NT3, BT1, BT2, BT3, each replicated four times.

Chemical analysis

All the chemical analysis methods were as described in Bell et al. (2015).

Results and discussion

Soil and biochar characteristics

Most soils were acidic with pH values at or below 5.5 (measured in 1 M KCl), but the very low levels of exchangeable aluminium pose no risk of toxicity to crops (Bell et al. 2015). Low organic carbon levels (<0.5%) and clay contents (2–3%) were found in all soils (Table 1), a common feature for the majority of sandy soils in SCC Vietnam. Low cation exchange capacity and water holding capacity values of these sites are constraints that can lead to low water and nutrient use efficiency.

Incorporation of manure, crop residues and/or composted manure in soils has been practised by farmers in the SCC region to boost crop productivity (Hoang Thi Thai Hoa et al. 2015b). Farmers have recently started to produce biochar from crop residues (rice, peanut, cassava etc.) since biochars have been shown to boost crop production. However, the ability to increase production depends on the levels of nutrients in the biochars, which are highly variable and depend upon processing and the type and source of raw material used for pyrolysis (Table 2). Most biochars have neutral to high pH and can help improve soils of this region as most of them are acidic. In addition, biochars may be able to supply nutrients like P, K, S and Zn which are deficient in these soils (Hoang Minh Tam et al. 2015).

Effect of biochar on cashew yield, soil moisture retention and profitability

The experiment was carried out on a 6-year-old established cashew orchard with application of 40 kg of biochar per tree in a circle at a radius of 1.5 m from the trunk in 2009. Cashew growth and yield were assessed each year till 2012 to determine the

Table 1. Physico-chemical properties of soils (0–20 cm) at the four experimental sites in Phu Cat district, Binh Dinh province

Crop	pH_{H_2O} (1:5)	pH_{KCl} (1:5)	EC (dS/m)	Org. C (%)	Olsen P (mg/kg)	Exch. Al^{3+} (cmol/kg)	CEC (cmol/kg)	Clay (%)	Silt (%)	Sand (%)	Soil water	
											–0.1 bar (%)	–0.33 bar (%)
Cashew	5.2	4.40	0.01	0.31	2	0.09	1.28	2	3	95	7.1	1.5
Mango	6.4	5.51	0.04	0.32	17	0.16	1.93	2	5	93	4.4	2.4
Peanut	6.1	5.23	0.04	0.09	42	0.03	3.12	3	9	88	5.2	2.7
Peanut	5.6	5.44	0.18	0.11	60	0.02	1.72	2	2	96	4.2	2.3

Note: pH_{H_2O} = pH measured in water; pH_{KCl} = pH measured in 1 M potassium chloride; EC = electrical conductivity; Org. C = organic carbon; Olsen P = extractable phosphorus; Exch. Al^{3+} = exchangeable aluminium cations; CEC = cation exchange capacity

Table 2. Chemical properties and nutrient levels in biochar from various sources

Biochar characteristic	Biochar source material			
	Wheat straw[a]	Chicken manure[a]	Rice husk 1[b]	Rice husk 2[c]
pH (1:5 H_2O)	8.39	7.69	8.60	7.40
Electrical conductivity (dS/m)	9.18	5.19	1.20	1.50
Water holding capacity (g/g)	287	180	NT	NT
Total nitrogen (%)	2.24	2.04	0.55	1.00
Cation exchange capacity (cmol/kg)	23.7	18.1	21.0	27.0
Potassium (mg/kg)	33,700	13,800	6,500	NT
Phosphorus (mg/kg)	4,150	11,600	720	4,840
Sulfur (mg/kg)	2,040	3,650	49	NT
Zinc (mg/kg)	54	334	14	NT
Calcium (mg/kg)	5,540	26,200	1,000	NT

[a] Source: Hall and Bell (2015)
[b] Rice husk biochar produced in the Philippines (data supplied by Peter Slavich), used in the cashew experiment
[c] Rice husk biochar produced by the Agricultural Science Institute for Southern Central Coast of Vietnam (ASISOV), used in the peanut and mango experiments
Note: NT = not tested

short- and long-term effects of biochar. The application of biochar had positive effects on growth, development and cashew yield (Figure 1). Cashew yield increased significantly each year from the time of application of biochar in 2009 till 2011 and thereafter stabilised in 2012. In the first year, cashew yield increased from 1,130 kg/ha where no biochar was applied (treatment B1F2) to 1,477 kg/ha where 40 kg of biochar was applied in addition to the inorganic and organic (manure) fertiliser (B2F2) (Figure 1a).

In 2011 alone, increased fertiliser rate increased cashew yield, without an additional effect from biochar (Figure 1c). Biochar treatments (B2F2 and B2F1), regardless of the level of fertiliser, increased cashew yield by 200–400 kg/ha in 3 of 4 years. In 2011, biochar increased cashew yield only with the lower fertiliser rate.

Soil moisture levels over a 4-month period (January to April) in the dry season of 2010 under cashew trees with biochar treament (B2) were lower within the active root zone (0–60 cm) than without biochar (B1) (Figure 2). The lower soil water storage at 0–60 cm depth with biochar may be because: (1) the measured root zone (60 cm) of cashew trees may not correspond to the active root zone; (2) shallow groundwater levels at this site could have

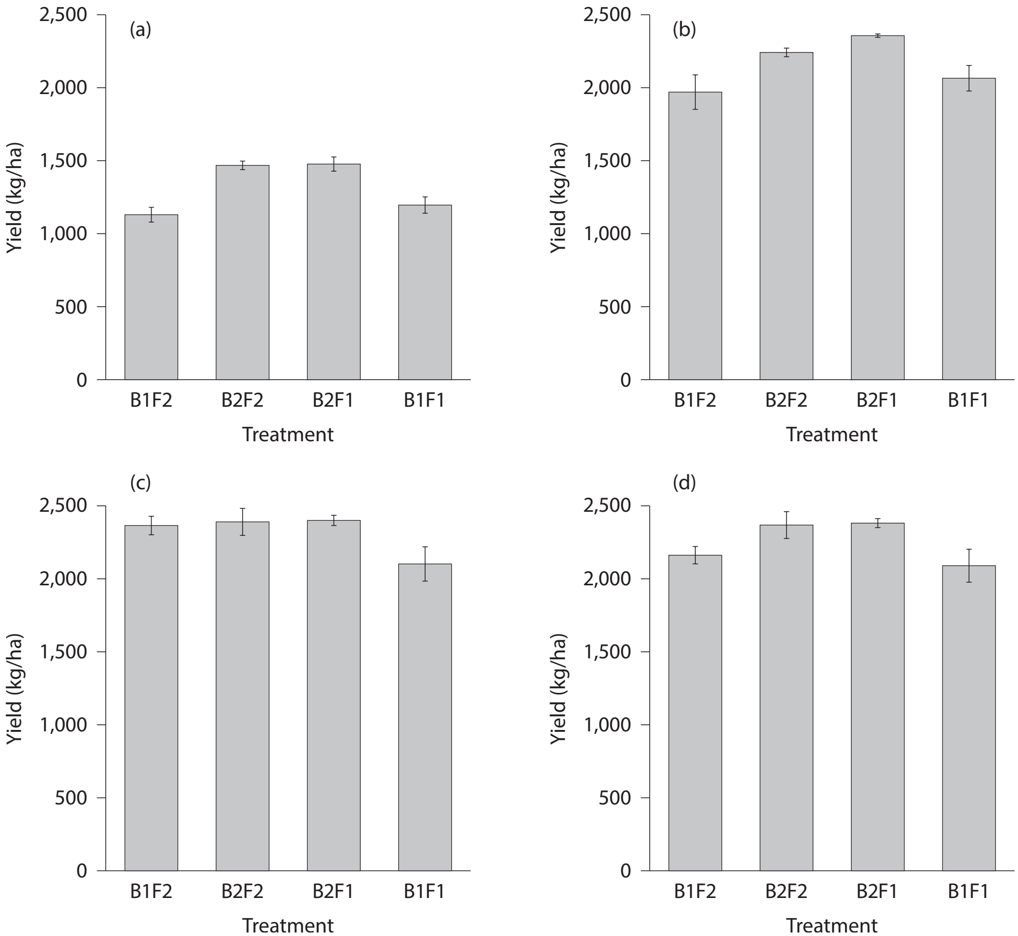

Figure 1. Effect of biochar on cashew yield in (a) 2009, (b) 2010, (c) 2011 and (d) 2012. Note: B1 = no biochar; B2 = biochar applied once (40 kg/tree) in 2009; F1 = 1 kg NPK fertiliser + 320 g urea + 30 kg manure/tree; F2 = as for F1, but with 2 kg NPK

met the moisture requirement of cashew for growth; (3) biochar influenced water storage in only the 20 cm deep ring of soil around the trunk where it was incorporated rather than the entire active root zone; and/or (4) water uptake may have been faster due to increased cashew growth with biochar, which depleted soil water storage.

Biochar application significantly increased input costs in 2009 and resulted in lower returns in comparison to where no biochar was applied (Table 3). In 2010, as a result of a significant increase in the yield of cashew nuts, the net profits increased compared with 2009 by over Vietnamese dong (VND)21 million as a result of the fertiliser application alone and VND30 million with biochar application. Cashew yields again increased in 2011, further increasing net profit margins. Profits declined in 2012 as a result of low cashew nut prices. The net profit where biochar was applied clearly showed higher returns than no-biochar treatments after the year of initial application. The net profits with biochar exceeded those without biochar by VND6.2 million/ha, VND5.1 million/ha and VND6.2 million/ha in 2010, 2011 and 2012, respectively. Over the 4 years of the trial, the overall net profit increased by VND15 million/ha, averaging 3.8 million/ha/year from biochar application.

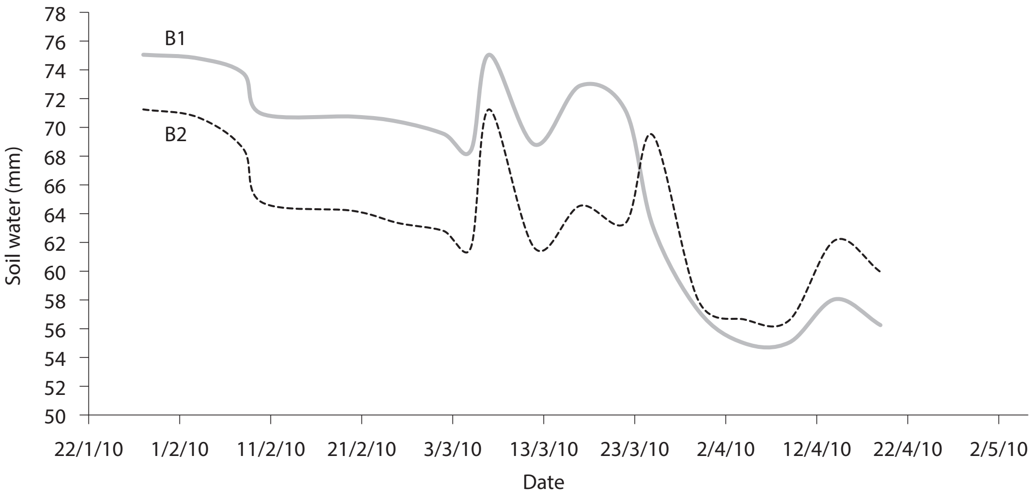

Figure 2. Soil water storage (in mm to 60 cm depth) in 2010 with biochar (B2) and without biochar (B1)

Table 3. Economic evaluation of fertiliser and biochar use for cashew production (VND million)

	2009		2010		2011		2012		Average over 4 years	
	B1	B2	B1	B2	B1	B2	B1	B2	B1	B2
Input costs	11.8	19.8	13.6	13.6	15.2	15.2	17.1	17.1	14.4	16.4
Materials	4.6	12.2	6.4	6.4	7.1	7.1	8.0	8.0	6.5	8.4
Labour	7.2	7.6	7.2	7.2	8.1	8.1	9.1	9.1	7.9	8.0
Output (cashew nut income)	20.9	26.5	44.4	50.6	71.5	76.6	53.2	59.4	47.5	53.3
Net profit	9.1	6.7	30.8	37.0	56.3	61.4	36.1	42.3	33.1	36.9

Note: B1 = without biochar; B2 = with biochar

Effect of integrated nutrient management on peanut yield and profitability

With the application of inorganic NPK fertiliser alone, peanut yields at the two sites were over 3 t/ha (Figure 3), which was higher than the average peanut yield in Vietnam (General Statistics Office 2012). Addition of S with NPK increased peanut yields at site 1 but not at site 2. However, S plus the micronutrients (B, Cu, Mo and Zn) increased peanut yield at both sites relative to NPK or NPK plus S alone. Application of either manure or biochar together with NPK increased the yield of peanuts by 18.5% and 21.1%, respectively, reaching approximately 4 t/ha (Figure 3). The highest yields were obtained when either biochar or manure were applied together with NPK plus S and micronutrients. This indicates that the highest yield of peanut could be achieved with supply of all limiting nutrients plus the organic amendment. The positive effects of manure or biochar, S and micronutrients were additive, indicating that the biochar and manure were not simply replacing nutrients supplied by inorganic fertiliser.

Application of 11.1 t/ha biochar in combination with inorganic fertilisers (BT3) gave the highest net profit increase (VND15.53 million) for peanut production compared with application of complete inorganic fertiliser without biochar (NT3; Table 4). This was followed by the other two biochar treatments that increased profit by VND15.0 million (BT2 compared with NT2) and VND12.3 million (BT1 compared with NT1). Application of manure in combination with inorganic fertilisers also increased net profits compared with the equivalent inorganic fertiliser treatment on its own. As with biochar, greatest profit was gained from the combination of manure with the complete fertiliser treatment (MT3). Even though the cost of manure (VND5.0 million)

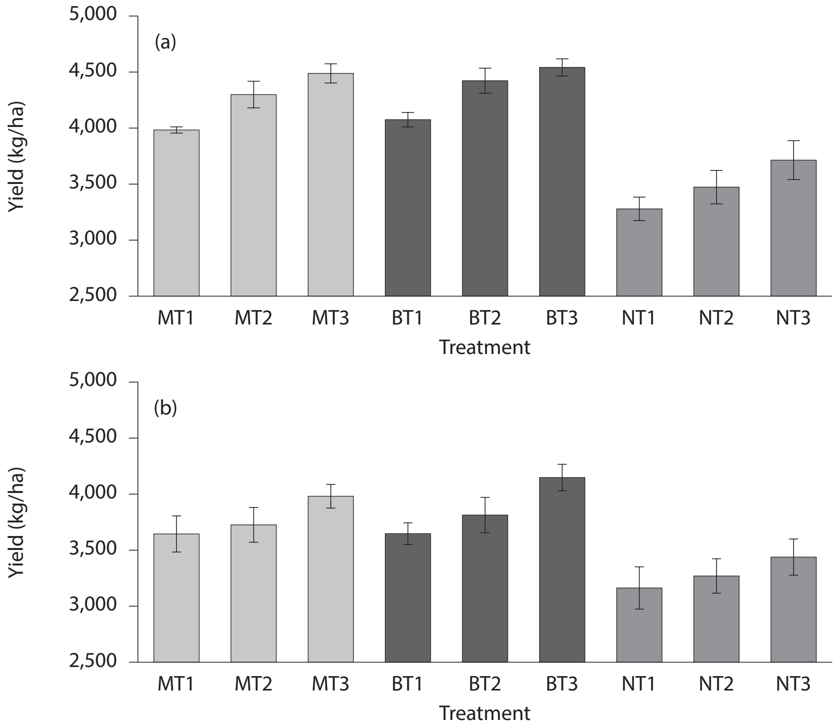

Figure 3. Effect of manure, biochar and inorganic fertilisers on peanut yield at Phu Cat (a) site 1 and (b) site 2. Note: for treatments, N = no organic fertiliser; B = 11.1 t biochar/ha; M =10 t manure/ha; T1 = nitrogen–phosphorus–potassium (NPK) (30:90:60 kg/ha); T2 = NPK + sulfur (S) (20 kg/ha); T3 = NPK + S + micronutrients (2.4 copper, 4.05 zinc, 0.25 boron, 0.54 molybdenum kg/ha)

and biochar (VND3.7 million) are significant, the increase in profit margins due to the increase in yield compensated for the investments made in manure and biochar application.

Although the cost of biochar application was high (VND3.7 million for 11.1 t/ha), given the long-term effect of biochar (at least 4 years) on yields as shown for cashew (Figure 1), it represents a lower annual cost than other forms of fertilisation. The cost of manure (VND5 million for 10 t/ha) is higher than for biochar; however, long-term effects of manure were not investigated.

The increase in productivity of peanut as a result of adding manure or biochar could be attributed to a range of factors but further research is needed to define the mechanisms responsible. The addition of biochar to the soil was shown elsewhere to: reduce nitrogen losses from leaching; increase water holding capacity; increase the soil microbial population; increase soil pH; increase K content; and increase fertiliser use efficiency (Glaser et al. 2002; Lehmann et al. 2003).

Concentrations of P, K, S and Cu in peanut leaves did not necessarily increase where these nutrients were applied in inorganic fertiliser or with the organic amendments. Higher levels of K were observed where biochar was applied compared with treatments without biochar (Table 5). Biochars may contain high levels of nutrients like P, K, S and Zn; however, the levels of most of these nutrients were not determined for the 'rice husk 2' biochar used for peanut and mango experiments and besides may vary with method of processing and raw material used (Table 2).

Table 4. Economic evaluation of manure and biochar use for peanut production in 2012

Treatment[a]	Material costs (VND '000/ha)	Yield (t/ha)	Total revenue (VND '000/ha)	Net profit (VND '000/ha)
MT1	32.97	3.81 ± 0.10	95.25	62.28
MT2	33.48	4.01 ± 0.14	100.32	66.84
MT3	34.50	4.23 ± 0.11	105.85	71.35
BT1	31.67	3.86 ± 0.10	96.52	64.85
BT2	32.18	4.11 ± 0.15	102.97	70.79
BT3	33.20	4.34 ± 0.10	108.62	75.43
NT1	27.97	3.22 ± 0.10	80.52	52.55
NT2	28.48	3.37 ± 0.11	84.27	55.79
NT3	29.50	3.58 ± 0.12	89.40	59.90

[a] N = no organic fertiliser; B = 11.1 t biochar/ha; M = 10 t manure/ha; T1 = nitrogen–phosphorus–potassium (NPK) (30:90:60 kg/ha); T2 = NPK + sulfur (S) (20 kg/ha); T3 = NPK + S + micronutrients (2.4 copper, 4.05 zinc, 0.25 boron, 0.54 molybdenum kg/ha)

Table 5. Effect of fertiliser on the levels of nutrients in peanut leaves at flowering stage at site 1

Treatment[a]	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Sulfur (%)	Copper (mg/kg)	Zinc (mg/kg)	Boron (mg/kg)
MT1	4.74	0.37	2.38	0.28	4.09	31.2	28.2
MT2	4.93	0.38	2.41	0.31	3.49	30.4	29.5
MT3	5.06	0.41	2.50	0.30	3.60	35.0	54.1
BT1	5.04	0.41	2.67	0.29	4.17	36.6	30.8
BT2	5.06	0.41	2.77	0.30	3.67	34.0	32.3
BT3	4.96	0.40	2.67	0.32	4.86	39.4	57.8
NT1	4.84	0.40	2.29	0.30	4.05	35.9	29.0
NT2	4.98	0.42	2.59	0.33	4.60	38.2	30.8
NT3	5.03	0.41	2.43	0.32	4.03	38.6	57.3

[a] N = no organic fertiliser; B = 11.1 t biochar/ha; M = 10 t manure/ha; T1 = nitrogen–phosphorus–potassium (NPK) (30:90:60 kg/ha); T2 = NPK + sulfur (S) (20 kg/ha); T3 = NPK + S + micronutrients (2.4 copper, 4.05 zinc, 0.25 boron, 0.54 molybdenum kg/ha)

Effect of biochar and inorganic fertilisers on mango yield and quality

Biochar significantly improved flowering and yield; however, the proportion of good-quality fruits (type 1) was not significantly altered by biochar application (Table 6). The inorganic fertiliser treatments had no significant effects on mango yield. The biochar and nutrient treatments were applied in November 2011 to 6-year-old mango trees. Mango trees normally achieve maximum flowering and fruiting when they are 8 years of age or older, hence it would be useful to assess response of older mango trees to biochar and inorganic fertiliser on sands.

General discussion

Multiple nutrient deficiencies on sands were identified by Hoang Minh Tam et al. (2015). The present results for peanut support the requirement for S in addition to micronutrients for maximum production of peanut on two sands in the Phu Cat district of Binh Dinh province. While the specific micronutrient deficiencies were not diagnosed in the present peanut experiment, the omission experiments in Phu Cat suggest that B and Cu were deficient (Hoang Minh Tam et al. 2015). However, the suite of micronutrient deficiencies varied in other sands, especially those from Ninh Thaun province (Hoang Minh Tam et al. 2015). Hence, it is critically important to have an accurate means of diagnosing the deficiencies on sands so that appropriate treatments can be applied. While field experiments can give a definitive diagnosis, they are costly and time consuming to run. Plant analysis can be used to diagnose nutrient deficiencies but depends on access to laboratories that are able to reliably determine low concentrations of micronutrients. Soil tests may give a general indication of deficiency risk but are generally not considered very accurate for predicting micronutrient deficiencies (Bell and Dell 2008). The double-pot approach appeared to predict the same deficiencies identified in the field and may be a suitable approach for SCC Vietnam (Hoang Minh Tam et al. 2015).

Current fertilisers used by farmers in SCC Vietnam supply N and/or P or N, P and K. However, the present results indicate the need for balanced fertiliser that supplies all the limiting nutrients. Balanced fertiliser can be designed by mixing two or more fertilisers to provide the recommended rates and proportions of nutrients; however, suitable S and micronutrient fertilisers may not be available in local markets. This suggests the need for engagement with fertiliser suppliers, manufacturers and blenders to ensure the most suitable balanced fertilisers are available in areas of sandy soils. This may involve the development of fertilisers specifically designed for crops on sands only.

Strong yield responses were obtained in peanut from balanced supply of inorganic fertilisers. By contrast with cashew, there was no response to increased rates of NPKS fertiliser, possibly because

Table 6. Effect of integrated nutrient management, biochar and fertiliser, on mango yield

Treatment[a]	Flowering ratio[b] (%)	Yield (kg/tree)	Yield (g/m^2 of canopy surface area)	Fruit quality[c]	
				Type I (%)	Type II (%)
BT1	19.4	9.4	523	71.1	28.9
BT2	27.5	8.5	524	73.4	26.6
BT3	26.7	10.0	572	74.1	25.9
NT1	18.0	7.4	406	73.2	26.8
NT2	21.9	8.0	458	75.7	24.3
NT3	21.2	8.6	459	72.2	27.8
CV (%)		14.7	11.1		
$LSD_{0.05}$		1.92	81.8		

a N = no biochar; B = biochar applied (50 kg/tree); T1: nitrogen–phosphorus–potassium (NPK) (1.26 kg di-ammonium phosphate (DAP) + 0.5 kg urea + 0.73 kg KCl/tree); T2: NPK + sulfur (S): (1.26 kg DAP + 0.5 kg urea + 0.86 kg K_2SO_4)/tree; T3: NPK + S + micronutrients (27 g $CuSO_4$ + 4.5 g $(NH_4)6Mo_7O_{24}.4H_2O$ + 45 g $ZnSO_4$ + 6.5 g H_3BO_3)/tree)

b Flowering ratio: flowering branches as a % of total branches per tree

c Type 1 = fruits with no defects; type 2 = fruits with visible defects which sell at one-third the price of type 1 fruits

Note: CV = coefficient of variation; $LSD_{0.05}$ = least significant difference at $p < 0.05$

growth remained limited by deficiencies of micronutrients. However, regardless of the inorganic fertiliser treatment, there were additive effects of manure or biochar on peanut yield. There is evidence from studies in Thailand that response to inorganic fertilisers on sands can be improved by combining with supply of organic amendments (Bell and Seng 2007). This may be related to improved soil water storage, slowed release of nutrients to match with crop demand, decreased nutrient leaching or increased total supply of one or more limiting nutrients. A range of organic resources are presently applied by farmers in SCC Vietnam to sands (Hoang Thi Thai Hoa et al. 2015a). This practice should be supported and encouraged. However, further research is needed to determine the main processes by which applying organic materials improve crop yield on sands. The variable composition of organic amendments makes it difficult to simply predict the effects expected. If organic amendments are primarily supplying nutrients then the nutrient composition of the materials, such as reported by Hoang Thi Thai Hoa et al. (2015a), is important. Biochar is a new organic material that could be used in SCC Vietnam. However, it is necessary to regulate the quality of biochar to provide greater confidence to farmers in the profitability and reliability of its use. Addition of biochar and/or manure has the potential to build soil carbon, increase soil pH and build resilience in the sands of SCC Vietnam. Longer term studies on sands in the region would be valuable to quantify the range of soil improvement benefits that can be achieved with biochar and the other organic amendments.

Conclusions

In general, use of biochar and/or manure in combination with inorganic fertilisers had positive effects on peanut yields. Application of biochar under cashew trees seemed to have a long-term positive effect even though the cost of the initial application cost was high. Costs of biochar were more than recovered by increased yields over the 4-year period of the cashew trial. Application of biochar increased productivity by 13% in cashew and economic returns over 4 years averaged VND3.8 million/ha/year. Application of biochar increased mango productivity by 16%; however, the trees were only 6 years old and their yield was still below potential. By contrast, in cashew, there was limited benefits from increased rates of inorganic NPK fertiliser, with or without biochar, possibly because other limitations such as micronutrient deficiencies were not treated.

The integrated use of manure or biochar with balanced inorganic fertilisers was most effective in increasing peanut yield and significantly increased profit compared with either organic amendments or inorganic fertiliser alone.

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Improving the value and effectiveness of manure

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Abstract

Organic amendments are very important in maintaining the soil productivity of sands. This research aimed at exploring the effects of variations affecting manure quality and nutrient availability that occur as a result of manure handling and storage. Secondly, the research evaluated the effects of these variations on the yield of peanut as well as soil properties of sands to which they are applied. The study was conducted by carrying out experiments on: (1) manure storage techniques; (2) manure storage using the pit method in three provinces; and (3) use of a combination of inorganic fertilisers and manure as a viable option for crop production for farmers. Our results indicated that pit storage produced better quality manure than the heap storage method traditionally used by farmers and could be a suitable option for extended storage of manure. In the field experiments, application of different organic treatments gave higher yields compared with application of inorganic fertiliser alone. The highest gross margins were found with an application rate of 10 tonnes manure/hectare produced by storage in a pit (manure:rice straw ratio of 1:0.5). Only few changes in soil properties were found after the peanut crop but incorporation of different types of organic amendments improved all soil properties more than application of inorganic fertiliser alone.

Introduction

Manure is an important source of nutrients for crop production which is used by many smallholder farmers in Vietnam who cannot afford the recommended rates of chemical fertilisers. Hoang Thi Thai Hoa et al. (2015) indicated there is a risk of increasing nutrient losses if the transition from open grazing of livestock to stall feeding is not accompanied by adoption of improved manure handling techniques. Nutrient losses during collection and storage of manure on smallholder farms have been studied less frequently than utilisation of nutrients from applied manure (Powell and Williams 1995). However, it is difficult to assess the combined effects of all factors on nutrient utilisation from manures because, among other reasons, there is a the lack of information on nutrient losses during manure handling.

Repeated applications of mature compost made from farmyard manure or rice straw and crop residues are often recommended in Vietnam in order to maintain soil fertility. However, the use of composted organic materials has been gradually decreasing over the last few decades, because of shortages of labour and animal production as well as the convenience of using chemical fertilisers (Pham Quang Ha and Tran Thuc Son 2002). In some areas of central coastal Vietnam, direct application of crop residues for crop production has been practised. In some cases, manure produced on intensive livestock farms is used in a raw form, while some farmers mix manure with a little animal bedding materials or straw. The composting of manure varies with farming practice. Farmers use manure and a range of diverse organic materials,

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such as rice straw, peanut stems and aquatic plants, to make compost.

The ability of organic materials to supply balanced plant nutrition, increase soil fertility and build up the level of organic matter in soils is strongly influenced by their decomposition rate and the nutrient content in the soil. However, the behaviour of various organic materials in soils is not yet clear because of the diverse nature of components and varying levels of compost maturity.

Resource-limited farmers maintain soil fertility through management of organic inputs. Those who have limited cash-flow options rely largely on the limited available organic resources for agricultural production. To sustain high crop yields and maintain soil fertility, it is important to work out the optimal rates of combinations of fertilisers and manures in the cropping system (Clark et al. 1998; Petersen et al. 1999; Pinitpaitoon et al. 2011). In highly weathered and nutrient-poor soils, such as the coastal sandy soils of central Vietnam, nominal addition of plant residues and manures can make substantial improvements to soil quality and crop yields (Ponnamperuma 1984; Meelu et al. 1994; Yadvinder-Singh et al. 1995). The use and management of crop residues and farmyard manure is an increasingly important aspect of environmentally sound sustainable agriculture (Timsina and Connor 2001).

There is limited research focused on the effect of different types of organic amendments on crop productivity and soil fertility in coastal sands. Considerable emphasis in the recent past has been given to improve rice production in these soils using different management strategies (Tran Thi Thu Ha 2006; Hoang Thi Thai Hoa 2007). However, there has been a very limited focus on the quality of manure to improve soil fertility, productivity and nutrient use efficiency in these fragile soils.

The objectives of this study were to: (i) compare the quality and nutrient availability of composts prepared by mixing cattle manure with crop residues in heaps and pits; (ii) evaluate the effect of compost quality in combination with inorganic fertilisers on yield and economics of peanut cropping; and (iii) examine possible short-term changes in soil quality following organic amendment of sands in south-central coastal (SCC) Vietnam.

Materials and methods

Manure storage techniques (experiment 1)

This study was conducted in Cat Trinh commune, Phu Cat district, Binh Dinh province, from October to December 2010. The experiment consisted of four treatments with three replicates in a single household (Table 1).

Collection and method of manure storage

Fresh cattle excreta with dung and rice straw litter were collected from 2–3 nearby cattle farms (the number depended on the availability of manure) and mixed thoroughly to overcome differences in quality that could have occurred as a result of different residence times in the collection pile (all manures were <15 days old). This mixture was then mixed with rice straw (previously chopped to 20 cm) in a volume ratio of 1:0.5. One tonne (t) of the final mix was then treated with 10 kg of lime and 10 kg of superphosphate before storage (Vu Huu Yem 1995) in a heap or pit.

Table 1. Treatments used in experiment 1

Treatment abbreviation	Type of manure	Method of storage	Amount of manure + straw (t)
CFH	Cattle dung	Control (farmer practice in open compost heap on soil)	0.6 + 0.0
CFP	Cattle dung mixed with rice straw from farmer household (1:1 ratio)	Compost pit in brick enclosure covered with plastic (1 m × 1 m × 0.7 m)	0.3 + 0.3
CTH	Cattle dung + rice straw (1:0.5 ratio)	Compost heap on compacted earth covered with plastic (1 m × 1 m × 0.7 m)	0.4 + 0.2
CTP	Cattle dung + rice straw (1:0.5 ratio)	Compost pit in brick enclosure covered with plastic (1 m × 1 m × 0.7 m)	0.4 + 0.2

Heaps were formed in a conical shape with 1 m basal diameter and 0.7 m height. Pits of 1 m × 1 m and 0.7 m deep were built with bricks and filled with manure mix on a base constructed of compacted earth. Heaps and pits were covered with plastic, except for the farmer practice (control). Replicated heaps and pits had the same shape and dimensions and composted material was sampled from each of the heaps and pits for laboratory analysis.

Management and monitoring

The mix of manure and straw in heaps and pits was turned three times (after 40, 70 and 90 days of storage) as per the local farmer practice. The turning was done by removing all the material from the heaps/pits and weighing it, then rebuilding the heaps and pits by placing the surface material at the bottom and vice versa to homogenise the heap. Temperature was measured throughout the experiment every morning at 9 am and every afternoon at 1 pm by placing a thermometer in the centre of the heap/pit.

Sampling and laboratory analysis

Six samples from each treatment (Table 1), each weighing approximately 0.5 kg, were collected from the piles at the start and the end of the composting period (90 days), and comprised two samples each from the upper surface, centre and bottom. Hence, the total number of samples was 24. Samples were thoroughly mixed on a plastic sheet and one subsample of 0.3 kg was taken and packed in a polythene bag, sealed and stored at 4 °C in a cool box, before analysing for mineral nitrogen (N), total N, phosphorus (P), potassium (K), water content and pH.

Soil sampling for mineral N, P and K

To assess N losses through leaching from stored manure, soil samples were taken from underneath the heaps/pits at 0–20 cm and >80 cm depth at the start and end of the experiment (90 days). Control samples were also taken at five different points within the field where the peanut experiment (see below) was located. These samples were taken from the same depths, then bulked per depth. Samples were analysed the following day for pH, organic carbon (C), total N, mineral N—ammonium-N (NH_4-N) and nitrate-N (NO_3-N)—total P and K.

Samples were oven dried at 65 °C and ground to pass through a 1 mm sieve. Organic C was analysed by wet oxidation (Walkley Black) and total N was determined using the Kjeldahl method. Potassium was measured by flame photometry after digestion with nitric acid (HNO_3) and hydrochloric acid (HCl). Phosphorus was measured colorimetrically using the molybdate-blue method. Mineral N was determined after extraction with 1 M potassium chloride following the Kjeldahl method. A ratio (1:5 manure:water) was used to determine the pH. All the samples were analysed following methods described by Page et al. (1996).

Manure storage using the pit method in three provinces (experiment 2)

Experiment 1 showed that composting in the pits was the best in terms of nutrient contents (see 'Results and discussion' below). Therefore, to validate the findings, the study was extended to five households in each of Cat Trinh commune (Binh Dinh province), An Chan commune (Phu Yen province) and Phuoc Dinh commune (Ninh Thuan province). The study was carried out from June to August 2011 in Ninh Thuan and from September to December 2011 in Binh Dinh and Phu Yen. Pit composting within a brick-walled enclosure was compared with farmer practice. The manure collected from the farms was mixed thoroughly to homogenise differences in quality. Each household collected 1 t of manure and divided it into two parts (half for pit composting and the rest for farmer practice). Rice straw was added in the same ratio as described previously.

The pits were turned three times during storage (after 30 days, 60 days and 90 days of storage), as described above.

Combined effect of inorganic fertilisers and manure on peanut yield and economic efficiency (experiments 3 and 4)

Treatments and crop performance parameters

Two trials were conducted in Cat Trinh commune, Phu Cat district, Binh Dinh province. The first trial, conducted in spring 2011, used four organic amendments as shown in Table 1, plus a control to give five treatments, with two application methods—surface broadcast and in rows of 30 cm width and mixed to 10 cm depth (Table 2).

All treatments in Table 2 were laid out in a split-plot design with three replicates. Each main plot (application method) had an area of 50 m² with five subplots (manure treatment) of 10 m² each. All treatments had inorganic fertiliser application of

30 kg/ha N, 39 kg/ha P, 50 kg/ha K and 500 kg/ha lime (control), together with 10 t/ha manure stored using the different storage methods. The fertiliser rates were based on the field survey reported in Hoang Thi Thai Hoa et al. (2015). They also correspond with the guidelines on fertiliser application rates for peanut from the extension office and also reported by Ho Huy Cuong (unpublished data 2008).

Table 2. Treatments applied for peanut trial in spring 2011 (experiment 3)

Method of application	Fertiliser and manure (per ha)
Surface	Control: 30 kg N + 39 kg P + 50 kg K + 500 kg lime (NPK)
	NPK + 10 t CFH
	NPK + 10 t CFP
	NPK + 10 t CTH
	NPK + 10 t CTP
Row	Control: NPK
	NPK + 10 t CFH
	NPK + 10 t CFP
	NPK + 10 t CTH
	NPK + 10 t CTP

Note: N = nitrogen (urea); P = phosphorus (thermophosphate); K = potassium (potassium chloride); CFH = cattle dung with heap composting (control); CFP = cattle dung mixed with rice straw from farmer household with pit composting; CTH = cattle dung + rice straw (1:0.5) with heap composting; CTP = cattle dung + rice straw (1:0.5) with pit composting

A second trial was conducted in spring 2012, comprising 10 treatments (experiment 4), with five types of organic amendments made in five households (using the pit composting method) as described above (experiment 2) and compared with a control (compost from their own households made by the heap composting method). All treatments were applied with N, P, K, lime and manure as described above. All treatments were laid out in a factorial design with three replicates.

Nitrogen, P and K were applied as urea (46% N), thermophosphate (7% P) and muriate of potash (MOP = potassium chloride (KCl), 50% K). Lime (calcium carbonate, 56% Ca) was broadcast 2 weeks before sowing and incorporated to a soil depth of 20 cm. The required amount of organic amendments and P were applied only at sowing time either in rows or broadcast by hand on the surface of the soil (Table 2). Nitrogen and K fertilisers were applied in rows at two stages of plant growth: (1) one-third of the amount at full expansion of the third leaf; and (2) the remaining two-thirds just before flowering.

Local peanut (*Arachis hypogea* L.) variety Ly, which is frequently used in central Vietnam, was chosen for these trials. Peanut seeds were planted with 30 cm between rows and 10 cm between seeds to reach a plant population of about 330,000 plants/ha.

At harvesting stage, sampling to estimate biomass, pod yield and other components was carried out by using a quadrat measuring 1 m^2.

The dates of sowing and harvest were 24 December 2010 and 15 April 2011 for experiment 3, and 23 January and 10 May 2012 for experiment 4, respectively.

Sampling and analyses of soils and organic materials

Composite soil samples were collected at 0–20 cm from each plot before and after the experiments in 2011 and 2012. The chemical properties analysed included pH measured in 1 M potassium chloride (pH_{KCl}), organic C, total N, total P, total K, cation exchange capacity (CEC) and mineral N. The analyses were performed using the methods given in Page et al. (1996). Samples of organic amendments were collected before applying them in these field trials. They were dried at 70 °C for the determination of N content and 105 °C for 6 hours for total C, P and K concentrations following the methods mentioned above. All the analyses were carried out at the Soil Science Department of Hue University of Agriculture and Forestry.

Results and discussion

Manure storage method

Effect of manure storage on manure quality

The conditions under which manure was stored affected its final quality and nutrient composition (Table 3).

After 90 days of storage, pH increased slightly for treatments CTH and CTP, although the difference was not significant. There there was no significant difference between storage in heaps or pits (Table 3).

The total amount of manure dry matter decreased to about a quarter of its initial amount after 90 days of storage, partly as a result of changes in the mass fraction of organic matter in the stored manure. The decline in dry matter during storage (Table 3) was not only due to C mineralisation, but also a high rate of decomposition as a result of high temperatures during storage as evidened by the decreased amount of organic C levels. Leaching of dissolved organic matter and consumption by invertebrates also contributed to the loss.

The total amounts of N, P and K contained in the stored manure decreased during storage due to a decrease in their mass fraction over time. The mass fractions of total N, mineral N, P and K varied significantly between storage practices ($p < 0.05$) (Table 3). The C:N ratios of the manure stored in heaps were greater on average than those of the manure stored in pits under cover, whereas the C:P ratios of the manure stored in heaps were lower than the ones stored in pits . The manure stored under cover in pits retained significantly more mineral N and K during storage. Most of the mineral N in the manure was low in the NH_4-N fraction at the beginning of storage and increased after 90 days of storage except treatment CTH. The manure stored in pits had significantly higher mass fractions of total N and total K than the manure in heaps. When compared with the quality of the manure at the beginning of storage, the manure stored in pits had 11% more mass fractions of N, and 20% more K after 90 days of storage. In the manure stored in heaps under the control treatment, the mass fraction of total N declined by 4% and that of K by 63% during storage. In the case of organic manures and crop residues, the C:N ratio can be used as the index for predicting the N mineralisation.

Soil chemical properties of compost after storage

Nitrogen losses through leaching were assessed by sampling the soil at different depths underneath the pits and heaps as reflected by concentrations of NH_4-N and NO_3-N in the soil after 90 days of storage (Table 4). Both NH_4-N and NO_3-N concentrations fluctuated with soil depth and storage method. In general, total N, P and K were found in higher concentrations below 80 cm depth, suggesting that they leached during storage.

The mineralisable N pool in the untreated soil was much lower compared with the soil that was amended with organic materials (Table 4). This suggests a high potential of such soils to mineralise N from organic residues. Srinivas et al. (2006) showed that under aerobic conditions there was a net immobilisation or mineralisation as a function of the organic amendments used.

Table 3. Effect of manure storage on some quality indicators of manure before and after 90 days (experiment 1)

Treatment[a]	Dry matter (%)	pH_{KCl}	C (%)	N (%)	NH_4^+ (mg/kg)	NO_3^- (mg/kg)	P (%)	K (%)
Day 0 (beginning of experiment)								
CFH	46.7 a	7.9 a	55.5 b	0.9 b	23.3 b	228 a	0.14 a	0.40 a
CFP	32.8 c	7.8 a	51.1 a	1.0 a	44.0 a	234 a	0.15 a	0.37 a
CTH	37.5 b	7.4 a	59.5 c	1.1 a	51.0 a	241 a	0.11 b	0.33 a
CTP	37.5 b	7.4 a	59.5 c	1.1 a	51.0 a	241 a	0.11 b	0.33 a
$LSD_{0.05}$	*4.1*	*0.8*	*2.6*	*0.1*	*11.6*	*23.4*	*0.03*	*0.11*
After 90 days of storage								
CFH	36.3 a	7.9 a	38.4 a	0.8 b	62.0 ab	236 c	0.19 a	0.25 b
CFP	35.9 a	7.8 a	39.9 a	1.2 a	72.0 a	234 c	0.17 ab	0.44 a
CTH	30.3 b	8.2 a	33.9 b	0.9 b	43.2 c	314 b	0.15 b	0.30 b
CTP	36.2 a	8.0 a	36.8 b	1.2 a	61.2 b	270 a	0.16 b	0.52 a
$LSD_{0.05}$	*2.60*	*0.74*	*3.64*	*0.16*	*10.2*	*59.6*	*0.03*	*0.08*

[a] CFH = cattle dung with heap composting (control); CFP = cattle dung mixed with rice straw from farmer household with pit composting; CTH = cattle dung + rice straw (1:0.5) with heap composting; CTP = cattle dung + rice straw (1:0.5) with pit composting

Note: ph_{KCl} = pH measured in 1 M potassium chloride; C = carbon; N = nitrogen; NH_4^+ = ammonium N; NO_3^- = nitrate N; P = phosphorus; K = potassium; $LSD_{0.05}$ = least significant difference ($p < 0.05$); means followed by the same letter(s) within the columns do not differ significantly at $p < 0.05$

Table 4. Soil chemical properties at different depths after 90 days of manure storage (experiment 1)

Treatment[a]	Nitrogen (N) (%)	Ammonium N (NH_4^+) (mg/kg)	Nitrate N (NO_3^-) (mg/kg)	Phosphorus (%)	Potassium (%)
Control	0.039	15.5	35.4	0.012	0.16
0–20 cm					
CFH	0.042 c	7.9 b	100.8 c	0.017 b	0.24 d
CFP	0.036 d	11.3 a	96.9 b	0.015 a	0.37 a
CTH	0.045 b	6.8 b	89.1 a	0.015 a	0.29 c
CTP	0.048 a	12.4 a	92.1 a	0.015 a	0.34 b
>80 cm					
CFH	0.048 a	20.3 b	91.8 d	0.020 b	0.34 b
CFP	0.034 b	14.6 a	65.9 a	0.021 b	0.22 a
CTH	0.050 a	18.0 b	86.8 c	0.018 a	0.31 b
CTP	0.037 b	13.8 a	72.1 b	0.018 a	0.26 a

[a] Control = soil taken from nearby field; CFH = cattle dung with heap composting (control); CFP = cattle dung mixed with rice straw from farmer household with pit composting; CTH = cattle dung + rice straw (1:0.5) with heap composting; CTP = cattle dung + rice straw (1:0.5) with pit composting

Note: means followed by the same letter(s) within the columns do not differ significantly at $p < 0.05$

Effect of application method and combination of inorganic fertilisers and manure on peanut yield, economic efficiency and soil characteristics

Effects of different organic amendments on peanut yield and economic efficiency

The combination of organic amendments and inorganic fertilisers significantly outperformed the NPK control (inorganic fertiliser only) for peanut yield (Table 5). However, among the treatments with organic amendment, there were no clear differences between application methods (surface broadcast or row). The response of peanut to the combined application of inorganic fertiliser and organic amendments was similar to that observed by Tinh (1997). Treatments comprising a 1:0.5 ratio of manure to rice straw composted in either pits (CTP) or heaps (CTH) generally performed better than that composted using farmer practice either in pits (CFP) or heaps (CFH). Increase in the number of pods per plant, number of filled pods per plant and 100 seed weight correlated well with the pod yield of peanut (data not shown). Pod yields in the treatments with 10 t/ha manure (1:0.5) stored in a the pit were significantly higher than other treatments for both application methods (broadcast and row), particularly under row application (Table 5).

The highest gross margins were found with manure stored in pits (1:0.5) at an application rate of 10 t/ha (VND28,190,000 and VND26,440,000) in row and surface application, respectively (Table 5). The value:cost ratio (VCR) and agronomic efficiency were highest with these treatments also. Such results indicate that the application of organic amendments in these trials could bring higher profits for peanut growers, especially with row application.

Effects of different organic amendments on soil characteristics (peanut field)

On average, maximum pH values were observed under NPK + CTH treatments when broadcast on the soil surface (Table 6). Although the addition of organic matter may not directly affect soil pH in the short term, soils that receive significant amounts of organic amendments tend to maintain (buffer) soil pH values for longer periods of time (Evanylo and McGuinn 2000).

Organic C content was also affected by application of inorganic fertiliser and organic amendments. On average, maximum organic C values of 1.5% were found in NPK + CFP treatments, which might have enhanced the biomass of peanut and hence the input of crop residues. The result was the same for both surface broadcast and row application, so application method had no effect on organic C content in this case (Kha 1996).

Table 5. Yield of peanut and economic efficiency evaluation in spring season 2011 (experiment 3)

Application method	Treatment	Pod yield (t/ha)	Total revenue (VND '000/ha)	Gross margin (VND '000/ha)	Agronomic efficiency (kg pod/t manure)	Value:cost ratio (VCR)
Surface	NPK	2.95 c	73,700	11,340	–	–
	NPK + CFH	3.52 abc	87,875	21,515	56.7	3.5
	NPK + CFP	3.57 abc	89,325	22,965	62.5	3.9
	NPK + CTH	3.52 abc	87,975	21,615	57.1	3.6
	NPK + CTP	3.71 ab	92,800	26,440	76.4	4.8
Row	NPK	3.08 bc	77,075	11,715	–	–
	NPK + CFH	3.52 abc	88,050	18,690	43.9	2.1
	NPK + CFP	3.75 a	93,700	24,300	66.5	3.5
	NPK + CTH	3.68 ab	91,875	22,515	59.2	3.1
	NPK + CTP	3.90 a	97,550	28,190	81.9	4.5

Note: NPK = inorganic fertiliser comprising 30 kg/ha nitrogen (N), 39 kg/ha phosphorus (P), 50 kg/ha potassium (K) and 500 kg/ha lime; CFH = cattle dung with heap composting; CFP = cattle dung mixed with rice straw from farmer household with pit composting; CTH = cattle dung + rice straw (1:0.5) with heap composting; CTP = cattle dung + rice straw (1:0.5) with pit composting; Means followed by the same letter(s) within the columns do not differ significantly at $p < 0.05$

Table 6. Characteristics of soils (0–20 cm) after peanut harvest (experiment 3)

Application method	Fertiliser	pH_{KCl}	Org. C (%)	Total N (%)	NH_4^+ (mg/kg)	NO_3^- (mg/kg)	P (%)	K (%)	CEC ($cmol_c$/kg)
Surface	NPK	5.5 a	1.2 c	0.040 f	20.3 c	9.4 d	0.02 a	0.04 b	0.6 d
	NPK + CFH	5.3 b	1.3 b	0.042 f	24.5 bc	12.9 c	0.02 a	0.05 a	1.0 c
	NPK + CFP	5.2 cd	1.5 a	0.053 de	28.4 a	15.2 b	0.01 b	0.04 b	1.7 b
	NPK + CTH	5.4 a	1.3 b	0.060 c	30.4 a	16.4 b	0.01 b	0.04 b	2.7 a
	NPK + CTP	5.3 b	1.4 a	0.064 b	29.4 a	10.4 cd	0.02 a	0.03 c	1.9 b
Row	NPK	5.2 cd	1.3 b	0.048 e	22.5 c	12.6 c	0.02 a	0.04 b	1.1 c
	NPK + CFH	5.1 d	1.2 c	0.057 d	26.3 b	18.3 a	0.02 a	0.04 b	1.8 b
	NPK + CFP	5.3 b	1.5 a	0.059 c	29.4 a	15.3 b	0.01 b	0.04 b	1.3 c
	NPK + CTH	5.3 b	1.3 b	0.067 a	30.2 a	14.5 bc	0.02 a	0.04 b	2.3 a
	NPK + CTP	5.3 b	1.4 a	0.067 a	28.9 a	15.5 b	0.02 a	0.04 b	1.7 b

Note: pH_{KCl} = pH measured in 1 M potassium chloride; C = carbon; N = nitrogen; NH_4^+ = ammonium N; NO_3^- = nitrate N; P = phosphorus; K = potassium; CEC = cation exchange capacity; CFH = cattle dung with heap composting (control); CFP = cattle dung mixed with rice straw from farmer household with pit composting; CTH = cattle dung + rice straw (1:0.5) with heap composting; CTP = cattle dung + rice straw (1:0.5) with pit composting; means followed by the same letter(s) within the columns do not differ significantly at $p < 0.05$

Total N increased significantly with fertilisation and different types of organic amendment application in most case. This is probably due to the fact that the leguminous crops are able to utilise N from symbiotic fixation as well as from manures and inorganic fertilisers (Myers and Wood 1987).

The effect on CEC was more pronounced in NPK + CTH treatments with both application methods. This might be related to differences in humification of organic amendments and crop residues.

Effects of organic amendments collected from different farmers on peanut yield and economic efficiency

Addition of organic amendments from different households increased yield of peanut, expecially from manure stored in pits from the Tran Minh Tinh household (Table 7). However, with pit composting, pod yield was not significantly different among the five households.

The gross margins among the five households were comparatively higher for composting in pits than in heaps (Table 7). Value:cost ratios (VCRs) for pit composting were marginally higher than for heap composting. Such results indicate that the application of organic amendments in these trials could bring higher profits for peanut growers if pit composting were practised.

Effect of composted material on soils collected from the peanut field

Maximum pH values were found in soils with organic amendments from pit composting compared with heap composting (Table 8); however, the difference was not significant. Maximum soil organic C values of 1.21% resulted from organic amendments made by pit composting. No significant differences were observed for total N, P, K and CEC between pit and heap composting methods.

Conclusions

Manure handling and storage affected nutrient retention and other quality parameters of compost. Our results suggest that storage of manure in pits could be more suitable for long periods with the aim of retaining organic matter and nutrients for smallholder crop–livestock systems in SCC Vietnam. Loss of more soluble fractions of nutrients, especially N and K via leaching, was evident during storage and composting. Covering manure during composting appeared to have a positive effect on its quality when stored for up to 90 days. Heaps in the open air retained approximately 20% less manure mass than pits but the manure was of better quality in the pits. The differences in nutrient retention between storage systems were not significant after 90 days of storage (data not shown).

Table 7. Yield of peanut and economic efficiency in spring season 2011 (experiment 4)

Composting method	Name of household	Pod yield (t/ha)	Total revenue (VND ’000/ha)	Gross margin (VND ’000/ha)	Value:cost ratio (VCR)
Pit	Nguyen Van Tai	3.87 a	96,750	27,150	1.39
	Le Van Xin	4.00 a	100,000	30,400	1.44
	Tran Minh Tinh	4.07 a	101,750	32,150	1.46
	Le Dinh Tuong	3.97 a	99,250	29,650	1.42
	Mac Thong Chin	3.83 a	95,750	26,150	1.38
Heap	Nguyen Van Tai	3.70 a	92,500	25,900	1.39
	Le Van Xin	3.77 a	94,250	27,650	1.42
	Tran Minh Tinh	3.80 a	95,000	28,400	1.43
	Le Dinh Tuong	3.57 b	89,250	22,650	1.34
	Mac Thong Chin	3.60 ab	90,000	23,400	1.35

Note: means followed by the same letter(s) within the columns do not differ significantly at $p < 0.05$

Table 8. Characteristics of soils at the end of the peanut trial (experiment 3)

Composting method	pH_{KCl}	Organic C (%)	CEC ($cmol_c$/kg)	N (%)	P (%)	K (%)
Pit	5.32 a	1.21 a	1.26 a	0.045 a	0.015 a	0.033 a
Heap	5.29 a	1.14 b	1.22 a	0.041 a	0.014 a	0.031 a
$LSD_{0.05}$	*0.07*	*0.06*	*0.06*	*0.005*	*0.001*	*0.003*

Note: pH_{KCl} = pH measured in 1 M potassium chloride; C = carbon; CEC = cation exchange capacity; N = nitrogen; NH_4^+ = ammonium N; NO_3^- = nitrate N; P = phosphorus; K = potassium; means followed by the same letter(s) within the columns do not differ significantly at $p < 0.05$; average values calculated from five households in each application type

The study revealed that the four types of organic amendments with two application methods had significant positive effects on pod yield in peanut in 2011 compared with NPK fertiliser alone. Different types of organic amendments produced from different households applied to peanut crops in 2012 improved pod yields, signifying the importance of using organic materials in sandy soils. The increase of peanut yield per t of organic amendment prepared in a pit was higher for both row and surface application and follows: cattle manure in pit (1:0.5) > cattle manure in pit (farmer ratio) > cattle manure in heap (1:0.5) > cattle manure in heap (farmer ratio). The highest gross margin and value:cost ratio (VCR) were also found for the organic amendments with pit composting in the multiple farm experiment. Although the changes in soil properties were small, the results did reveal that different types of organic amendments improved soil properties compared with inorganic fertiliser application alone.

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Potential of variable rate fertiliser application for cashew production in Phu Cat district, Binh Dinh province, Vietnam—a case study

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Abstract

Sandy soils in the south-central coastal areas of Vietnam have a number of limitations including low nutrient status and retention. Inorganic fertilisers are required for these soils to produce commercial yields. However, these fertilisers are expensive as they account for more than 35% of total production costs. A preliminary study was initiated to investigate ways of increasing fertiliser use efficiency (FUE). The 'desktop' investigation included: (1) identifying potential mismatches between nutrient demand and supply using a nutrient replacement approach; and (2) identifying the potential for variable rate (VR) fertiliser applications. The nutrient budget approach indicated that phosphorus and sulfur were applied at rates four to nine times higher than that removed. Conversely, nitrogen and potassium were applied at levels half to three-quarters of that removed during harvest in the cashew nut and apple. Crop yields were interpolated into a VR prescription map with of areas producing high, medium and low yields. While the VR approach had the potential to increase FUE, the lack of yield data over time, lack of tissue testing to diagnose specific nutrient deficiencies and other competing soil limitations limited the validity of VR fertiliser applications in this study.

Introduction

Deep sandy soils derived from granite are common in south-central coastal (SCC) Vietnam. These soils are often found in upland areas and are widely used to produce fruit and nut trees (mango, cashew nut) and annual crops (cassava, peanut). The sands are naturally acidic, often with high exchangeable aluminium levels and low organic carbon (<1%). Nutrient retention, defined by cation exchange capacity, is very low at 3 cmol$^+$/100 g (Nguyen Cong Vinh 2007). This is compounded by highly seasonal rainfall patterns resulting in leaching of the nutrients. More than 80% (up to 1,300 mm) of annual rain falls during the September to December monsoon. Macro- and micronutrient deficiencies are common in the absence of fertiliser applications (Nguyen Cong Vinh 2007; Keen et al. 2013; Hoang Minh Tam et al. 2015). Consequently, inorganic fertilisers are used to supplement biochars or manures in cashew production (Hoang Vinh et al. 2015). Inorganic fertilisers are expensive, comprising up to 58% of annual input costs (Nguyen Duy Duc et al., unpublished data 2012).

Increasing the profitability of cashew production may be achieved through increased fertiliser use efficiency (FUE). Here FUE is defined as the profit from cashew production per cost of applied fertiliser. Increasing FUE involves optimising relationships between nutrient supply and plant demand. Methods used to increase FUE include nutrient budgeting, fertiliser placement, timing of applications, splitting applications and altering nutrient release rates. Despite the adoption of these practices, yields within

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paddocks can remain variable, often due to spatial differences in soil properties. An alternative method of improving FUE is through site-specific management using variable rate (VR) technology. Previous research has shown the potential of increasing FUE using VR technology in crops (Koch et al. 2004) and tree orchards (López-Granados et al. 2004), particularly where spatial differences in yields are large and consistent over time (Robertson et al. 2007). VR fertiliser application uses the inherent variation in production across a paddock to vary fertiliser rates with the aim to increase FUE. This involves collecting yield data spatially to produce a yield map, interpolating the map to generate production zones and assigning fertiliser rates to each zone based on nutrient demand.

The application of VR technology to improve FUE was investigated using data from a cashew orchard in SCC Vietnam. The aim of this preliminary 'desktop' investigation was to determine:

- the reasons causing the variation in cashew yield
- if there was sufficient variation in yields, whether site-specific management could overcome variation
- whether the current fertiliser recommendations could be improved using a nutrient replacement approach
- whether a combination of nutrient replacement and VR technology would potentially result in improvements in FUE and profitability
- what additional information would be required to test the effects of VR technology on cashew production and profitability on the central coast of Vietnam.

Methods and materials

The cashew (*Anacardium occidentale* L.) orchard used in this study was situated in the Phu Cat district of Binh Dinh province, Vietnam (Lat 13.9758°, Long 109.1248°). The soils are described as white dunal sands developed from granite (Hoang Thi Thai Hoa et al. 2010) and are classified as Arenosols (FAO 2006). Properties of the soils are given in Table 1. The soils are deep, uniform acidic loamy sands, low in phosphorus and with high levels of exchangeable aluminium within the subsoil.

The cashew orchard was part of an irrigation (normal farmer practice, mini pan scheduled) experiment with four subplot fertiliser treatments which were replicated three times. Each treatment consisted of four trees, giving 96 trees for the experiment. The fertiliser treatments were 200 or 400 kg/ha of a locally blended composite fertiliser (CF)—16% nitrogen (N), 16% phosphorus (P), 8% sulfur (S) and 13% potassium (K)—with or without urea (46% N) at 70 kg/ha. The cashew orchard had been established for 16 years with trees spaced approximately 8 m apart in a square grid, giving a tree density of 200 stems/hectare (ha). Cashew yields were measured for each of the 96 trees in the experiment in 1 year only. The yields presented are the sum of eight consecutive hand harvests conducted for each tree as the cashew apples ripened in 2011. Apart from general soil survey information (Table 1), there were no other soil test or leaf tissue data to determine nutrient levels.

A nutrient replacement approach was used to estimate fertiliser requirements. Nutrient replacement was calculated from the combined nutrient levels in cashew apples, nuts and shell (Table 2). Nutrient levels (%) were multiplied by yields (kg/ha) of cashew (Table 3) for each of four fertiliser treatments and the three production zones to give nutrient removal (Table 4) which, for the purposes of this exercise, equates to crop demand. Two fertiliser strategies were compared. The first strategy (treatments (T) 1–4) compared the four experimental fertiliser

Table 1. Soil chemical properties of the experimental cashew orchard in Phu Cat district, Binh Dinh province

Depth (cm)	pH_{KCl}	EC (dS/m)	Org. C (%)	Olsen P (mg/kg)	Exch. acid ($cmol^+/kg$)	Exch. Al^{3+} ($cmol^+/kg$)	CEC ($cmol^+/kg$)	Clay (%)	Silt (%)	Sand (%)
0–11	4.00	0.015	0.51	2.50	0.11	0.03	1.70	2	2	96
11–29	4.40	0.008	0.24	7.80	0.10	0.04	1.80	8	4	88
29–51	4.20	0.004	0.20	2.00	0.39	0.23	2.80	17	4	79
>51	4.10	0.020	0.21	2.40	0.37	0.19	2.70	16	4	80

Note: pH_{KCl} = pH measured in 1M potassium chloride; EC = electrical conductivity; Org. C = organic carbon; Olsen P = extractable phosphorus; Exch. acid = exchangeable acid; Exch. Al^{3+} = exchangeable aluminium cations; CEC = cation exchange capacity rates with those determined using the replacement approach. This was done to give insights into how well the fertiliser inputs matched nutrient demand. The second strategy (zones 1–3) involved nutrient (N, P, K and S) replacement within differing production zones using a mixture of composite fertiliser (CF), urea and potassium chloride (muriate of potash) fertilisers so that N, P, K and S nutrients supplied were equal to nutrient removal. Zones were created by mapping the spatial distribution of cashew yields from the fertiliser experiment and interpolating the data (inverse distance weighting) into three zones of different productivity using SMS-Advanced software (Ag Leader 2012). The zones were created as standard deviations of the mean. The spatial distribution of the treatments, replicates and zones are given (Figures 1). The variable rate map should be viewed as developing a concept as opposed to a definitive strategy for the site. This is because the map reflects the crop response to both the natural variation in soil properties and those induced by the fertiliser treatments.

The costs associated with each fertiliser strategy were calculated based on Australian prices of A$850/tonne (t) for CF, A$720/t for MOP (= potassium chloride) and A$605/t for urea. A gross margins analysis was performed for each of the four experimental fertiliser treatments (T1–T4) and for the three zones. Costs and returns for cashew production are based on actual farmer data obtained within the province of Binh Dinh (Summers et al. 2013).

Table 2. Total nutrient content of cashew apple, nut and shell

Nutrient	Average	Range
Nitrogen (%)	5.93	3.59–9.46
Phosphorus (%)	0.52	0.35–0.71
Potassium (%)	2.23	1.00–3.20
Sulfur (%)	0.28	na
Calcium (%)	0.45	0.30–0.61
Magnesium (%)	0.34	0.20–0.48
Copper (ppm)	41.5	na
Iron (ppm)	635	na
Zinc (ppm)	112	na
Manganese (ppm)	86	na

Note: na = not available; ppm = parts per million
Source: Grundon (2001)

Results

Cashew nut yields averaged 1,698 kg/ha (Table 3) (range 820–2,760 kg/ha) for the 96 trees in the experiment. T1 and T2 had significantly lower yields in 2011 than T3 and T4, in terms of both yield/tree adjusted for canopy area and yield/ha. The fertiliser effect on yield occurred across the irrigation treatments (Table 3). The responses to both urea and CF were significant ($p < 0.05$). The average increase due to the addition of 70 kg of urea was 80 kg cashew/ha. The average increase in cashew yields from 200 to 400 kg CF fertiliser was 448 kg/ha. The effect of irrigation treatment was not significant and there were no significant interactions between fertiliser and irrigation treatments.

Table 3. Crop yields for three replicates (R) of irrigation and fertiliser treatments in the experimental cashew orchard in Phu Cat district in 2011

Treatment	Irrigation schedule	Composite fertiliser (kg/ha)	Urea (kg/ha)	Yield (kg/ha)			Average yield (kg/ha)
				R1	R2	R3	
T1	Farmer	200	0	1,530	1,675	1,565	1,590
T2	Farmer	200	70	1,670	1,720	1,490	1,627
T3	Farmer	400	0	1,960	2,145	2,010	2,038
T4	Farmer	400	70	2,055	2,145	2,105	2,102
T1	Mini pan	200	0	1,345	1,220	1,305	1,290
T2	Mini pan	200	70	1,405	1,390	1,365	1,387
T3	Mini pan	400	0	1,710	1,600	1,820	1,710
T4	Mini pan	400	70	1,805	1,780	1,925	1,837

Note: least significant difference (LSD 5%) for average yield = 242 kg

The yield map (Figure 1) for the site shows individual tree yields within the interpolated cashew plantation. While the fertiliser treatments have affected the spatial distribution of yields, visually there is spatial variation in cashew yield that is independent of the experimental fertiliser treatments with differences in yield between the three production zones being approximately 500 kg/ha.

Nutrients supplied in the four fertiliser treatments resulted in less N and K and more P and S being supplied than removed in the cashew apple, nut and shell (Table 5). To illustrate, the ratios of nutrients supplied to nutrients removed are given in Table 6. The ratios for N, P, K and S were in the range 0.4–0.8, 4.1–6.6, 0.5–0.8 and 6.2–9.9, respectively, for the highest rate of fertiliser application (Table 6). The estimated cost of the four fertiliser treatments ranged from A$362/2.13 ha for T1 to A$814/2.13 ha for T4 (Table 5).

The nutrients removed during harvest and the fertiliser rates required to replace those nutrients for each production zone are presented in Tables 4 and 5, respectively. Blending MOP with the CF and urea improved the ratio between supplied and removed nutrients in each production zone (Table 6). The total cost of the fertiliser for the three zones was estimated to be A$462 over 2.13 ha which equates to A$217/ha.

Economics

The higher rates of CF fertiliser increased both yields and profitability in the experiment. The increase in profits from applying 400 kg/ha of CF compared to 200 kg of CF was approximately A$196/ha (Table 7). Applying 70 kg/ha of urea increased profits by $24/ha. The effect of urea was more effective at the highest NPK rates. On average, fertiliser made up almost 47% of input costs compared with labour (20%) and pesticides (23%). Input costs were approximately 40% of revenue.

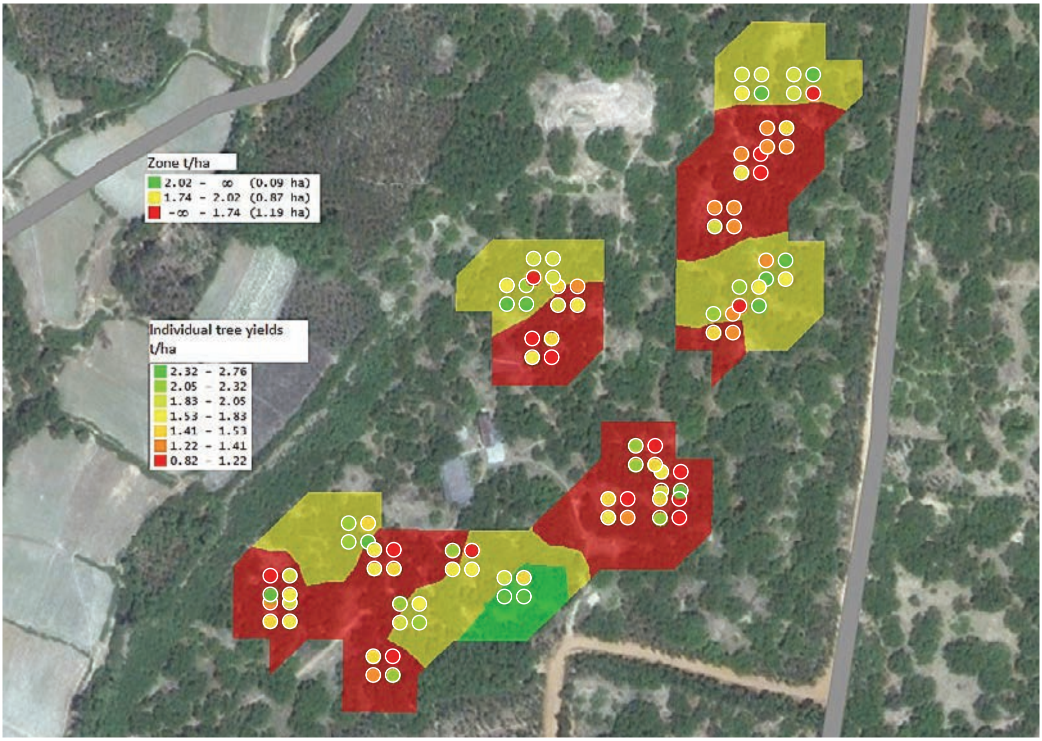

Figure 1. Cashew nut yields (t/ha: dots) and interpolated yield zones (t/ha: shaded areas) for the irrigation × fertiliser experiment, Phu Cat district, Binh Dinh province. Average cashew yields for the low, medium and high producing zones were 1.60, 1.83 and 2.1 t/ha, respectively.

Table 4. Nutrients removed (kg/ha) for the four fertiliser treatments and three production zones

Treatment/ zone	Yield (kg/ha)	Nitrogen	Phosphorus	Potassium	Sulfur	Calcium	Magnesium	Copper	Iron	Zinc	Manganese
Strategy 1											
T1	1,440	85.40	7.49	32.09	4.03	6.48	4.90	0.06	0.91	0.16	0.12
T2	1,507	89.36	7.83	33.57	4.22	6.78	5.12	0.06	0.96	0.17	0.13
T3	1,874	111.15	9.75	41.76	5.25	8.43	6.37	0.08	1.19	0.21	0.16
T4	1,969	116.78	10.24	43.88	5.51	8.86	6.70	0.08	1.25	0.22	0.17
Strategy 2											
Zone 1	1,600	94.9	8.3	35.7	4.5	7.2	5.4	0.066	1.016	0.179	0.138
Zone 2	1,830	108.5	9.5	40.8	5.1	8.2	6.2	0.076	1.162	0.205	0.157
Zone 3	2,106	124.9	11.0	46.9	5.9	9.5	7.2	0.087	1.337	0.236	0.181

Table 5. Nutrients supplied and costs associated with the four experimental fertiliser treatments (strategy 1) and nutrient replacement production zones (strategy 2)

Treatment/ zone	CF (kg)	MOP (kg)	Urea (kg)	Nitrogen (kg)	Phosphorus (kg)	Potassium (kg)	Sulfur (kg)	Total area (ha)	Cost/ha (A$)	Total cost/2.13 ha (A$)
Strategy 1										
T1	200	–	–	32.0	32.0	16.0	26.0	2.13	170	362
T2	200	–	70	64.2	32.0	16.0	26.0	2.13	212	452
T3	400	–	–	64.0	64.0	32.0	52.0	2.13	340	724
T4	400	–	70	96.2	64.0	32.0	52.0	2.13	382	814
Strategy 2										
Zone 1	50	60	185	93.1	8.0	34.0	6.5	1.19	197	462
Zone 2	65	70	220	111.6	10.4	40.2	8.5	0.87	238	
Zone 3	80	80	240	123.2	12.8	46.4	10.4	0.09	270	

Note: fertilisers used included a composite fertiliser (CF: N 16%, P 16%, K 8%, S 13%), potassium chloride (K 50%), and urea (N 46%). The costs of the CF, muriate of potash (MOP = potassium chloride) and urea were A$850/t, A$720/t and A$605/t, respectively.

Table 6. Calculated ratios of nutrients supplied (kg) to those removed during harvest for the two fertiliser strategies.

Treatment/ zone	Nutrient ratio			
	Nitrogen	Phosphorus	Potassium	Sulfur
Strategy 1				
T1	0.37	4.27	0.50	6.45
T2	0.72	4.08	0.48	6.16
T3	0.58	6.57	0.77	9.91
T4	0.82	6.25	0.73	9.43
Strategy 2				
Zone 1	0.98	0.96	0.95	1.45
Zone 2	1.03	1.09	0.99	1.65
Zone 3	0.99	1.17	0.99	1.76

Table 7. Profitability of cashew production for the four fertiliser treatments.

	Fertiliser treatment				Zoning trial			
	T1	T2	T3	T4	Zone 1	Zone 2	Zone 3	Total
Area (ha)					1.19	0.87	0.09	2.15
Yield (kg)	1,440	1,507	1,874	1,969	1,600	1,830	2,106	1,714
Price/kg (A$)	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
Gross revenue (A$)	*1,176*	*1,230*	*1,531*	*1,608*	*1,307*	*1,495*	*1,720*	*1,400*
Input costs (A$)								
Seedlings	48	48	48	48	48	48	48	48
Inorganic fertiliser	170	212	340	382	197	238	270	217
Pesticide	132	132	132	132	132	132	132	132
Labour	113	113	113	113	113	113	113	113
Gross costs (A$)	*463*	*505*	*633*	*675*	*490*	*531*	*563*	*510*
Profit (A$)	713	726	898	933	817	964	1157	890
Fertiliser use efficiency	4.2	3.4	2.6	2.4	4.1	4.0	4.3	4.1

Zoning achieved similar profits to T3 but approximately A$43/ha less than T4. However, the input fertiliser costs of the zoned treatments were markedly below than those for T3 and T4. The lower costs are mainly due to blending fertilisers so that they more accurately reflect crop demand. This is important in terms of mitigating risk. The FUE was almost 60% higher through better matching fertiliser requirements and zoning.

Discussion

The white granitic sandy soils in Phu Cat district are limited in terms of macro- and micronutrient fertility, pH and water holding capacity. Each one of these has the potential to reduce yields and result in spatial variation in cashew yields. At this site, soil pH was low throughout the profile with exchangeable aluminium values below 30 cm depth exceeding 20 mg/kg (Table 1). Responses to inorganic fertilisers were found at the site; however, little is known about the micronutrient status of the soils and potential deficiencies. No soil or tissue analyses had been conducted within the orchard. Above all, there is little known about how close to potential the cashew yields are. This is important in determining the 'yield gap' and deciding the need for intervention. Nguyen Duy Duc et al. (unpublished data 2012) used yields of 2.4 t/ha in their economic analysis of cashew production in Binh Dinh province. This suggests that the yields achieved at this site are 30% lower than those expected in an average year. This suggests that there may be a need for intervention to increase yields; however, altering macronutrients may not be the total solution.

The results from this desktop study showed spatial variation in cashew nut yields across the orchard. The high-, medium- and low-yielding zones identified in this study had yields that varied by 500 kg cashew/ha valued at A$400/ha. In Australian agriculture, zoning is recommended where yields consistently vary by more than 1 t/ha of wheat valued at A$300/ha (Robertson et al. 2008). Hence, the variation in yields found in this cashew orchard is sufficient to justify VR fertiliser applications should the yield variation be consistent between years. This qualifier is important as there is currently insufficient information to test the consistency of yields between years in each zone or the variation in value of production between each zone.

Information on cashew nut yield responses to individual nutrient rates for the Phu Cat site was not available. Consequently, the approach used in this study to identify nutrient and fertiliser requirements was by nutrient replacement of macronutrients only. The weakness of this approach is that it does not take into account any other soil property that may impact more on crop yields than those tested in this study. Also, we have assumed that the nutrients applied were completely used by the cashew trees with no losses associated with biological fixation, mineral fixation and leaching. Given the nature of the soils and climate there is a high probability that nutrient losses would have occurred.

The experimental fertiliser rates were substantially lower in N and K and higher in P and S than required to replace nutrients removed in the cashew crop. Potential inefficiencies in nutrient supply were therefore found in this study that could be overcome by adding MOP and adjusting the amounts of urea and CF to better match plant requirements. Conversely, it is interesting to note that in the experiment there was only a minor increase in yield and profitability where urea was added despite the calculated replacement levels of N being 37% (T1) and 58% (T3) of that required (Table 5).

This study found that VR applications combined with MOP and changing the balance of fertiliser products used had the potential to better match the estimated nutrient requirements of the cashew trees and resulted in cost savings compared with T3 and T4. Currently, cashew farmers in the province of Binh Dinh spend on average $285–313/ha on inorganic fertilisers (Nguyen Duy Duc et al. unpublished data 2012; Summers et al. 2013). The cost of fertiliser given in this study using VR and a better balance of fertilisers was $217/ha. Assuming that the changed fertiliser strategy does not compromise yield and the additional cost of collecting the data is minimal, then the VR and blending approach outlined here would potentially be more profitable than that currently achieved by local cashew farmers.

The practicality of applying VR technology in cashew orchards is perhaps the main limitation to adoption. In this study, yields from one season were used to create a yield map. Yield maps from multiple seasons are required to have confidence that the variation in yields is constant over time. It is also important to ensure that the yields in the poorer performing zones cannot be readily improved through other means.

Variable rate fertiliser applications are best used where there are sufficient spatial data to convert into production zones, the zones have large differences in production levels that are consistent over time, and the reasons for the production differences between the zones are known and cannot be profitably rectified. In this case study, the causes of the production differences and the consistency of the production zones are unknown. Hence, the gains in FUE from VR fertiliser application may not be as great as those associated with knowing the true causes of the yield gap and yield variation. Furthermore, improved fertiliser management through nutrient budgeting, fertiliser placement, timing of applications, splitting applications and using slow-release fertilisers may improve productivity and FUE more so than VR technology. While the results presented here are encouraging, much more work needs to be done before the VR approach can be recommended.

Conclusions

Sandy textured soils in SCC Vietnam exhibit a number of limitations of which some are related to macronutrient deficiencies. At the experimental site in the Phu Cat district of Binh Dinh province, significant cashew yield responses to NPK fertilisers were found. Nutrient input and removal budgets for this site indicated that applied N and K fertiliser rates were lower than amounts removed, whereas excess P and S were applied.

There was sufficient variation (>500 kg) in cashew yields between zones to justify site-specific management using VR fertiliser applications. Improvements in FUE were also shown to be theoretically possible through improved matching of fertiliser supply with demand and through the VR approach. However, given insufficient yield data over time and the uncertainty surrounding the causes of the yield variation at this site, the promotion of a VR approach without further information would be premature.

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Mini–evaporation pan irrigation scheduling: a tool for improving on-farm water use efficiency for peanut and tree crops in south-central coastal Vietnam

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Abstract

Groundwater-dependent agriculture is an important component of south-central coastal (SCC) Vietnam's economy and maximising on-farm water use efficiency (WUE) is a vital factor in sustaining the groundwater resource. During this study, mini–evaporation pan irrigation scheduling was introduced to cashew, peanut and mango crops in SCC Vietnam. Mini-pan scheduling was compared with the farmers' commonly used irrigation practice for each crop. Irrigation treatments were also combined with several fertiliser treatments in cashew and mango experiments. Mini-pan use improved WUE in each crop type with up to 1.4 kL/ha water saved. Mini-pan irrigation scheduling also improved canopy productivity of cashew by 15–30% and peanut yield by 22%. Yield increases were not observed for mango but the number of irrigation events and, therefore, labour inputs were halved. Labour inputs for peanut were also reduced but increased labour inputs were required for cashew. Outcomes from this study indicate that the mini evaporation pan has potential for use as a tool to assist farmers in SCC Vietnam improve on-farm WUE. The results also indicate that there is further scope to optimise WUE and opportunities to improve fertiliser and micronutrient management in tree crops in the SCC region.

Introduction

Fresh water is a critical and finite resource for agricultural production and its judicious use is central to the sustainability of irrigated agriculture. The south-central coastal (SCC) region of Vietnam has limited freshwater resources, especially in areas where irrigated agriculture is groundwater dependent. Several provinces within the region are affected by low annual rainfall (e.g. 600 mm in coastal areas of Ninh Thuan province). The whole region is affected by water shortages during the 8–9-month dry season and many low-lying areas are affected by flooding due to intense rainfall during the 2–3-month wet season. The region is also vulnerable to extended droughts and severe tropical storms, the frequency of which is influenced by the El Niño Southern Oscillation (ENSO). Groundwater-dependent agriculture in the SCC region is mostly associated with large areas of infertile sandy soils (around 300,000 ha; Bell et al. 2105). Cashew and peanut are important cash crops in these areas. Mango covers a smaller area but has been identified as a crop with strong market

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potential (Luong Ngoc Trung Lap and Nguyen Minh Chau 2015).

Irrigation in SCC Vietnam typically involves laborious methods such as watering cans (in smaller plots, e.g. intensive vegetables), surface flood irrigation and large diameter hoses, and a 'rule-of-thumb' approach is applied to irrigation management. As a consequence, water use efficiency (WUE) tends to be variable, with over-irrigation common. Over-application of irrigation water leads to inefficient use of water resources and degraded water quality due to leaching of nutrients. Poor fertiliser use efficiency due to nutrient leaching also represents a financial loss to farmers.

To improve the current situation, farmers in SCC Vietnam need simple, inexpensive methods to assist with maximising WUE. 'Irrigation scheduling' encompasses a number of approaches to guide irrigation frequency and volume to meet crop water requirements. Evapotranspiration of a crop (ET_c) is defined as the sum of water vapour removed to the atmosphere through plant transpiration and evaporation from the soil surface. Daily ET_c is variable depending on atmospheric demand, which is determined by a number of climatic factors; especially, solar radiation, air temperature, relative humidity and wind speed (Allen et al. 1998). Daily ET_c is determined by using climate monitoring instruments to estimate the reference crop evapotranspiration (ET_o calculated using the Food and Agriculture Organization of the United Nations (FAO) Penman-Monteith equation; see Allen et al. 1998) and then multiplying this by a predetermined crop coefficient (K_c), specific for the growth stage of the crop. Another method involves the use of Class A evaporation pans built and installed according to explicit specifications (Allen et al. 1998). Evaporation of water from the Class A pan (E_{pan}) is correlated with ET_o but a pan coefficient (K_p) is applied ($E_{pan} \times K_p$) to obtain an estimate of ET_o.

Both approaches are effective methods for scheduling irrigation but operators require a moderate to high level of technical capacity to utilise them. 'Mini evaporation pans' (Rashad and Omran 2012) are a simple and inexpensive technology that may be more suitable for farmers in SCC Vietnam. Mini evaporation pans feature a rod with an indicator mark. When evaporation causes the water level in the pan to fall to the indicator mark, the farmer initiates an irrigation event with a predetermined volume of water that refills the soil profile.

This chapter reports on the outcomes from field experiments undertaken between 2010 and 2012 with the aim of evaluating the potential benefit in SCC Vietnam of using mini evaporation pans to improve WUE and productivity in cashew, mango and peanut crops.

Materials and methods

Mini evaporation pans

Mini evaporation pans were constructed from 200 L, 600 mm diameter, steel or plastic drums cut to 300 mm height (Figure 1). An indicator rod was positioned in the centre of the pan. The indicator mark placed on the rod was determined using the equation (1):

$$E_{pan} = RAW/(K_p \times K_c) \quad (1)$$

where RAW = readily available water content of soil within the effective root zone (mm); K_p = pan coefficient; and K_c = crop coefficient. The RAW value was multiplied by 0.6 so that an irrigation event would be initiated when soil moisture fell to 60% of its readily available water content.

Before initiating mini-pan irrigation scheduling, plots were irrigated to fill the soil moisture profile. The mini pan was also filled. The next irrigation event was implemented when water in the pan fell to the indicator mark. The pan was then refilled and the irrigation cycle repeated. Variations to the placement of the indicator mark and operation of the mini pan are described for each crop below.

Cashew irrigation and fertiliser rate experiments

A field experiment was established in Phu Cat district, Binh Dinh province, with 18-year-old productive cashew trees established at a planting density of 120 trees/ha. The trial was laid out using a split-plot design with a total of eight treatments replicated three times. Each plot consisted of 16 trees. Data were collected from four trees within each plot selected for their uniformity, with the remaining trees used as buffers.

Irrigation treatments involved mini–evaporation pan scheduling compared with the common farmer practice. The farmer practice treatment involved irrigation applied at the farmer's discretion, based on their perception of whether there had been adequate rainfall and whether the soil was sufficiently dry to justify an irrigation event. The mini pan was constructed as described above. The indicator mark was determined using a RAW value (see above) of 50 mm with an effective rooting depth of 0.6 m. The crop coefficient (K_c) value applied for cashew was 0.85. Irrigation treatments were applied from flowering to nutset (January to April) 2010 and the experiment was repeated in 2011. Four fertiliser treatments were nested within each irrigation treatment. Fertiliser treatments are shown in Table 1. Nitrogen (N), phosphorus oxide (P_2O_5); potassium oxide (K_2O) and sulfur (S) were applied at a pre-mixed ratio of 16:16:8:13.

Gross cashew yield (tonnes/hectare; t/ha) values were scaled up from a kg nut in shell (NIS)/tree basis. Due to variation in tree canopy size, yield assessments were based on normalised values defined as g NIS/m^2 canopy surface area (CSA).

Table 1. Fertiliser treatments applied to cashew trees in 2010 and 2011

Treatment	2010	2011
F1	1 kg NPKS	1.5 kg NPKS
F2	1 kg NPKS + 0.34 kg urea	1.5 kg NPKS + 0.34 kg urea
F3	2 kg NPKS	3 kg NPKS
F4	2 kg NPKS + 0.34 kg urea	3 kg NPKS + 0.34 kg urea

Note: NPKS = fertiliser comprising nitrogen (N), phosphorus (P), potassium (K) and sulfur (S) in the ratio 16N:16P:8K:13S

Peanut irrigation and fertiliser rate experiments

Three field experiments were established in Phu Cat district, Binh Dinh province, in 2010, 2011 and 2012. The 2010 winter–spring cropping season (December 2010 to April 2011) experiment involved seven treatments. Five crop stages were defined as: (1) branch formation; (2) flower bud initiation; (3) anthesis; (4) pod formation; and (5) seed formation. Irrigation treatments were applied as follows: T1 = farmer practice (control); T2 = irrigation applied at all crop stages (once/stage); T3 = no irrigation during pod formation; T4 = no irrigation during branch and pod formation; T5 = no irrigation at flower initiation; T6 = no irrigation at flower initiation and pod formation; T7 = mini-pan scheduling. The 2011 winter–spring (December 2011 to April 2012) and 2012 summer–autumn (June to September 2012) cropping seasons involved a simple comparison between farmer practice and mini-pan scheduling. The ‘farmer practice’ (T1) involved irrigation applied at the farmer’s discretion. Irrigation water was applied to T2, T3, T4, T5 and T6 once for each crop stage relevant to that treatment. Mini–evaporation pan irrigation scheduling (T7) was applied throughout the crop cycle. The indicator mark for the mini pan was determined using a RAW value (see above) of 27 mm for an effective rooting depth of 0.3 m. Crop coefficient (K_c) values used for the first experiment were as follows: seedling stage = 0.45; vegetative growth to end of

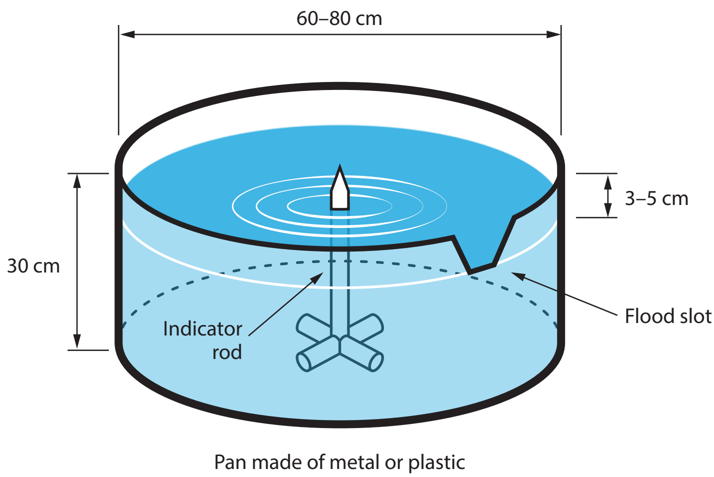

Figure 1. Mini–evaporation pan design

anthesis = 0.75; seed formation = 1.0; preharvest = 0.6. For the 2012 summer–autumn experiment, each K_c value was increased by 0.05 to reduce the risk of accruing a water deficit during the crop period. The position of the indicator marks placed on the rod were as presented in Table 2. To simplify mini-pan irrigation management, the farmer was instructed to apply 10 L/m^2 for each irrigation event.

For each season, experiments were established in a randomised complete block layout with 15 m^2 plots. Each treatment was replicated four times. All plots were treated with 10 t/ha of cow manure + 30 kg N/ha^{-1} + 90 kg phosphorus oxide (P_2O_5)/ha + 60 kg potassium oxide (K_2O)/ha + 500 kg/ha calcium carbonate ($CaCO_3$).

Mango irrigation experiment

A single field experiment was established with mango in Phu Cat district, Binh Dinh province, in 2011. The trial used a split-plot design with six treatments replicated three times. Each plot consisted of four trees.

Irrigation treatments compared the farmer's irrigation practice with mini–evaporation pan irrigation scheduling. The farmer practice treatment involved irrigation applied at the farmer's discretion from flowering to harvest (December 2010 to May 2011). The mini-pan indicator mark was determined using a RAW value (see above) of 48 mm for an effective rooting depth of 0.6 m. The crop coefficient (K_c) value applied for mango was 1.6 with irrigation events initiated when soil moisture fell to 60% RAW. Irrigation treatments were applied from flowering to harvest (December to May).

Each main irrigation treatment was nested with three fertiliser treatments. Fertiliser treatments were as follows (rates are per tree): (1) 5 kg NPK fertiliser + 30 kg cow manure; (2) 5 kg NPK + 0.34 kg urea + 30 kg cow manure; (3) 5 kg NPK + 0.34 kg urea + 0.4 kg potassium chloride (KCl) + 30 kg cow manure + foliar applied micronutrients (Hoang Vinh et al. 2015). Cow manure was applied at the start of the rainy season (September), a common farming practice. Application of inorganic fertiliser was split, with half applied pre–wet season and half applied post–wet season.

Soil moisture measurements

A micro-gopher© capacitance probe (Odyssey, New Zealand) was used to monitor soil water with measurements recorded at 10 cm depth intervals. Soil moisture was measured to 0.6 m depth and at 3–5-day intervals for cashew and mango and to 0.3 m depth at 2-day intervals for peanut.

Results and discussions

Cashew experiments

The 2010 cashew field experiment was affected by above-average rainfall frequency and volume. Consequently, soil moisture remained adequate until 5 March (Figure 2) when the first mini-pan treatment irrigation event was initiated 6 weeks after the onset of anthesis. An irrigation event was not initiated in the farmer practice treatment until 12 April as the farmer considered rainfall and soil moisture to be adequate until that time.

The frequency and volume of rain during the 2011 season was closer to average than the 2010 season. Consequently, both farmer practice and mini-pan irrigation events were initiated at the start of anthesis and continued through to fruit fill. Between flowering and harvest, there were three farmer-initiated irrigation events spaced at 30- to 45-day intervals and five mini-pan irrigation events spaced at 16- to 24-day intervals. Under the farmer's regime, soil moisture fell below the refill point (42 mm) and remained at

Table 2. Indicator mark positions for mini–evaporation pan irrigation scheduling for peanut in 2010, 2011 and 2012 field experiments

Experiment	Indicator mark position (mm below maximum water level)			
	Seedling stage (17–18 days)	Vegetative growth– anthesis (21–23 days)	Seed formation (37–41 days)	Preharvest (21–23 days)
2010 + 2011 winter–spring	29	18	14	22
2012 summer–autumn	32	19	14	24

suboptimal levels for 14 or more days on three occasions, compared with no more than 2 days on two occasions with the mini-pan procedure (Figure 2).

During the 2010 experiment, cashew yield ranged between 9.5 and 10.4 kg nut in shell (NIS)/tree. Based on a planting density of 120 trees/ha, these values translate to 1.14–1.25 t/ha, but no significant differences were detected. However, significant treatment differences ($p < 0.01$) were observed when canopy productivity values were compared. Canopy productivity in the mini–evaporation pan plots averaged 99 g NIS/m^2 canopy surface area (CSA) compared with 86 g NIS/m^2 CSA for the farmer practice plots (Figure 3). During the 2011 crop, the increased availability of soil moisture in the mini-pan plots appears to have significantly ($p < 0.01$) increased canopy productivity from an average 66.8 g NIS/m^2 CSA in the farmer-practice plots to 89.1 g NIS/m^2 CSA under the mini-pan regime (Figure 3). These differences ($p < 0.01$) were also detected based on yield results, with 7.8 kg NIS/tree (0.94 t/ha) and 9.2 kg NIS/tree (1.1 t/ha) for farmer practice and mini-pan treatments, respectively. Total irrigation volumes were 528 m^3/ha and 616 m^3/ha to deliver WUE of 30.7 and 26.0 kg NIS/m^3 water applied for the mini-pan and farmer practice treatments, respectively.

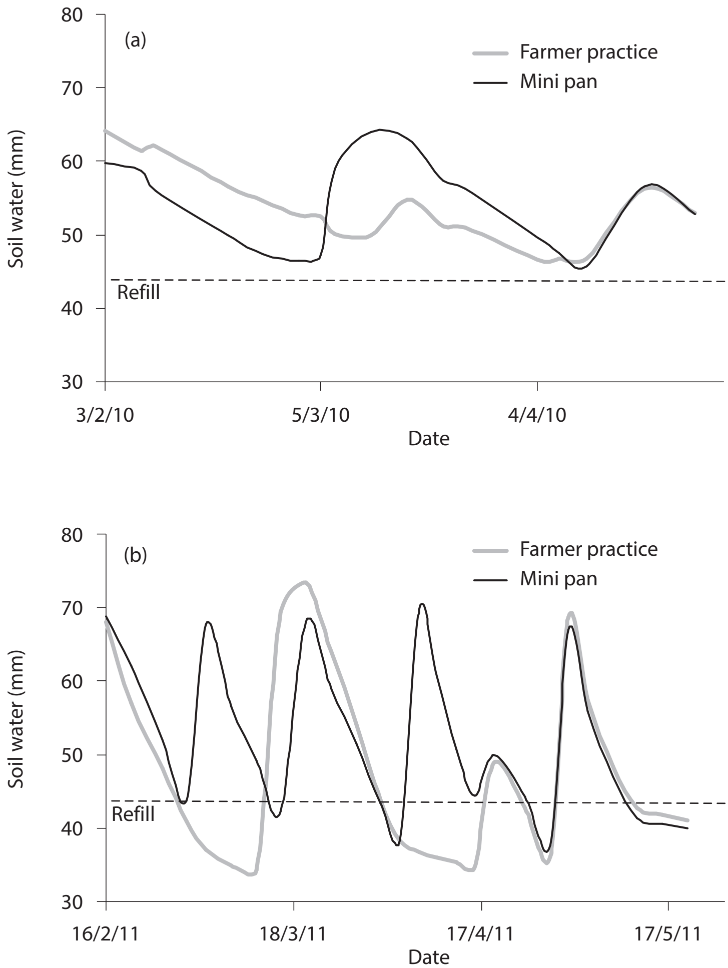

Figure 2. Volumetric soil water content within the effective root zone (to 0.6 m depth) under cashews in (a) 2010 and (b) 2011 using farmer practice or mini-pan irrigation regimes

The influence of mini-pan irrigation scheduling on canopy productivity was more notable than that of the fertiliser treatments, with no differences between fertiliser treatments in 2010. This result indicated that fertiliser inputs could be reduced to 1 kg NPK/tree without a yield penalty. During the 2011 season, there was an apparent trend toward increased canopy productivity from applying 3 kg NPKS/tree compared with 1.5 kg NPKS/tree but the differences were not significant. However, it should be noted that the trend indicated a potential 27% increase in canopy productivity at the higher fertiliser rate. There were only three replications for this experiment and the absence of a statistical difference may be an artefact of high variability and low repetition. Thus, further examination of optimal fertiliser application rates for cashews grown in SCC Vietnam is justified (Hoang Vinh et al. 2015).

Overall, the results from the two seasons indicate that, compared with the common farmer irrigation practice, mini–evaporation pan irrigation scheduling has the potential to deliver a 15–33% yield dividend for cashew. However, under mini-pan scheduling, irrigation was more frequent and so farmers need to consider whether the gross benefit is commensurate with the increased labour and energy input.

Peanut experiments

During the 2010 field experiment, omitting irrigation at the branch formation and flowering stages

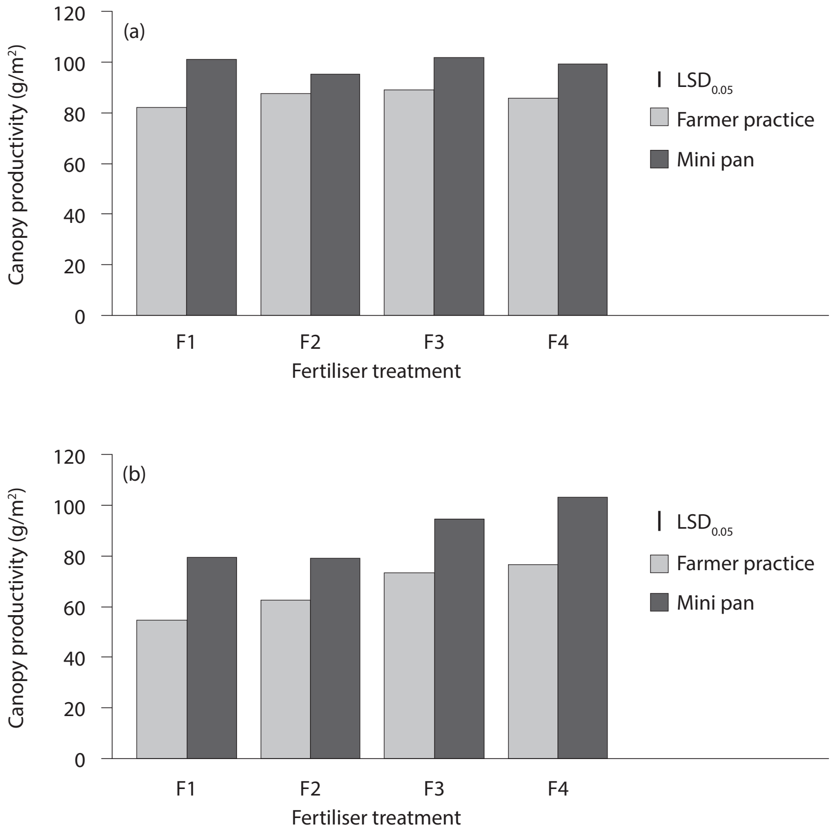

Figure 3. Canopy productivity (g nut in shell/m² canopy surface area) of cashew trees in (a) 2010 and (b) 2011. Note: farmer practice and mini-pan irrigation treatments were nested with four fertiliser treatments; refer to Table 1 for details of fertiliser treatments; columns indicate mean (n = 3) values; Fisher's least significant difference (LSD) significant at $p < 0.05$.

had little effect on peanut biomass accumulation (Figure 4). However, withholding irrigation at branch formation, early anthesis and pod formation resulted in a significant ($p < 0.05$) reduction in biomass at maturity compared with uninterrupted irrigation. Peanut biomass was around 5 t/ha when irrigated according to farmer practice, but around 2 t/ha or less when irrigation was withheld at branch formation, early anthesis and pod formation stages. Peanut crop biomass for the farmers' irrigation regime was similar to that of the mini–evaporation pan treatment for both the 2011 and 2012 seasons (Figure 5).

Withholding irrigation at branch formation, early anthesis and pod formation during the 2010 experiment resulted in significantly ($p < 0.05$) lower peanut yields, ranging between 0.17 and 0.53 t/ha, compared with 1.0 t/ha for the farmer practice treatment and 1.5 t/ha for the mini-pan irrigation treatment (Figure 6). Peanut yields for the farmer practice treatment in 2011 and 2012 averaged 3.3 and 1.1 t/ha, respectively. Yields for the mini–evaporation pan treatment were significantly higher ($p < 0.05$), with 3.7 t/ha in 2011 and 1.4 t/ha in 2012 (Figure 7). Water use measured for the 2012 crop indicated a total of

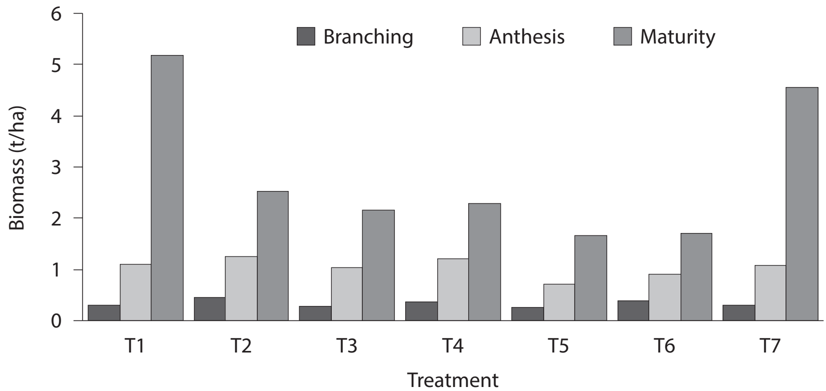

Figure 4. Peanut biomass measured during the 2010 irrigation experiment. Note: T1 = farmer practice (control, based on farmers perception all throughout the crop stages and could be irrigated many times at a particular crop stage); T2 = irrigation applied at all crop stages (once/stage); T3 = no irrigation during pod formation; T4 = no irrigation during branch and pod formation; T5 = no irrigation at flower bud initiation; T6 = no irrigation at flower bud initiation and pod formation; T7 = mini-pan scheduling; columns indicate mean values ($n = 4$)

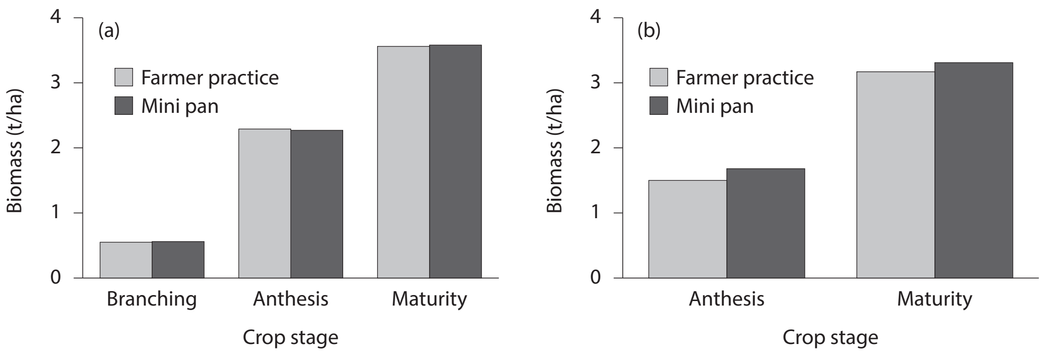

Figure 5. Peanut biomass measured for the (a) 2011 and (b) 2012 irrigation experiments. Note: columns indicate mean values ($n = 4$)

3,937 m3/ha water applied under the farmer practice regime and 2,500 m3/ha water applied using mini-pan irrigation scheduling (Table 3). WUE was also improved under the mini-pan treatment, with 0.28 kg peanut pod produced per m3 water applied under the farmer regime and 0.56 kg peanut pod produced per m3 water under the mini-pan treatment.

An alternative explanation for lower yields in the farmer practice plots could be that irrigation under the farmer regime was excess to crop requirements. Yield reductions in response to over-irrigation have been observed elsewhere (Metochis 1993). In the present study, nearly 4 ML/ha water was applied to the farmer practice plots over the 12-week 2012 summer–autumn cropping period. This is equivalent to 400 mm, or an average of 4.8 mm/day compared with an average of 3.0 mm/day under the mini-pan regime. Average daily Class A pan evaporation for Phu Cat district (source: Binh Dinh Weather Forecast Centre) is 2.5 mm for winter–spring and 4.7 mm for summer–autumn. This indicates that the farmers' irrigation inputs were probably appropriate for the seed formation stage (crop coefficient (K_c) = 1.0) during the summer months but were excessive for other crop stages (where K_c values are <1.0). In addition to possible stress due to overwatering, excess

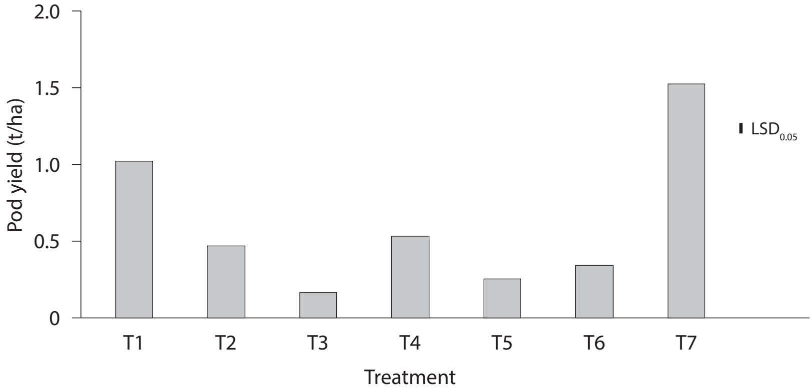

Figure 6. Peanut pod yield measured during the 2010 irrigation experiment. Note: T1 = farmer practice (control); T2 = irrigated at all crop stages (once/stage); T3 = no irrigation during pod formation; T4 = no irrigation during branch and pod formation; T5 = no irrigation at flower bud initiation; T6 = no irrigation at flower bud initiation and pod formation; T7 = mini-pan scheduling; columns indicate mean values (n = 4); Fisher's least significant difference (LSD) significant at $p < 0.05$

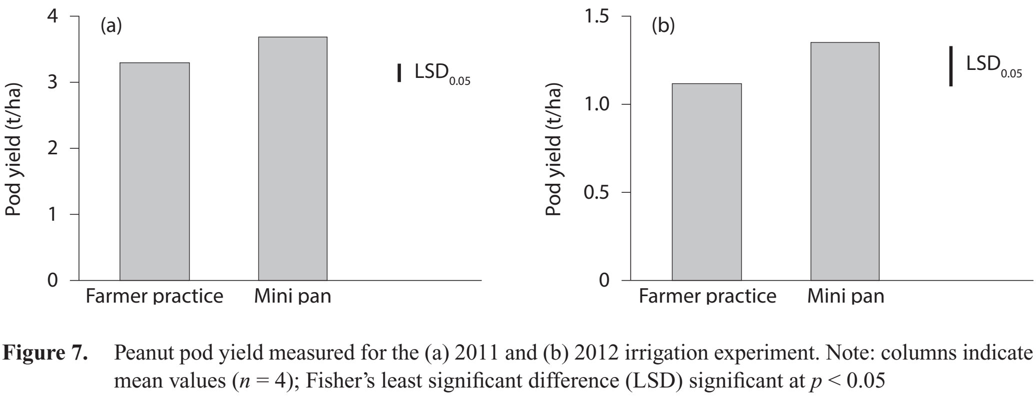

Figure 7. Peanut pod yield measured for the (a) 2011 and (b) 2012 irrigation experiment. Note: columns indicate mean values (n = 4); Fisher's least significant difference (LSD) significant at $p < 0.05$

irrigation early during the crop period is also likely to have contributed to leaching of N and other nutrients such as K, S and boron below the root zone, which may have reduced nutrient availability at mid and later stages of crop development.

Mango experiments

Between flowering and harvest, eight irrigation events, totalling 616 m^3/ha, were initiated under the farmer practice treatment, whereas only four irrigation events, totally 528 m^3/ha, were required for mango with the mini–evaporation pan scheduling (Figure 8; Table 4). Soil water storage in the farmer practice plots was mostly maintained above 60 mm within the effective root zone (to 0.6 m depth) throughout the irrigation period. In the mini-pan treatment, soil water was drawn down to the estimated refill threshold of 48 mm on three occasions (Figure 8). Despite clear differences in soil water dynamics, mango yields were little affected by irrigation treatments (Table 4), averaging 73.6 and 72.9 kg/tree for farmer practice and mini-pan treatments, respectively. This result indicates that water inputs under the mini-pan regime were adequate to meet crop requirements. With similar yields across treatments, WUE improved from 26.0 kg fruit/m^3 water under the farmer regime to 30.7 kg fruit/m^3 water under the mini-pan regime. This result demonstrates the potential for the mini

Table 3. Volume of water applied under farmer practice and mini–evaporation pan irrigation treatments during the 2012 summer–autumn peanut experiment

Crop stage	Mini-pan scheduling		Farmer practice		Water saved[a] (m^3)
	Water applied (m^3/ha)	Number of irrigation events	Water applied (m^3/ha)	Number of irrigation events	
Germination to branch formation	400	4	573	4	173
Branch formation to end anthesis	200	2	580	4	380
End anthesis to seed formation	1,600	16	2,269	18	669
Seed formation to maturity	300	3	515	4	215
Total	2,500	25	3,937	30	1,437

[a] Water savings with mini-pan irrigation scheduling compared with the farmer practice treatment

Table 4. Mango yield recorded during the 2011 irrigation field experiment

Irrigation treatment	Fertiliser treatment	Yield (kg/tree)	Yield (g/m^2)	No. fruit/tree	Grade I (%)	Grade II (%)	Grade III (%)	Volume of water used (m^3)[a]
Farmer practice	NPK + manure	67.5	1,324	153	45	30	25	
	NPK + urea + manure	72.6	1,447	158	38	32	30	
	NPK + urea + manure + foliar micronutrients	80.8	1,618	172	41	31	28	616
Mini-pan scheduling	NPK + manure	70.4	1,247	150	44	31	25	
	NPK + urea + manure	71.4	1,328	162	36	34	30	
	NPK + urea + manure + KCl + foliar micronutrients	76.8	1,563	171	39	33	28	528
	CV (%)	*3.1*	*9.0*					
	$LSD_{0.05}$	*4.01*	*234*					

[a] Water use is across all fertiliser treatments within the irrigation regime
Note: grades refer to fruit quality, with grade 1 being the best; NPK = nitrogen, phosphorus and potassium fertiliser; KCl = potassium chloride; CV = coefficient of variance; $LSD_{0.05}$ = least significant differerence at $p < 0.05$

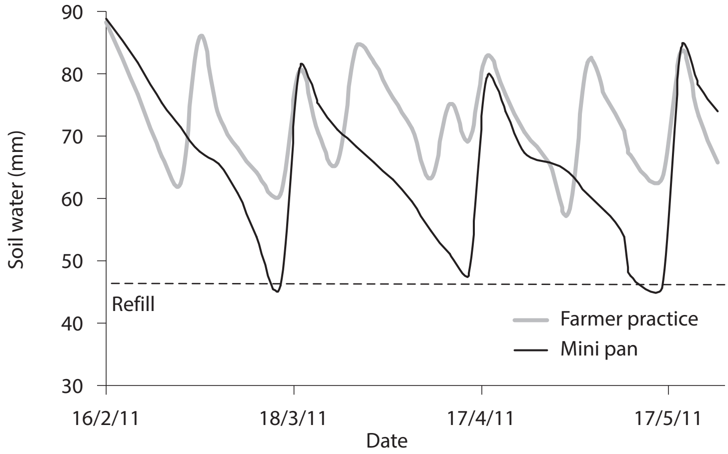

Figure 8. Volumetric soil moisture recorded under mango trees irrigated from flowering to harvest in 2011

evaporation pan to be used as a tool to improve on-farm WUE in SCC Vietnam, reduce labour inputs and reduce nutrient leaching.

Adding 0.34 kg urea/tree to the current farmer NPK + manure practice had little effect on mango productivity but appeared to cause lower fruit quality (Table 4). A 23% increase in fruit yield was achieved by combining NPK + manure with 0.4 kg/tree KCl + foliar applied micronutrients (Table 4; Hoang Vinh et al. 2015). The sands of SCC Vietnam are known to have multiple nutrient deficiencies (Hoang Thi Thai Hoa et al. 2010) and so it is likely that mango productivity under mini-pan irrigation can be further enhanced with the supply of additional nutrients. Further work is justified to confirm this and to determine which of the micronutrients is most critical to mango productivity in SCC Vietnam. There is also scope to undertake further work to optimise nutrient management in combination with optimised mini-pan irrigation scheduling.

Conclusions

The outcomes from this series of field experiments demonstrate that, if calibrated correctly, mini–evaporation pan irrigation scheduling has the potential to be utilised by farmers in SCC Vietnam to improve WUE in cashew, peanut and mango crops and reduce total water consumption in peanut and mango crops. Improved management of irrigation scheduling with the mini pan was also found to improve crop productivity in cashew and peanut. For cashew, mini-pan irrigation scheduling increased the frequency of irrigation which increased labour inputs and total water consumption. The additional effort and potential economic gains are factors that cashew farmers need to consider before adopting mini-pan irrigation scheduling. For peanut growers, the benefits from the mini pan are clearer. Labour inputs, pumping costs and fertiliser losses are likely to be reduced and yields are likely to increase. The mini pan also offers mango growers reduced labour inputs as well as a potential reduction in fertilisers lost due to leaching. We believe that this simple and affordable technology is suitable to promote for adoption by cashew, peanut and mango farmers in SCC Vietnam. Testing of this technology by farmers is now recommended. There is also scope for adapting the mini evaporation pan for use with other crops, such as vegetables. The results from this study also indicate that there remains a need to optimise irrigation scheduling with integrated nutrient management for crops grown in the sands of SCC Vietnam.

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Section 3: Value-chain analysis of crops, with suggestions to improve farmers' incomes

Value-chain analyses from the production to consumption stages of crops comprising peanut, cassava, cashew, mango, sesame and garlic and for livestock, specifically beef cattle, are discussed in this section. Limitations to small landholders' income through processes of the value chain and ways of improving the chain are described.

Opportunities for expansion of peanut cultivation in south-central coastal Vietnam

Phan Thi Giac Tam[1] and Allan McKay[2]

Abstract

Peanuts are a profitable and environmentally sustainable crop for south-central coastal (SCC) Vietnam. Growing peanuts in the sandy soils of the SCC region not only helps increase income for farmers, it also contributes to the improvement of soil fertility and the prevention of land degradation and desertification. There are local and export market opportunities for SCC peanuts; however, several identified impediments to profitable industry expansion need to be overcome, including declining availability of irrigation water, market facilities and crop drying. Proposed strategies and actions for overcoming identified impediments are discussed.

Introduction

Peanuts (also known as groundnuts), the edible seeds of the legume *Arachis hypogaea*, are an important food crop that is high in protein, oil and fibre. In Vietnam, the main uses of peanuts are as shelled nuts that are consumed roasted or boiled as an appetiser or snack, in confectionery products and, to a much lesser extent, as a source of edible oil.

World production and trade of peanut

World peanut consumption is increasing. Global production of peanut increased from 34.4 million tonnes (Mt) to 41.2 Mt in 2012 (FAO 2013). China is the leading peanut producer, accounting for 41% of the total world production in 2012, followed by India with 14% and the United States of America (USA) with 8% (Table 1). FAO (2013) reported that Vietnam produced 470,000 t of peanuts in 2012. Average yields for selected countries are listed in Table 1.

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Table 1. Production and yield of peanut in 2012 and exports in 2010 for selected countries and worldwide

	Production (Mt)	Yield (t/ha)	Exports ('000 t)
World	41.2	1.7	1,220
China	16.8	3.5	127
India	5.7	1.2	372
USA	3.1	4.7	154
Argentina	0.68	2.2	218
Vietnam	0.47	2.1	11

Source: FAO (2013)

In China, domestic demand for peanut products has risen in recent years and, consequently, Chinese peanut exports in 2013 accounted for only 22% of world trade, down from 45% in 2008. Argentina and India are now major peanut exporters. In 2013, Argentinian exports reached 32% of world trade, followed by India with 19% of the total exports.

Peanut production and importance in south-central coastal Vietnam

Peanut prices in Vietnam have increased over recent years. Prices fluctuate through the year according to local demand, with prices generally higher in August to September, and again in October to December. Wholesalers in Ho Chi Minh City may import peanuts from China in December. However, after the Tet (Vietamese New Year) festival in late January or early February, demand falls.

Since 1995, the peanut cultivation area in Vietnam has been stable at 250,000 hectares (ha) while peanut production has increased from 335,000 t/year to 534,000 t/year, due to increasing yields. However, north-central and south-central coastal (SCC) Vietnam have lower productivity on average than other production areas. In 2009, the average peanut yield in the north-central and SCC areas was only 1.94 t/ha, compared with 2.33 t/ha in the Red River Delta, 2.88 t/ha in the western highlands and 3.33 t/ha in the Mekong River Delta.

Binh Dinh province is the most productive area for peanuts in SCC Vietnam and there is an important informal peanut-trading centre at Dap Da town.

Peanuts are well adapted to many regions of Vietnam. Growing peanuts in sandy soils of SCC Vietnam not only helps provide an income for farmers, it also contributes to the improvement of soil fertility (though nitrogen fixation) and the prevention of land degradation and desertification, which is occurring largely in Quang Ngai and Binh Dinh provinces. Peanuts are important for crop rotation and are grown with other annual species or intercropped with perennials (e.g. mango). Systems of intercropping peanuts with crops such as cassava, sesame and maize have been widely adopted. The adoption of peanuts in order to break the rice monocropping system on thousands of hectares of sandy coastal soils in Phu Cat district, Binh Dinh province, has resulted in smallholder income growth. Peanut produces 2.5–5-times higher income than other crops such as rice and cassava. Hence, peanuts are considered one of the main crops with potential to contribute to raising farm income and alleviating rural poverty in SCC Vietnam.

Peanut in the context of other grain legumes

A diverse range of grain legumes are grown throughout the three provinces of Binh Dinh, Phu Yen and Ninh Thuan (Table 2); spreading from mountainous regions and highlands, down to sandy coastal plains. These grain legumes can be divided into two groups. One group, including soybeans, mungbeans and peanuts, is widely grown and intensively farmed, usually with irrigation. The second group (e.g. the small red beans *dau san* and *dau van*), is grown specifically by ethnic minority people in the mountainous regions in an extensive farming system with self-supplied seeds and no irrigation.

Peanut is the most significant grain legume crop grown in SCC Vietnam in terms of poverty alleviation and sustainable farming systems, especially in areas dominated by sandy soils.

Table 2. Common legume crops in south-central coastal Vietnam by cultivation method

Province	Cultivation method	
	Intensive farming	Extensive farming
Binh Dinh	Peanut, soybean, mungbean, black bean	
Phu Yen	Peanut, soybean, mungbean, black bean	Small red bean: *dau van*
Ninh Thuan	Peanut, mungbean, black bean, *dau bi*	Small red beans: *dau van, dau san, dau cuc, dau cua*

Source: Component 1 survey, 2010

Aspects of the peanut value chain in Binh Dinh, Phu Yen and Ninh Thuan provinces

The peanut value chain in SCC Vietnam is an inter-province chain with trading within the region and also in other regions (buying seed inputs from the highlands and selling product to the north and south).

In the three SCC provinces (Binh Dinh, Phu Yen and Ninh Thuan) where surveys were conducted as part of Australian Centre for International Agriculture Research (ACIAR) Project SMCN/2007/109 (*Sustainable and profitable crop and livestock systems for south-central coastal Vietnam*), the growing area and peanut output were not as high as the north-central provinces of Thanh Hoa, Nghe An and Ha Tinh. Peanut productivity in Phu Yen and Ninh Thuan is relatively low compared with other provinces within the SCC region. However, in Binh Dinh, peanut productivity is higher with an increasing trend in yield. For example, the yield in 2009 was the highest in the region at 2.6 t/ha (General Statistics Office 2010).

In the three study provinces, the main peanut crop is winter–spring (from December to March). In some irrigated areas, peanuts can be grown as a consecutive crop but winter–spring gives the highest yield. Every year, the majority of farmers in Binh Dinh and Phu Yen have to buy seeds from private traders, mainly from Dak Lak, Gia Lai and Dong Nai provinces.

Binh Dinh as focal province for peanut trade

Binh Dinh has emerged as a primary provider of peanuts in the region (with peanut production ranked eighth in the country) and as the lead producer in SCC Vietnam. Recognising this, the Dap Da Centre in An Nhon district now has a well-known group of merchants (e.g. Mrs Son Duong and Huong Thai). There are also four assemblers who own threshing and sorting machines, and some of them have bought dryers to dry peanut seeds.

A group of about 40 local collectors in Binh Dinh buys peanuts from local farmers to sell to the merchants/assemblers in Dap Da. In addition, assemblers from Phu Yen and Ninh Thuan purchase peanuts locally from their respective provinces and sell to assemblers in Binh Dinh. Binh Dinh assemblers buy and sell peanuts all year round and now have warehouses to store and sell at the right time. Also, while they purchase peanuts from within the SCC region, they also buy peanuts from other provinces in the north (Hanoi, Nghe An), central region (Binh Thuan, Phu Yen), western highlands (Gia Lai, Dak Lak) and the south (Tay Ninh, Ho Chi Minh City, Dong Nai) and then sell to areas with peanut shortages. They have sold peanuts in Binh Dinh and to Nghe An, Dak Lak, Gia Lai, Dong Nai, Hanoi and Ho Chi Minh, and also exported to China.

The reasons why Dap Da emerged as a peanut-trading centre:

- Historically, Dap Da was an important peanut-growing region, giving rise to a group of assemblers specialising in trading peanuts. However, some of the other merchants and traders went out of businessas a result of failing to sell undried nuts.
- It is relatively close to a port in Quy Nhon city, which became a major exporting port for peanuts.
- Dap Da and surrounding regions have numerous peanut-processing facilities, such as dryers, threshing machines, oil pressing units, peanut candy making machines, peanut roasting facilities and other home craft businesses that use by-products of peanuts such as peanut husk as fuel for rice paper and noodle factories. This helps the local assemblers to buy assorted peanuts at relatively high prices, grade and market them through different channels.

Quality considerations

Local traders judge peanut quality by measuring the shelling percentage (kernel relative to pod weight), moisture, seed colour and plumpness of grain (should be 'well-rounded and glossy'). Good-quality peanuts should have a shelling percentage of above 75% while 60–65% or below is considered poor quality. Even so, low-quality grades in Dap Da are also sold after sorting.

City-based Vietnamese peanut wholesalers are considering larger imports of peanuts from China even though they themselves admit that Vietnamese peanuts have a better flavour. The main reason for importing is the poor postharvest management of peanuts in Vietnam. In addition, high humidity and shortage of storage facilities are of major concern to distributors.

Even though seed quality assurance is provided by the majority of traders, a few traders purchase seeds directly from farmers, paving the way for poor seed quality and non-compliance. Realising this, the Department of Agriculture in Binh Dinh conducts a program of bulking seed from autumn–winter crops grown in sandy soils of Phu Cat district for use as seed for the main winter–spring crop.

Peanut value chain, costs and profitability

The peanut value chain is a traditional agricultural chain involving farmers, collectors, assemblers, traders, processors and wholesalers (Figures 1 and 2). The highlands are the main source of peanut seeds for the SCC region.

The profit in the chain accounts for 58% of the retail price which is calculated by dividing profit by margin times 100 (Table 3). For unshelled peanuts, farmers collect the highest proportion of profits in the chain. Furthermore, with peanuts being in high demand, there are many local collectors who purchase peanuts at the farm gate at competitive prices. Collectors incur the highest costs (59% of total) with a low profit margin (4%). However, due to their low capital investment (Vietnamese dong

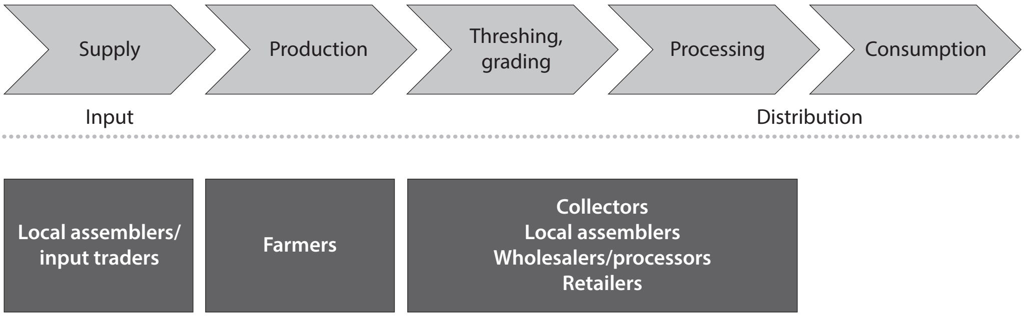

Figure 1. The product flow for the peanut value chain in south-central coastal Vietnam

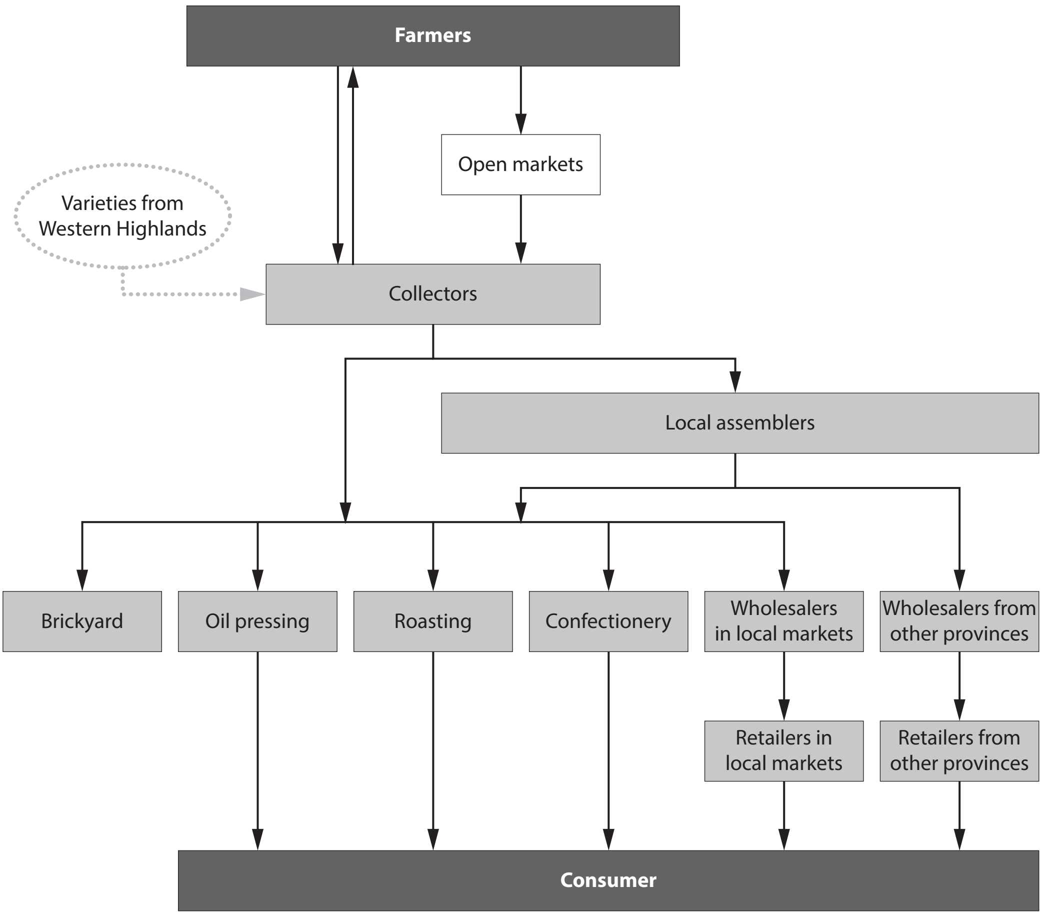

Figure 2. Distribution channels of peanuts in south-central coastal Vietnam

(VND)15–50 million), their earnings for a short duration (after harvesting of crop), are reasonable and in the range of VND100,000–300,000/day during the harvest season which lasts about 1 month. Most of their capital investment is recouped from the assemblers within a short period of time (5–7 days). In addition, the collectors have additional earnings from selling low-quality peanuts that make up 5% of the total volume as well as peanut husks. Thus, the collectors are still able to make a profit of VND610/kg.

Assemblers/wholesalers receive the lowest rate of return (2%) on a per tonne basis (Table 3). Their profits depend on volume and the small margin between buying and selling. Peanuts are highly perishable if the moisture content is higher than 9%, so only a few experienced assemblers who have substantial capital and have multiple market outlets or processing facilities available are able to thrive in this market environment.

Peanut market facilities

Poor market facilities and underdeveloped postharvest technologies result in peanut quality risks. Local trading for most agricultural goods in Binh Dinh and Phu Yen provinces is mainly through an open-air wholesale market system with poor infrastructure and where trading occurs in darkness. Open markets usually start around 2 or 3 am on a large area, mostly near an established/official market that operates later in the morning. Farmers bring agricultural products for sale and assemblers come to buy. Depending on the season, there are key products such as peanuts or coconuts.

In Binh Dinh province, markets selling peanuts include Cay Bong, An Thai (An Nhon district), Gom, Phu Cat (Phu Cat district), Binh Duong and Cay Da (Phu My district). Markets operate on different days, with 5 days between two sessions at the same market.

The trading facilities are dark, with poor facilities and have no street lights. Collectors carry scales, flashlights, notebooks, pens and calculators. At least two sellers come together, bringing in peanuts using numerous kinds of vehicles. The vehicles used by collectors are parked in a disorderly fashion, making movement within the market difficult. All buyers and sellers have to walk back and forth through the market several times to get the best prices. Some sellers admit that their peanuts are not dry enough. They mix them with dried ones before selling. Hence, under such market conditions they are easily able to easily sell inferior quality products (mixed peanuts).

Local industry development

The People's Committee of Binh Dinh province encourages organisations and individuals to invest in developing peanut seed production mainly for the autumn–winter crop season to supply and meet seed demand for the winter–spring crop (Decision No. 43/2009/QD-UBND dated 10/20/2009 of the People's Committee of Binh Dinh province). Provincial budgets subsidised 60% of the seed price in 2010 and further reduced the price by 10% in 2011 for farmers participating in this program. The planned peanut seed production area was 100 ha for the autumn–winter crop in the Phu Cat district. This project was implemented by the Centre for Agricultural Extension.

The main constraint to development of a larger scale profitable peanut industry in SCC Vietnam is the difficulty in drying peanuts grown during the wet season. As a result, 75% of farmers reported postharvest damage affecting peanut germination.

Table 3. Costs, prices and margins in the value chain for unshelled peanuts in south-central coastal Vietnam

Participant	Costs			Revenue	Profit		Margin	
	Total cost (VND '000/t)	Additional cost (VND '000/t)	% of additional cost	Price (VND '000/t)	Profit (VND '000/t)	% of profit	Margin (VND '000/t)	% of margin
Farmer	4,161		38	15,000	10,839	77	15,000	61
Collector	21,520	6,520	59	21,500	610	4	6,500	27
Wholesaler	21,650	150	1	22,000	350	2	500	2
Retailer	22,150	150	1	24,500	2,350	17	2,500	10
Total		10,981	100		14,149	100	24,500	100

In 2011, the provincial Department of Agriculture and Rural Development (DARD) in Binh Dinh provided farmers with two small dryers with a capacity of 1.5 t/batch/48 hours designed by the Energy and Farm Machinery Centre (University of Agriculture and Forestry at Thu Duc). The cost of buying the machine was VND65 million/unit. The two dryers were transferred to two municipal farmers representing 20 poor households in Cat Hiep commune to operate. The application of dryers has opened up prospects for increasing local peanut seed production. These machines can also be used for drying of other products such as cassava.

Effect of peanut cultivation on available water resources

The rapid expansion of intensive peanut-based cropping systems has put pressure on the local groundwater aquifers. In Binh Dinh, water for irrigation is primarily extracted from groundwater wells. The total number of wells increased rapidly between 1995 and 2005. The number of new wells increased sharply in 2000 due to the expansion of peanut cultivation. Since then, the number of wells has continued to rise due to further adoption of peanut-based farming systems driven by the transfer of agricultural technology from extension services.

Estimates of water volumes used by peanut crops ranged from 210 m^3/0.1 ha (autumn–winter crop) up to 837 m^3/0.1 ha (winter–spring crop), which is much higher than for other cash crops. Awareness of water scarcity among farmers has increased the opportunity for the adoption of water-saving technologies (see below).

About 80% of peanut farmers commented that groundwater levels had dropped. In Cat Hiep commune, Binh Dinh, 63% of farmers assessed that the water reduction was a **serious to a very serious** problem. Groundwater is the only source for irrigation in this commune and the area of upland crops, including peanuts, has grown rapidly.

Study into potential adoption of water-saving measures

The evidence for the drop in groundwater levels during the dry season, according to farmers, was the decline in the water level in wells (50% of total responses), longer watering times (25%) and water shortage in the following season (22%). The cause of the depletion of water, according to farmers, was drought and climate change (48% of total responses), and also overexploitation (15%) or both (33%). Water for irrigation is almost free of charge. However, due to the awareness of the decline in the groundwater resource, about 35% of farmers had applied measures to save water. These included manure application (14%), biochar application (12%) and use of sprinklers (9%).

Biochar made from rice husks was researched by the Agricultural Science Institute for Southern Central Coast of Vietnam (ASISOV), as part of this ACIAR project. Experiments in Phu Cat district, Binh Dinh province, in 2010–11 showed 15–30% higher peanut yields as a result of biochar use. This productivity gain may have been through: increased water holding capacity of the soils; nutrients in the biochar; and/or a reduced rate of nutrient leaching after application of biochar (Hoang Vinh et al. 2015). Having given this information to farmers, 45 of the 60 farmers interviewed (75% of total) agreed to test the use of biochar. Of the 45 farmers, 35 households (78%) offered to self-produce biochar and 10 households (22%) agreed to buy biochar if it were commercially available.

In order to assess the likelihood for farmer adoption of water-saving technology, a binary logit regression model was used that can predict results and give a 70% confidence interval as to whether a person will choose to apply one of the measures to save water. The regression results showed that a farmer with higher education, more years in growing peanuts and especially more awareness of the severity of water resource decline would more easily adopt water-saving measures. In addition, the size of the farm was also a factor that affected adoption. The outcome of the model was that larger the landholding, the higher the likelihood of adoption.

Opportunities, constraints and recommendations for the peanut value chain in SSC Vietnam

Key opportunities for the local peanut industry include:

- world market and domestic market prices for peanut have been strong
- peanut crops are suitable for the natural environment in sandy soils of the SCC region

- supporting policies for peanut growing in the coastal areas are being implemented by some local authorities, such as in Binh Dinh province
- international projects are supporting research and development in local areas
- growing peanut crops as an adaptive measure to climate change is supported
- mechanical peanut dryers have been introduced to Binh Dinh province.

Key constraints in the peanut value chain include:

- lack of quality control and poorly developed relationships in the value chain
- groundwater depletion in the dry season caused by rapid development of peanut cropping
- poor wholesale market facilities resulting in poor peanut quality control
- city wholesalers are concerned about high moisture causing losses during storage. As a result, they are considering larger imports of Chinese peanuts
- local assemblers lack finance and adequate market information
- local collectors also lack finance.

Recommended actions include:

- development of water-saving technologies, such as sprinkler or drip irrigation systems and use of biochar
- mechanisation of peanut-harvesting operations
- continuing support for farmer adoption of peanut dryers
- better control of peanut moisture via improvement of wholesale market facilities, including lights for night markets, and training traders on peanut-quality management
- provision of credit to local traders for improvement of postharvest practices.

What is needed to implement these chain improvements?

- public–private partnership to improve wholesale market facilities
- better cooperation between research institutes and DARDs to transfer technology to farmers
- support from international and Vietnamese experts to deliver relevant training.

Action plan for changes that are feasible to implement

In the short-term, the following priority activities should implemented:

- establish a peanut association in Binh Dinh province to include wholesalers, collectors, farmers, researchers and agricultural extension staff
- train peanut wholesale traders in quality control and business management
- train farmers in efficient irrigation systems (sprinkler and drip) and scheduling, use of biochar and grain-drying techniques
- train local government officers in information technology (IT).

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Value-chain analysis of cassava in south-central coastal Vietnam

Ho Cao Viet, Huynh Tran Quoc, Le Van Gia Nho and Nguyen Van An[1]

Abstract

Value-chain analysis of cassava was carried out in the provinces of Binh Dinh, Phu Yen and Ninh Thuan in south-central coastal (SCC) Vietnam to assess limitations that occurred from the production to the consumption stage and to develop strategies and make recommendations to enhance profitability for farmers.

The key findings of cassava value-chain analysis are: (i) farmers and collectors/wholesalers play a very important role in the chain; however, the processing factory is the primary factor that influences the whole cassava chain; (ii) information about the market and prices governs farmers' benefits and income; (iii) cooperation and coordination among farmers are the best means to reduce risk and loss if the price were to depreciate; (iv) interaction between cassava producers and beef-cattle enterprises is necessary for a sustainable farming system; and (v) small-scale flour-processing units are dependent upon the price of cassava root to mitigate risks.

Introduction

Cassava production came into force in Vietnam at the beginning of the 21st century when some cassava starch–processing factories were established in Binh Dinh and Phu Yen provinces. Initially, the cassava-processing units were very traditional, small-scale and low capacity, using simple equipment and family for labour. The product was mainly supplied to the local people and sold in small markets. After that, processing factories started to process cassava roots to manufacture large amounts of flour and chips to sell to overseas markets such as China, Singapore and Thailand, and a small portion was used as a raw material for the domestic industry. With time, realising the potential of cassava as a niche and cash crop, farmers started to shift their focus from other crops to cassava cultivation. Cassava now plays an important role for farming households, particularly for the poor in south-central coastal (SCC) Vietnam. Over 90% of cassava produced annually is processed into high-value products, such as cassava chips and starch, to supply both domestic and overseas markets. These products are the main source of income for farmers, processors and other agents in the value chain, including collectors, middlemen, dealers, wholesalers and retailers. The by-products of cassava are also used as animal feed (for livestock such as cattle and pigs) in this region, and this aspect has played a very important role in improving the income of farms.

Surveys of different actors involved in the cassava value chain were conducted to collect information, analyse the chain and assess if it could be improved for the benefit of all the participants. The price of cassava root fluctuates based on supply and demand in the world market, which affects its production domestically. Price fluctuations are also indirectly influenced by the way vertical coordination occurs among farmers and other value-chain actors, such as flour-processing units, factories and related enterprises. Based on the survey results, there was a need to identify limitations that occur along the cassava value chain, and to further improve it to

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create a better social and economic environment for all involved.

The specific objectives for this cassava value-chain project were to:

- analyse markets and identify the advantages and disadvantages of the process
- support activities and recommend policies for implementation and improvement of the value chain
- identify short-term solutions and develop long-term strategies by engaging stakeholders and agents.

Methodology

Analytical frameworks were adopted from international organisations involved in evaluating value chains, such as Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), ACDI/VOCA and Making Markets Work for the Poor (M4P), and were applied to develop the investigation framework in the context of cassava value-chain research. The methodology of value-chain study of the Food and Agriculture Organization of the United Nations (FAO) (Bockel and Tallec 2005) was also applied.

Qualitative methods

The participatory rural appraisal (PRA) method, formal discussions, key informant panel (KIP) discussions, problem trees, SWOT (strengths, weaknesses, opportunities and threats) analysis and Venn diagrams were used to identify the: (i) structure of the chain in different provinces; (ii) interaction of each factor, including the actors in the chain; and (iii) impact of institutions and policies on the chain. Collection and analysis of secondary data (annual reports of People's Committees, statistical data, scientific reports and information from the Ministry of Agriculture and Rural Development (MARD), Department of Agriculture and Rural Development (DARD) in each province, non-government organisations (NGOs), plus institutional and political papers) were also undertaken. Individual in-depth interviews, case studies and observations added to the data collection. These databases were updated yearly.

Quantitative methods

Face-to-face interviews or discussions were held with the value-chain actors to collect data which were subjected to statistical analysis, cost–benefit analysis and value-added analysis to build a scenario to interpret the overall chain, including subchains and products.

Survey sampling strategy and participants

A non-probability sampling method (proportionate quota sampling combined with a convenience sampling approach) was used in this study mainly due to financial (approach) and technical (timescale and performance) constraints. Hence, there was limited ability of the surveyors to expand the sample size of the actors involved in the cassava value chain. Consequently, although the population of farmers was very large, surveying was restricted to one commune in each of the three study provinces. These comprised:

- Cat Trinh commune, Phu Cat district, Binh Dinh province
- An Chan commune, Tuy An district, Phu Yen province
- Phuoc Dinh commune, Thuan Nam district, Ninh Thuan province.

From each of these communes, 30 farming households with different land sizes were selected to carry out annual surveys and face-to-face interviews. The other actors included eight collectors/middlemen of various levels, five dealers (who trade cassava chips), five processing units (cassava flour and starch) and three processing factories (starch and other products). Note that processing units are small-size operations that use mainly family labour (1–2 persons/unit) and have a low volume capacity (1–2 tonne (t) cassava root/day). They buy cassava root from farmers and sell to local dealers or processing factories in cities.

Data analysis

Descriptive statistics were used to analyse the data. The basis for calculating the benefit:cost ratio is presented in Table 1 and financial factors that were considered for the descriptive statistics for the cassava value chain are outlined in Figures 1 and 2.

World cassava production and trade

Global cassava production increased by 5% between 2006 and 2011, reaching around 250 million tonnes (Mt) (Figure 2). The demand for cassava from industrial sectors, particularly for producing ethanol and other products (food and foodstuffs processed from cassava) increased sharply in South-East Asia and Africa in 2011. In Asia, cassava production was estimated to be 83 Mt, an increase of 6% in 2011. Thailand was the largest producer of cassava in Asia, with a total production of 30 Mt; however, Thai production reduced by 8% in 2011 due to pest damage (caused by the pink hibiscus mealybug). China produced around 8.5 Mt of cassava in 2011.

Trading of cassava fluctuates yearly both in terms of product quantities (Figure 3) and price (FAO 2011). China is the biggest consumer of cassava in the world and imports 65% of the total cassava produced. Thailand was the largest exporter of cassava products during 2008–2011 and recorded its highest exports in 2009 (Table 2).

Cassava production and trade in Vietnam

Production trends

Total cassava production in Vietnam in 2008 was 1.4 Mt, with an export value of US$555 million, which was much lower than Thailand where 7 Mt had an export value of US$1.4 billion. Although the cultivated area has fluctuated over time according to price, by 2011, in Vietnam it had increased to 510,000 hectares (ha)—mainly in response to the high price of cassava root—with production of nearly

Table 1. Economic parameters used in the cost–benefit analysis of the cassava value chain in south-central coastal Vietnam

Parameter	Formula
Production (total income) (P)	(Productivity × selling price of main product per unit) + income from by-products (if any)
Total cost (TC)	Variable costs (VC) + fixed costs (FC)
Fixed costs	Maintenance + depreciation + tax
Variable costs	Fertilisers + pesticides + labour wage
Collector/middlemen costs	Input materials + labour wage + transportation + energy (fuel, electricity) + tax on product (if any)
Processing unit costs	Input materials + labour wage + transportation + energy + tax
Intermediate cost (IC)	Input materials + energy
Gross profit (GPr)	Production (P) – total cost (TC)
Value added (VA)	Labour wage + interest on loan + communication fee + tax + maintenance & repair + depreciation + gross profit
Net profit (NPr)	Gross profit (after tax)

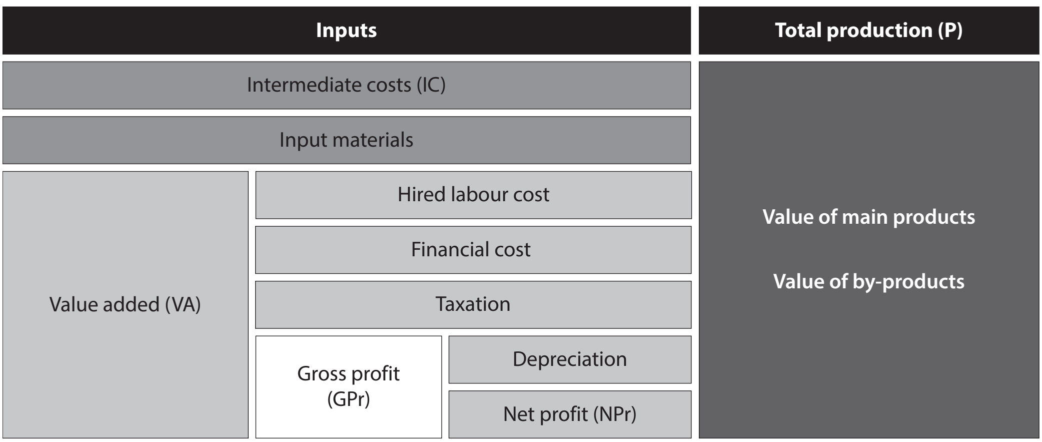

Figure 1. Financial parameters for the value chain of cassava

9 Mt. However, this increase in area was against government policy, which was to keep the cassava cultivation area under 450,000 ha, to avoid deforestation. The average yield was 17.8 t/ha, which was low compared with Thailand, where average yield was 21.1 t/ha. Of total cassava production in 2009 of 8.1–8.6 Mt, 22.4% was used for animal feed, 16.8% for artisanal processing, 12.2% for fresh meals and the remaining 48.6% for export. It was estimated that by 2013, about 85% of cassava would be used for ethanol production for domestic use and for exportation. This is expected to result in increasing overall demand for cassava to cater for this as well as its traditional uses.

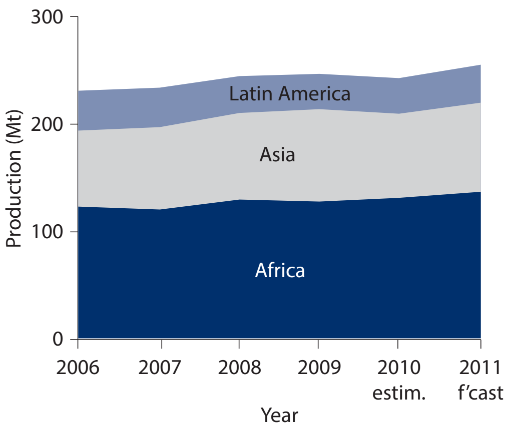

Figure 2. World cassava production of cassava, 2006–2011. Source: FAO (2011)

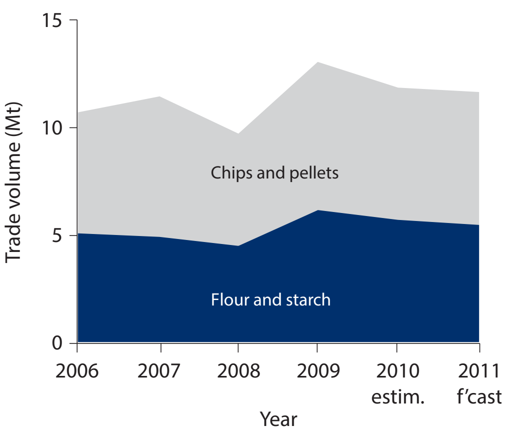

Figure 3. Trade of cassava in global market, 2006–2011. Source: FAO (2011)

Export statistics and opportunities

According to the Customs General Office, in 2011 Vietnam exported 3.2 Mt of cassava and other products valued at US$974.5 million—an increase of 67.5% in quantity and 43% in value. The main markets for Vietnamese cassava exports include China, Korea, Taiwan, Philippines, Malaysia and Japan, and Vietnamese cassava products also have a presence in other Asian countries (Indonesia, India, Burma etc.) as well as Australia, Europe and Russia. China imported 2.9 Mt of cassava products from Vietnam valued at about US$855 million, worth 88% of the total value of Vietnamese cassava exports in 2011. Korea imported cassava products worth US$30.6 million, followed by Taiwan (US$22 million), the Philippines (US$13.55 million), Malaysia (US$8.3 million) and Japan (US$3.15 million). MARD estimated cassava exports to fetch over US$1 billion by the end of 2012—an increase of US$250 million compared with 2011.

Supply problems in Thailand have meant that international buyers have begun to source cassava products from other countries, especially Vietnam and Cambodia (Table 2). There is an opportunity to increase exports if the Vietnamese cassava value chain can improve its performance. The export value may further increase if cassava is used for biofuels to replace fossil fuels and may develop into opportunities for cassava processors to produce ethanol.

Table 2. World exports of cassava and major exporting countries, 2008–2011 ('000 t)

Year	2008	2009	2010	2011
Starch and flour				
Total	4,265	5,929	5,483	5,249
Thailand	3,963	4,993	4,864	4,427
Vietnam	946	600	250	500
Chips and pellets				
Total	5,187	6,862	6,127	6,155
Thailand	2,848	4,411	4,411	2,927
Vietnam	437	2,000	1,200	2,000
Cambodia	170	100	250	1,000
Overall total	9,452	12,791	11,610	11,404

Source: FAO (2011)

Potential for cassava as fuel

The Vietnam Government's project on *Development of biofuels to 2015 with a vision to 2025* aims to replace fossil fuels, ensure energy security and protect the environment. This project will provide an opportunity for cassava value-chain development in Vietnam. According to the plan, by 2015, production of ethanol and vegetable oil will reach 250,000 t (producing 5 Mt of gasoline E5 and B5) to meet 1% demand of fuel domestically. By 2025, these figures are expected to be five times higher. With this initiative in mind, four ethanol factories have already been set up in Quang Nam, Phu Tho, Quang Ngai and Binh Phuoc provinces. With ethanol production of 100 million litres per year per factory, the total demand for cassava is estimated to be about 1 Mt of dried root per year, requiring nearly 58,000 ha of cassava plantation, assuming the yield to be 17 t/ha. With a further 10 ethanol-production projects being set up, the Ministry of Trade estimates that 510,000 ha with an average yield of 15.7 t/ha would be required for this use alone. Given that the cultivation area for cassava already exceeds the limit set by government (as discussed above), to meet demand it would be necessary to improve cassava yield by introducing new varieties and/or new cultivation techniques to achieve similar yield levels as in India (31.4 t/ha) and Thailand (21.1 t/ha) (KHPT 2010).

Fluctuations in price of cassava products and impact on cultivated area

The domestic cassava price of roots and processed products such as chips and starch fluctuated during 2009–12. In 2010–11, the farm-gate prices of cassava root (Vietnamese dong (VND)35 million/ha) and dried chips (5,300 VND/kg) were double those of the previous year (information compiled from key informant panel (KIP) discussions in Binh Dinh, Phu Yen and Ninh Thuan provinces). This higher price of cassava attracted farmers to shift from other crops (such as sugarcane) to cassava cultivation.

The market price of cassava (chips, fresh root) fluctuated a lot during 2000–2010. The prices were high during 2006–2011 due to high demand from the Chinese market. Hence, the cultivated area of cassava increased at the beginning of 2006, as shown for Binh Dinh province in Figure 4. However, during 2009–2010, the price of cassava reduced substantially and a slowdown in the processing of cassava flour was also seen at the factories because the influence of the Chinese market. Chinese traders reduced both the amount and buying price of imported cassava. As a result, in 2010, the area of cassava cultivation reduced by 58,000 ha in Vietnam in comparison to 2008 (General Statistics Office 2011, 2012). North-central coastal and SCC areas were also affected as a result and the cultivation area reduced by 13,000 ha (8%).

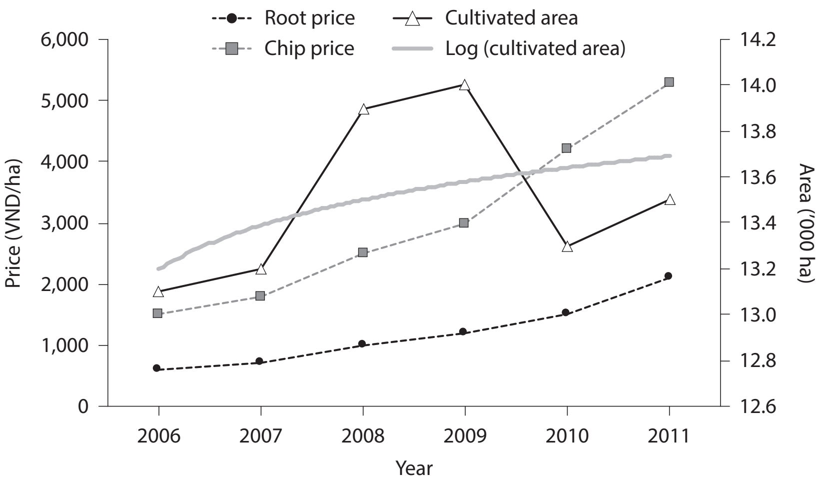

Figure 4. Relationship between cassava price and cultivated area in Binh Dinh, 2006–2011. Source: calculated from survey data (2011)

Similar effects were seen in Ninh Thuan province (Figure 5). In contrast, in Phu Yen province, the area increased by 1,000 ha in 2010 compared with 2009 (Figure 5) due to the establishment of a new processing factory that began operating in 2009.

However, due to poor weather conditions in 2009–2010, cassava production in most of the SCC region was reduced by nearly 5% and the impact was less severe in Phu Yen (Figure 6).

Analysis of the cassava value chain in SCC Vietnam

There are two main value subchains of cassava that exist in the SCC region: the first deals with the export of cassava products (mostly starch) to other countries; and the second operates within the domestic market with flour as the main product (Figure 7).

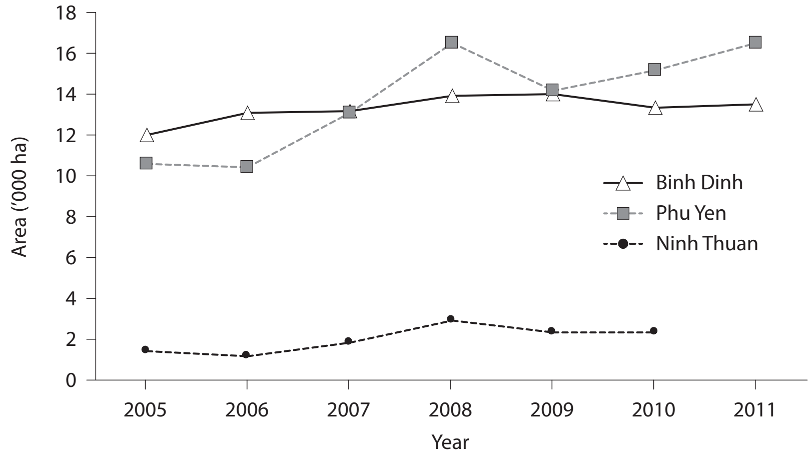

Figure 5. Change in cultivated area of cassava in three provinces, 2005–2011. Source: General Statistics Office (2011, 2012)

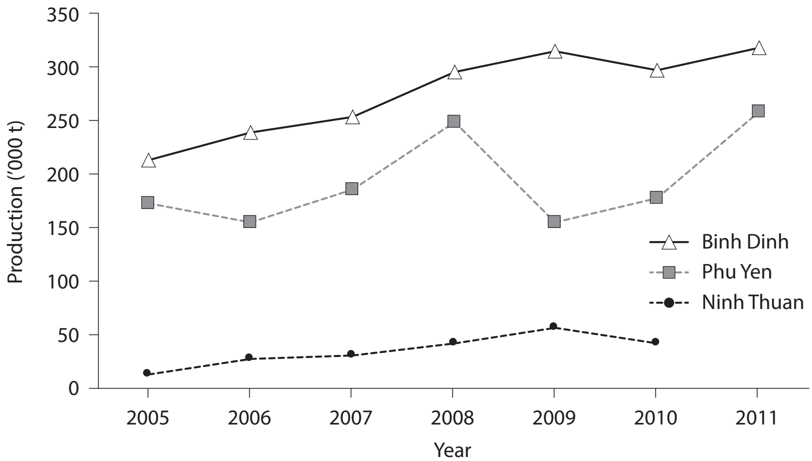

Figure 6. Change in cassava production in three provinces, 2005–2011. Source: General Statistics Office (2011, 2012)

Cassava farmers/producers

Cassava yield varies between 18 and 24 t fresh root/ha, with an overall average of 20 t/ha which equates to 10 t of dried chips. The local collectors buy root directly from farmers and sell directly to starch-processing factories or processing units. The producers also sell cassava chips to local collectors after harvesting in the dry season and sell dried chips to get a higher margin than they get from selling root. Based on average yield of 20 t/ha root at a selling price of VND1,400/kg, the farmers are able to generate an income of VND28 million/ha (Table 3). The intermediate costs are estimated to be VND9.156 million, accounting for 32.7% of the total income (total production), the majority of which is the cost of fertilisers. Value added accounts for 67.3% of total income, of which 34.1% is spent on labour costs. Hence, the net profit for farmers is around 65.9% of value added. These figures indicate that the cassava crop generates high economic efficiency and low intermediate costs. The economic efficiency per VND1 investment of total production/intermediate costs (P/IC), value added (VA)/IC and net profit (NPr)/IC is 3.1, 2.1 and 1.4, respectively. Producing dried cassava chip incurs extra costs of about VND2.0 million/ha; however, based on cassava root yield of 20 t/ha, with a ratio of fresh root to chip to be 50%, and average chip selling price of VND3,000/kg, the total production (P) per hectare for cassava chips would be around VND30 million (Table 4) which is much higher than for cassava root. In addition, the dried chips are easy to store, which potentially gives farmers the opportunity to wait until the selling price increases. Also, farmers can take advantage of family workers to save on value-added labour costs Although the costs associated with producing chips are higher than for roots, these factors help make chip production an attractive option. Selling dried chips to collectors costs VND2 million/ha compared with supplying directly to the market.

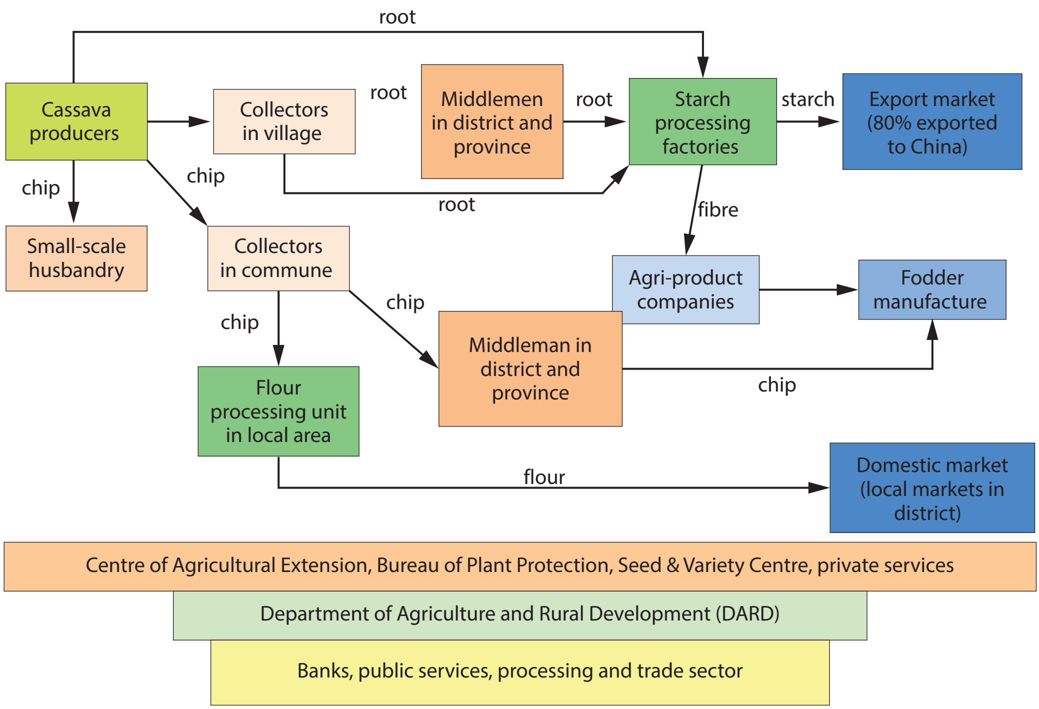

Figure 7. Description the cassava value chain in south-central coastal Vietnam

Table 3. Financial analysis of farmer, based on per hectare cassava root production, 2010–12

Item	Total (VND ’000)	Proportion (%)
Total production (P)	28,000	100.0
Intermediate costs (IC) (materials costs)	9,156	32.7(IC/P)
Seed	470	
Chemical fertilisers and pesticides	7,886	
Manure/compost	800	
Value added (VA) (labour costs + GPr)	18,844	67.3 (VA/P)
Land preparation	1,400	
Planting	600	
Fertiliser & pesticide application	660	
Weeding	360	
Harvesting	2,400	
Transportation	1,000	
Net profit	12,424	

Source: project survey data

Table 4. Financial analysis of farmer, based on per hectare dried chip production, 2010–12

Item	Total (VND ’000)	Proportion (%)
Total production (P)	30,000	100.0
Intermediate costs (IC)	9,156	30.5 (IC/P)
Seed	470	
Chemical fertilisers and pesticides	7,886	
Manure/compost	800	
Value added (VA)	20,844	69.5 (VA/P)
Land preparation	1,400	
Planting	600	
Fertiliser and pesticide application	660	
Weeding	360	
Harvesting	2,400	
Transportation	1,000	
Processing (remove peel, slice root into chips)	1,440	
Drying chips	720	
Net profit	12,264	

Source: project survey data

Purchase of root by local collectors

The collectors purchase root from farmers/producers in or near the village. The expenditure to buy 1 t of cassava root varies from VND1.0 to1.4 million. The transportation cost from farmer to delivery dealers is VND50,000–60,000 and labour wage is VND20,000–25,000/t (Table 5), giving a margin of VND100–200/kg depending on harvesting time. When purchasing from farmers, collectors often deduct 5% to the total cassava weight to account for impurities.

Table 5. Financial analysis of local collector (1 t fresh root), 2010–12

Item	Total (VND ’000)	Proportion (%)
Total production (P)	1,500	100.0
Intermediate cost (IC)	1,400	98.0 (IC/P)
Cassava root	1,400	
Value added (VA)	100	2.0 (VA/P)
Labour wage	20	
Communication	1	
Transportation	50	
Gross profit (GPr)	29	
Depreciation	1	
Net profit (NPr)	28	

Source: project survey data

The quality of root is dependent on the harvesting season and length of storage. The starch ratio is reduced by 10% if stored in a warehouse for more than 4 days. The processing factory often delays paying the collector for 1–2 weeks due to its own financial constraints, which has a negative impact on the collector’s business, but they have no choice but to accept this, as there are only one or two factories in the area/province.

Purchase of chips by local collectors

As well as fresh root, the collectors buy dried chips from farmers, which they sell to flour-processing units (70%) and wholesalers (30%) in adjacent districts. The profit margin for 1 t of dried chips varies between VND139,000 and VND150,000 (Table 6).

Table 6. Financial analysis of local collector (1 t dried chips), 2010–12

Item	Total (VND '000)	Proportion (%)
Total production (P)	3,200	100.0
Intermediate cost (IC)	3,038	94.9 (IC/P)
Dried chip	3,000	
Bags & packaging	38	
Value added (VA)	162	5.1 (VA/P)
Labour wage	15	
Communication	4	
Gross profit (GPr)	143	
Depreciation	4	
Net profit (NPr)	139	

Source: project survey data

Purchase of chips by local wholesalers

During July to September, the wholesalers buy dried chips from local collectors in the district. The transaction quantity varies from 15 to 20 t/day in the peak season and at other times varies from 5 to 15 t/day, with an average purchase of 2,000 t/year. During the rest of the year, the wholesalers buy dried chips from neighbouring provinces (e.g. Gia Lai province). The margin for 1 t of dried chips varies between VND88,000 and VND101,000 (Table 7).

Table 7. Financial analysis of wholesaler agent (1 t dried chips), 2010–12

Item	Total (VND '000)	Proportion (%)
Total production (P)	3,401	100.0
Intermediate cost (IC)	3,210	94.4 (IC/P)
Cassava chips	3,200	
Energy for transportation	10	
Value added (VA)	191	5.6 (VA/P)
Labour wage (salary)	20	
Handling	45	
Communication	1	
Tax	1	
Gross profit (GPr)	124	
Depreciation	36	
Net profit (NPr)	88	

Source: project survey data

Flour-processing enterprises/units

The local collectors sell dried chips to flour-processing units. The selling price of flour is VND4,000–4,200/kg, and is mainly purchased by feedstuff companies. On average, the processing unit buys around 20 t dried chips/month, with an estimated 280 t/year. The processing unit makes a profit of VND292–320,000 by processing 1 t dried chips to flour (Table 8).

Table 8. Financial analysis of processing enterprises/units (1 t flour), 2010–12

Item	Total (VND '000)	Proportion (%)
Total production (P)	4,040	100.0
Intermediate costs (IC)	3,452	85.6 (IC/P)
Cassava chips	3434	
Electricity & fuel	18	
Value added (VA)	588	14.4
Labour wage	214	
Communication	2	
Transportation	40	
Gross profit (GPr)	332	
Depreciation	40	
Net profit (NPr)	292	

Source: project survey data

Starch-processing factory

The starch processing factory of Binh Dinh province was equipped by a German joint-venture company, uses Thai technology to minimise costs, and can be upgraded in the future to match changing demand for different cassava materials. The current processing capacity of the factory produces 15,000 t starch/year. The factory has a wastewater treatment facility covering an area of approximately 10 ha. The current strategy of the factory is to process starch from dried cassava chips.

The processing cost is VND0.9–1.0 million/t starch. Starch prices increased by 250% during 2008–2011, from VND3.5 million/t in 2008 to VND12 million in 2011.

Nearly 3.5 t of cassava root produces 1 t of cassava starch and about 315 kg of dried cassava pulp valued at around VND6.3 million. The intermediate costs are around 87% leaving a net profit of VND232,000–250,000 (Table 9).

Analysis of the contributions made and profit shared in cassava chain

The value-added contribution for the starch-processing chain for the farmers, processing factories and the local collectors is calculated to be 74%, 18% and 8% with a net profit of 87%, 9% and 4%, respectively (Table 10). However, for the cassava flour and chips chain, the value-added proportion and the profit margin of the farmer are lower than for the export chain (Table 10).

In an assessment of the economic efficiency of investing VND1 of intermediate cost (IC) for both the export of starch and the domestic market, the farmers have better ratios of production (P)/IC, value added (VA)/IC and net profit (NPr)/IC than other actors in the chain (Table 11).

Table 9. Financial analysis of flour-processing factory in Binh Dinh province (1 t starch), 2010–12

Items	Total (VND ’000)	Proportion (%)
Total production (P)	6,360	100.0
Starch	6,000	
Cassava pulp	360	
Intermediate costs (IC)	5,553	87.3 (IC/P)
Cassava root	5,250	
Bags & packaging	110	
Electricity & fuel	193	
Value added (VA)	807	12.7 (VA/P)
Labour wage	245	
Transportation	100	
Gross profit (GPr)	462	
Depreciation	230	
Net profit (NPr)	232	

Source: project survey data

Table 10. Contribution and profit sharing of actors in the two principal cassava value chains, 2010–12

	Value added		Gross profit		Net profit	
	Production (VND ’000)	Proportion (%)	Production (VND ’000)	Proportion (%)	Production (VND ’000)	Proportion (%)
Chain 1: starch export	4,455	100.0	2,738	100.0	2,504	100.0
Farmer	3,298	74.0	2,174	79.4	2174	86.8
Collector	350	7.9	102	3.7	98	3.9
Factory	807	18.1	462	16.9	232	9.3
Chain 2: cassava flour (domestic consumption)	3,045	100.0	1,838	100.0	1,758	100.0
Farmer	2,105	69.1	1,239	67.4	1,239	70.5
Collector/middleman	162	5.3	143	7.8	139	7.9
Wholesaler	190	6.2	124	6.7	88	5.0
Processing unit	588	19.3	332	18.1	292	16.6

Source: project survey data

Strategies to improve the cassava value chain

Through the range of qualitative methods employed, including surveying the actors in the cassava value chain in the SCC region, the problems in the chain became apparent. In Tables 12 and 13, we outline the problems and suggest solutions as well as identify the agencies and agents who would need to be involved to bring about those actions. The problems are categorised into technical (Table 12) and economic and market (Table 13) challenges.

Table 11. Economic efficiency of each actor in the cassava value chain

	Parameter		
	P/IC	VA/IC	NPr/IC
Chain 1: starch export			
Farmer	3.06	2.06	1.36
Collector/middleman	1.07	0.07	0.02
Factory	1.15	0.15	0.04
Chain 2: cassava flour (domestic consumption)			
Farmer	3.28	2.28	1.34
Collector/middleman	1.05	0.16	0.05
Wholesaler	1.06	0.06	0.03
Processing unit	1.16	0.16	0.08

Table 12. Technical challenges and proposed solutions to improve the cassava value chain in south-central coastal Vietnam

Problem	Solution	Relevant agents/ agencies
Cassava varieties	Testing and introducing new cassava varieties that have high productivity and starch, short growth duration (compared with commonly grown variety KM94) Farmers should organise self-help group to produce the cassava varieties, to meet local demand and reduce costs of the new varieties	Government, private enterprises, multimedia agents, agricultural extension service, universities and research institutes
Fertiliser application	Transferring modern technologies in fertiliser application and use of manures for soil-quality improvement	
Processing and storage	Training farmers in processing and storage techniques, combined with using cassava by-products (fermented cassava leaf, peelings) in animal husbandry (particularly for beef cattle), used as supplementary feed for animals in the dry season	
Marketing knowledge & skills	Organising training courses on marketing and providing timely market information to farmers using a range of media	
Processing technology	Investing and enhancing high-value processing technologies to produce a wider range of end products, such as pharmaceuticals, cosmetics, industrial chemicals, biofuels etc.	

Table 13. Economic and market challenges and proposed solutions to improve for the cassava value chain in south-central coastal Vietnam

Problem	Solution	Relevant agents/ agencies
Economic		
Extent of cassava cultivation area	Adjusting the government master plan for cassava according to market signals and available resources (land, labour, capital)	Government, private enterprises, cassava producers/farming households
Export and domestic consumption	Diversifying the market, adding new product lines for export, searching for new markets and mitigating risks by avoiding dependence on the Chinese market, stimulating domestic demand (and thus the processing industry) for cassava for high-value products, including biofuels and value-added food items, e.g. traditional cakes and monosodium glutamate (MSG)	
Vertical coordination between farmers and factories/ processing units	Forming and consolidating vertical coordination of farmers and enterprises through policy development and institutional agreements	
	Strengthening horizontal coordination among cassava farmers in the region through cooperatives or self-help groups, leading to greater opportunities to sign contracts with factories	
	Devising a master plan and policies to support artisanal processing units for domestic consumption of products such as sticky fresh and dried flour for food, cassava cake, chips, ethanol, pharmaceuticals, cosmetics, premium and functional foods etc.	
Market		
Distribution channels	Improving transparency of market information and methods used by starch factories for root sampling and assessing for impurity ratios	Starch factories
	Introducing contracts between farmers and factories to provide cassava root	
Market fragmentation	Conducting market research to identify opportunites for product diversification, such as supplying cassava for animal feed manufacture and devising new product lines	Business, government, processing units
	PromotingVietnamese cassava more widely to export markets	

Conclusions

High prices for cassava starch, flour and chips provided farmers with higher incomes during 2009–2010. However, a 20% reduction in price combined with increasing input-material costs lowered their income by 30% in 2011 compared with 2010.

The artisanal and small-scale processing units generated stable incomes and were able to mitigate relative risks of falling price during the past years.

The storage of cassava root by traditional methods and its use as a feed for fattening the cattle and as a source of modified feed during the dry season was a highly efficient option for farmers, especially during the period of falling cassava prices.

Processing of cassava chips was a better option than relying on fluctuating fresh root prices. However, the processing of chips is weather dependent and needs a big labour force even if carried out on a small scale.

Processing factories play a very important role in the cassava value chain; however, they are dependent upon the Chinese market which is very unstable and risky.

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Analysis and improvement of beef-cattle value chains in south-central coastal Vietnam

Ho Cao Viet, Huynh Tran Quoc, Le Van Gia Nho and Nguyen Van An[1]

Abstract

Value-chain analysis of beef cattle was carried out in three provinces of south-central coast (SCC) Vietnam. Key findings from the analysis are: (i) the beef-cattle industry is an important source of income for the farmers in this region; (ii) the price of live cattle and beef meat increases each year as the demand for beef meat is relatively high, particularly in big cities; (iii) farmers have become aware of the potential of raising beef cattle as a source of income and made capital investments to improve cattle genetic potential; (iv) introduction of government policies for new slaughterhouses, provision of veterinary services, introduction of artificial insemination, expansion of pasture and forage areas, and support from government and private enterprises could further improve the quality and size of cattle herds and the livelihood of farmers in the SCC region; (v) cassava and its by-products have become a source of feed for beef-cattle raising and fattening during the dry season when there is a shortage of feed—in addition, manure from these animals contributes to the improvement of degraded infertile sandy soils in the region; (vi) income generated from cattle helps maintain family budgets and cash flows; (vii) lack of transparency and information about prices in the market chain is a critical factor that significantly influences farmers' decision-making; (viii) cooperation between farmers and vertical coordination among business enterprises in the value chain could be the best solutions for farmers to reduce risk and cope with financial loss if the cattle price falls.

Introduction

The sustainable generation of income for smallholder farmers in the central provinces is a major development issue for Vietnam. Cattle production plays a very important role in farming systems and in Vietnamese life. Demand for beef has been constantly increasing over time, particularly in the major cities of Ho Chi Minh and Hanoi, due to the expanding tourism industry and an increase in disposable incomes. As a result, increasing cattle production by farmers is seen as an opportunity to help alleviate poverty in south-central coastal (SCC) Vietnam, where small farmholders suffer from poverty for reasons explained elsewhere in these proceedings (Hoang Thi Thai Hoa et al. 2015). However, there are problems associated within the beef-cattle value chain which required an in-depth analysis to make recommendations for further improvement to benefit the poor farmers in this region.

Identifying and overcoming problems associated with beef-cattle value chains would eventually help Vietnam's socioeconomic environment and, more specifically, the farmers who are at the receiving end. The processes followed in this study to identify, assess and improve the beef-cattle value chain were to:

- analyse markets to identify associated advantages and disadvantages of the value chain
- identify activities and provide recommendations for policy implementation that would lead to better value-chain performance
- identify short-term solutions and long-term strategies for engaging stakeholders and agents.

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Methodology

Analytical frameworks were adopted from international organisations involved in evaluating value chains, such as Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), ACDI/VOCA and Making Markets Work for the Poor (M4P), and were applied to develop the investigation framework in the context of beef-cattle value-chain research. The methodology of value-chain study of the Food and Agriculture Organization of the United Nations (FAO) (Bockel and Tallec 2005) was also applied.

Qualitative methods

The participatory rural appraisal (PRA) method, formal discussions, key informant panel (KIP) discussions, problem trees, SWOT (strengths, weaknesses, opportunities and threats) analysis and Venn diagrams were used to identify the: (i) structure of the value chain in different provinces; (ii) interaction of each factor, including the actors in the chain; and (iii) impact of institutions and policies on the chain. Collection and analysis of secondary data (annual reports of People's Committees, statistical data, scientific reports and information from the Ministry of Agriculture and Rural Development (MARD), Department of Agriculture and Rural Development (DARD) in each province, non-government organisations (NGOs), plus institutional and political papers) were also undertaken. Individual depth-interviews, case studies and observations added to the data collection. These databases were updated yearly.

Quantitative methods

Face-to-face interviews or discussions were held with the value-chain actors to collect data which were subjected to statistical analysis, cost–benefit analysis and value-added analysis to build a scenario to interpret the overall value chain, including subchains and products.

Survey sampling strategy and participants

A non-probability sampling method (proportionate quota sampling combined with a convenience sampling approach) was used in this study, mainly due to financial (approach) and technical (timescale and performance) constraints. Hence, there was limited ability of the surveyors to expand the sample size of the actors involved in the beef-cattle value chain. Consequently, although the population of farmers was very large, surveying was restricted to one commune in each of the three study provinces. These comprised:

- Cat Trinh commune, Phu Cat district, Binh Dinh province
- An Chan commune, Tuy An district, Phu Yen province
- Phuoc Dinh commune, Thuan Nam district, Ninh Thuan province.

From each of these communes, 30 farmer households with different herd sizes were selected to carry out annual surveys and face-to-face interviews.

Collectors, middlemen, slaughterhouses and semi-industrial slaughter enterprises are relatively difficult to contact and required surveyors to develop close relationships with them in order to get in-depth information. In time, we were able to survey five collectors, four slaughterhouses across the three provinces and two semi-industrial slaughter companies based in Bien Hoa city and Ba Ria–Vung Tau province (both located close to Ho Chi Minh City).

Data analysis

Descriptive statistics was used to analyse the data. Financial factors that were considered for the beef-cattle value chain are shown in Figure 1 and the basis for calculating benefit:cost ratio is presented in Table 1.

Production, consumption and trade of beef in the global market

Global demand for beef has been constantly increasing over time as shown by increasing exports (Figure 2). Brazil has been the world's largest beef exporter.

The financial crisis of the last decade led to downfall of the European currency (Euro) and shifted the beef export market to other parts of the world, such as Russia and Turkey. Conversely, strengthening of the Australian and New Zealand currencies led to declines in beef exports from these countries, allowing other developing countries like India to increase beef exports and, as a result, India now ranks as the fourth largest exporter in the world. Strong demand for low-priced buffalo beef in South-East Asian countries, such as Malaysia and the Philippines, also led to an increase in bovine meat (cattle, buffalo, kudus etc). Indian buffalo meat is cost-competitive and of better quality compared with other countries such as Australia and Brazil, with the notion that buffalo meat comes from naturally fed animals and is cheap as no breeding costs are involved.

Of the total annual world beef consumption of 64.4 million tonnes (Mt) in 2011, the Asian population consumed about 17.7 Mt (Table 2). Asia produces nearly 15.3 Mt of beef each year and imports approximately 3.5 Mt (Table 2). The largest beef importer among Asian countries is Japan.

Vietnam imports 40,000 t of beef meat from the United States of America (USA) annually. In the first 9 months of 2013, 32,500 live cattle were imported (Vietnamnet 2013) from Australia for slaughtering and for the supply of meat to restaurants and supermarkets. The price of beef meat imported from Australia is 10–15% higher than that of beef produced in Vietnam. Hence, there is potential for Vietnamese farmers to invest in beef cattle to benefit from the high demand and high price of beef. However, fluctuating prices in the world market (see Figure 4) restrict the farmers' investment and benefit from the beef industry.

Table 1. Economic parameters used in the cost–benefit analysis of the beef-cattle value chain in south-central coastal Vietnam

Parameter	Formula
Production (total income) (P)	(Productivity × selling price of main product per unit) + income from by-products (if any)
Total cost (TC)	Variable costs (VC) + fixed costs (FC)
Fixed costs (FC)	Maintenance + depreciation + tax
Variable costs (VC)	
Beef-cattle producers	Feeds + veterinary + labour wage
Collectors/middlemen	Input materials + labour wage + transportation + energy (fuel, electricity) + tax on product (if any)
Slaughterhouses	Input materials + labor wage + transportation + energy + tax
Intermediate cost (IC)	Input materials + energy
Gross profit (GPr)	Total production (P) – total cost (TC)
Value added (VA)	Labour wage + interest on loan + communication fee + tax + maintenance & repairs + depreciation + net return of producers
Net profit (NPr)	Gross profit – depreciation

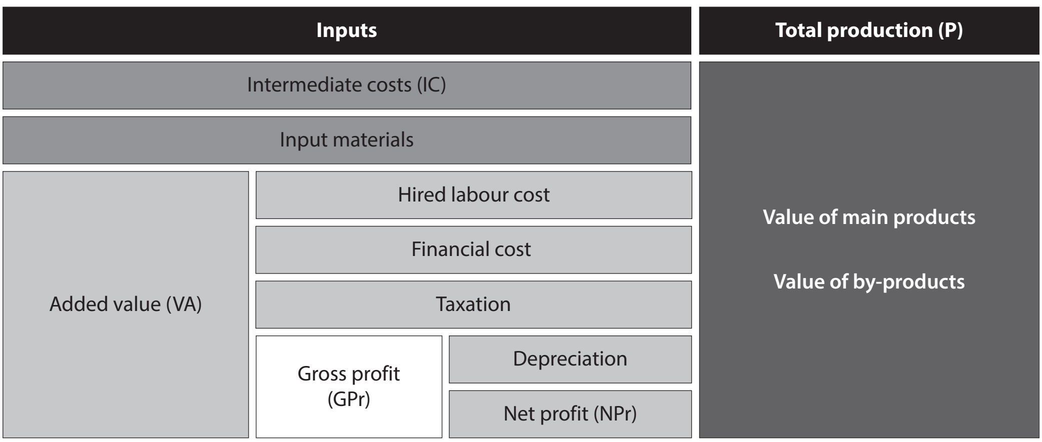

Figure 1. Financial parameters in the beef-cattle value chain

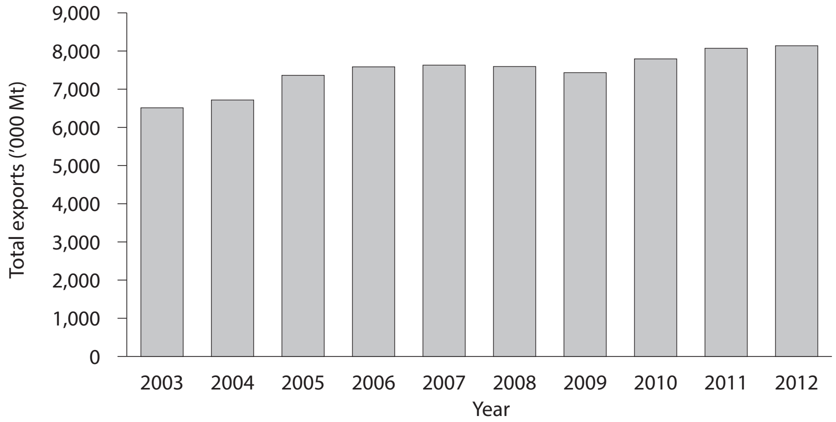

Figure 2. Global beef exports, 2003–2012. Source: Foreign Agricultural Service (2013)

Table 2. Bovine meat statistics for selected Asian countries ('000 t, carcass weight equivalent)

Country	Production		Imports		Exports		Utilisation	
	2010	2011	2010	2011	2010	2011	2010	2011
China	5,617	5,517	343	520	121	120	5,929	5,917
India	2,610	2,740	1	1	716	800	1,895	1,941
Indonesia	454	440	120	120	1	1	574	580
Japan	514	488	725	760	6	7	1,223	1,241
Korea	247	252	366	429	2	1	608	641
Malaysia	28	29	155	165	7	8	176	186
Philippines	287	290	130	145	2	2	415	433
Asia	15,285	15,269	3,183	3,493	952	1,035	17,503	17,690

Source: FAO (2011)

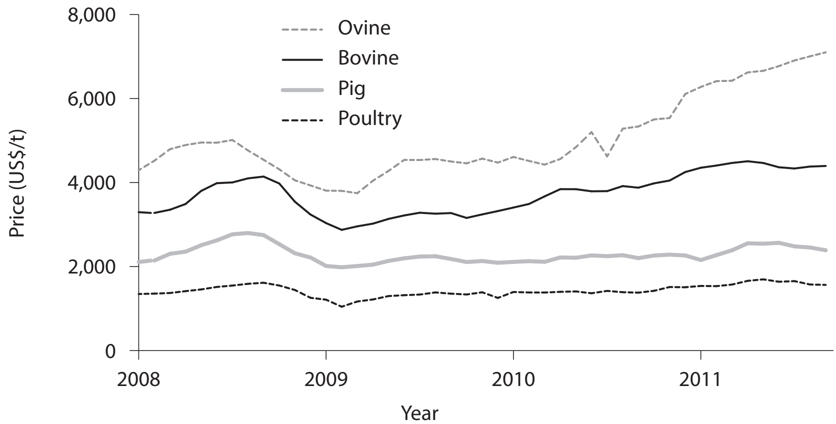

Figure 4. Price fluctuations of meat in the global market, 2008–2012 (trade-weighted international prices). Source: FAO (2011)

In recent years, the price of bovine meat has increased domestically as per the trend in the global market. For example, the price of bovine meat increased from approximately Vietnamese dong (VND)140,000/kg in 2005–06 to nearly VND280,000/kg (US$9–13/kg) in 2011–12 and further moved to VND300,000–350,000 VND/kg in 2013. This price increase in beef meat was also influenced by the reduced demand for pork and chicken meat due to the presence of antibiotic residues. Quality of beef and other meats produced domestically in Vietnam is highly regulated for food safety which has led to the adoption of organic farming. Even though the quality and quantity of domestic beef cattle have increased over time, Vietnam still has to import an additional 200,000–300,000 t of beef meat yearly, indicating a great opportunity for farmers to expand domestic beef production (MARD 2012).

Production and consumption of beef cattle in SCC Vietnam

Beef cattle are the main animals raised by farming households in SCC Vietnam. In particular, they are the main source of income during the dry season and help the households to balance their budget as well as help them to repay their debts. By-products of crops are the source of feed for cattle, which does not compete with food for human consumption. Cattle manure can be sold or used to improve the infertile sandy soils prevalent in the SCC region and generate extra income for the households. This sector can also generate additional employment for people living in this region where unemployment has been a cause of concern. However, families are limited to raising only 2–5 head of beef cattle as a result of the problems associated with the value chain. Lack of cooperation and collaboration among agents in the chain seems to be the major cause. The fluctuating prices of meat and of input materials further limit farmers' confidence. Beef-cattle production requires knowledge of market trends on supply and demand, which can only be achieved by implementing policies and by having a master plan for all sectors of beef-cattle value chain, including fodder/pasture for feed, veterinary services for health care, choice of breeds, breeding facilities, feed processing, animal husbandry techniques, credit systems, slaughterhouses, marketing and distribution. Interlinking of all the factors with chain actors and deploying an effective driver or conductor would be necessary to drive the chain to be more effective; however, natural, ecological and economic factors would need to be considered for them to be adopted for a sustainable outcome for this region.

Phu Yen province

Animal husbandry, particularly beef-cattle breeding, has been customary in the farming communities in Phu Yen province. A local cattle species called *bò vàng* is very famous in this region. Weather conditions are relatively conducive to the growth of natural pastures and other crops that provide feed for animals. Provincial policies and strategies have prioritised beef cattle as the key animal for the crop and livestock industry of Phu Yen. As a result, the cattle population has been increasing by 3–6% annually. At present, there are 233,600 head of beef cattle—mainly in mountainous districts of Son Hoa, Song Hinh and Dong Xuan—representing 60% of the whole herd population in this province. Beef exports to other provinces from Phu Yen comprise approximately 30,000 head/year, of which 70–75% is supplied to Ho Chi Minh City—considered to be the hub for meat trading and consumption. The majority of beef cattle (70%) are small in size, weighing 180–220 kg/head and 230–270 kg/head for cows and bulls, respectively, and are below the standard for export outside the country. Lack of forage during the dry season, poor health and diseases are the main reasons for the restricted body weight.

The provincial government has a strategy in place to develop and improve the quality of herd beef cattle by 2015 by: (i) improving beef breeds and services for animal husbandry; (ii) controlling epidemics and diseases effectively; (iii) advocating and campaigning among farmers to leave extensive grazing and switch to intensive breeding; (iv) investing in nutritionally balanced composed feed for fattening; (v) introducing high-biomass grass and fodder varieties; and (vi) training local staff, technicians and veterinarians to support artificial insemination of cows with purebred bulls to enhance crossbred beef-cattle ratio to 70% of herd by 2015 (Baomoi 2009).

Binh Dinh province

A survey conducted by the provincial DARD in 2011 reported that Binh Dinh had 251,485 head representing 27% of the total herd population in SCC Vietnam. The average yearly growth rate is estimated to be 11.0% compared with 6.8%/year for the entire SCC region. The ratio of crossbred cattle was 29% of the total herd in 2001 and increased to 68% by 2012. The total meat consumption in this region was approximately 23,300 t/year in 2012, representing an increase in consumption of 14,341 t/year compared with 2001. The main market for beef meat produced in Binh Dinh is Ho Chi Minh City, Dong Nai province and Da Nang (city). Beef-cattle husbandry is a stable income source for farmers and helps create jobs in rural areas.

However, there are some issues that need attention to improve the value chain, such as: (i) small-size herds and scattered production; (ii) constraints in technical application at the farm-household level; (iii) difficulties in obtaining credit for investment in animal husbandry; (iv) frequent occurrence of epidemics and diseases during cattle breeding; and (v) unstable supply for export and local markets. Most of the policies in Binh Dinh are similar to Phu Yen; however, more emphasis has been directed towards beef-cattle breeding, and slaughterhouse and industrial processing. In addition, the industry in Binh Dinh has seen: reorganisation of slaughterhouse systems; investments in developing new modern slaughterhouse facilities; introduction of more exotic breeds, such as zebu-blood bulls for insemination (increased to 82.5%); agricultural extension and demonstration of animal feed processing; exemption from land tax for introduction of large-scale cattle farms; construction of an animal-feed factory; creation of animal feeder/farmer credit from small financial sources; and building of brand names to promote demand for beef cattle from Binh Dinh (DARD Binh Dinh 2012) Studies or surveys conducted by Hoang Manh Quan (2006) and Le Duc Ngoan and Tran Thi Bich Huong (2008) reached similar conclusions to what have been discussed here for Phu Yen and Binh Dinh.

Ninh Thuan province

According to Nguyen Phu Son (2012), the natural conditions in Ninh Thuan are relatively conducive to beef-cattle husbandry, especially for grazing. Animal husbandry plays a very important role in the economy of poor households in remote mountainous areas, as it diversifies income sources and increases value generated per land unit. Despite these advantages, overall the herd population reduced by 0.5% annually in 2006–2012. Although the number of cattle increased in 2006–2010, it then decreased in 2011 and 2012 because the price of beef meat was high and a large number of live cattle were slaughtered in this period without adequate replacement. Production of beef meat increased annually by 10% from 2006 to 7,600 t in 2011.

The herd population is located mainly in the districts of Ninh Phuoc (20% of total), Ninh Son (17.5%) and Thuan Bac (17%) (DARD Ninh Thuan 2012). Local cattle species *bò vàng* comprises 65% of the herd population, with the remainder being Zebu or crossbred Sind. The average weight of mature cattle (3–5 years old) varies from 180 to 250 kg. The provincial government has a strategy to improve the quality of the cattle herd during 2010–2020 by importing new species and breeding local species with exotic ones. The average area of pasture is 0.4 hectares per household which supplies sufficient year-round forage to meet demands in many cases; however, 12% of farmers must buy forage during February to April (part of the dry season of December to May). Most cattle producers are poor, and hence 50% of households lack capital for investment in cattle husbandry (a household with four head of cattle needs VND21.5 million).

Income from beef-cattle husbandry accounts for 22–26% of the total family income. Figures from 2007 show that intermediate costs amount to nearly VND6.4 million (per head), of which 88% relate to investments for new breeds with a minor cost of 11% attributed to feed for the animals. In 2007, the annual gross return from cattle was VND10.9 million with a benefit:cost ratio of 0.7.

Recent regional trends

Production of beef cattle slowed during 2007–12 in SCC Vietnam (Figure 5) due mainly to diseases, ineffective technical input (veterinary, artificial insemination) and a fall in the price of beef meat. However, the herd population began to stabilise in 2011 due to demand for meat exceeding supply in cities such as Ho Chi Minh, Ha Noi, Da Nang, Nha Trang and Vung Tau, but it dropped again in 2012 (data not shown) because of drought, a reduction in pasture area and lack of forage in the dry season.

The price of beef meat fluctuated during 2010–11, varying between VND180,000/kg and VND250,000/kg. The price of beef meat was double to triple that of pork meat in this period. As a result, prices paid for live cattle increased and improved the beef-meat market and farmers raising cattle received a higher income than in previous years. Further, this sector is continuing to contribute an important part of farmers' incomes; it generates available capital for investments, improves cash flow and effectively uses by-products of crops (e.g. cassava leaf, peel and root, peanut stems, paddy straw, green forage etc.).

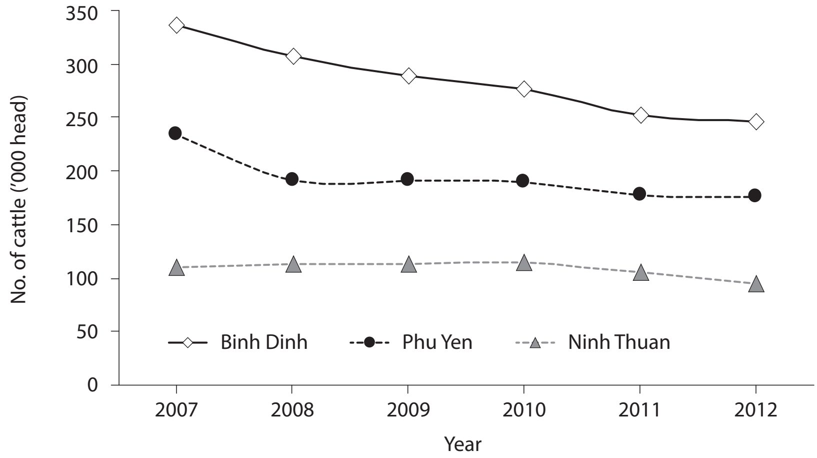

Figure 5. Population of beef cattle in three provinces of south-central coastal Vietnam (2007–2012). Source: General Statistics Office (2012)

Positioning and analysing the beef-cattle value chain

The beef-cattle value chain in the SCC region includes several actors: (i) farmers, (ii) collectors/middlemen, (iii) slaughterhouses; (iv) dealers/distributors and other agents; and (v) retailers/processing units (Figure 6).

Farmers

Farmers have 2–5 head of cattle with mixed litters of different ages which are fed together on the farm. Cattle that are 1–2 years old (beef) or a few months old (veal) are often traded through local collectors or middlemen in the latter part of the dry season and during holidays or festive occasions. In recent years, such farmers have invested capital in cattle breeding and fattening. Transactions are based on negotiations between farmers and collectors in an informal market. However, farmers face several problems, such as: (i) lack of awareness of a suitable selling price and of the market demand; (ii) weight of animals is not accurately measured (farmer loses 5–10 kg per live animal); and (iii) assessment of the live-cattle quality by the middlemen is based on the number of cattle (the assumption is higher the number, the poorer their quality) .

Assuming that a farmer buys a 1-year-old calf, this calf will be sold at 2 years old, as beef cattle, to a local collector/middleman. Total production (P) includes the value of cattle, which accounts for 69%, and manure (by-product), 31%. Intermediate costs (IC) account for 65% of P, including supplementary feed that accounts for 33% of IC. Value added (VA) accounts for 35% of P, which is contributed mainly by family labour. The net profit (NPr) generated is only VND230,000/head of cattle/year (Table 3).

Table 3. Financial analysis of live cattle husbandry of farmer, 2010–12, calculated per head of cattle for an animal bought when 1 year old and sold 1 year later

Item	Total (VND '000)	Proportion (%)
Total production (P)	5,800	100.0
Cattle	4,000	69
Manure	1,800	31
Intermediate cost (IC)	3,753	64.7 (IC/P)
1-year-old calf	2,500	
Rice straw, peanut stems	433	
Cassava pulp, flour, salt	820	
Value added (VA)	2,047	35.3 (VA/P)
Labour	1,800	
Gross profit (GPr)	247	
Depreciation	17	
Net profit (NPr)	230	

Source: project survey data

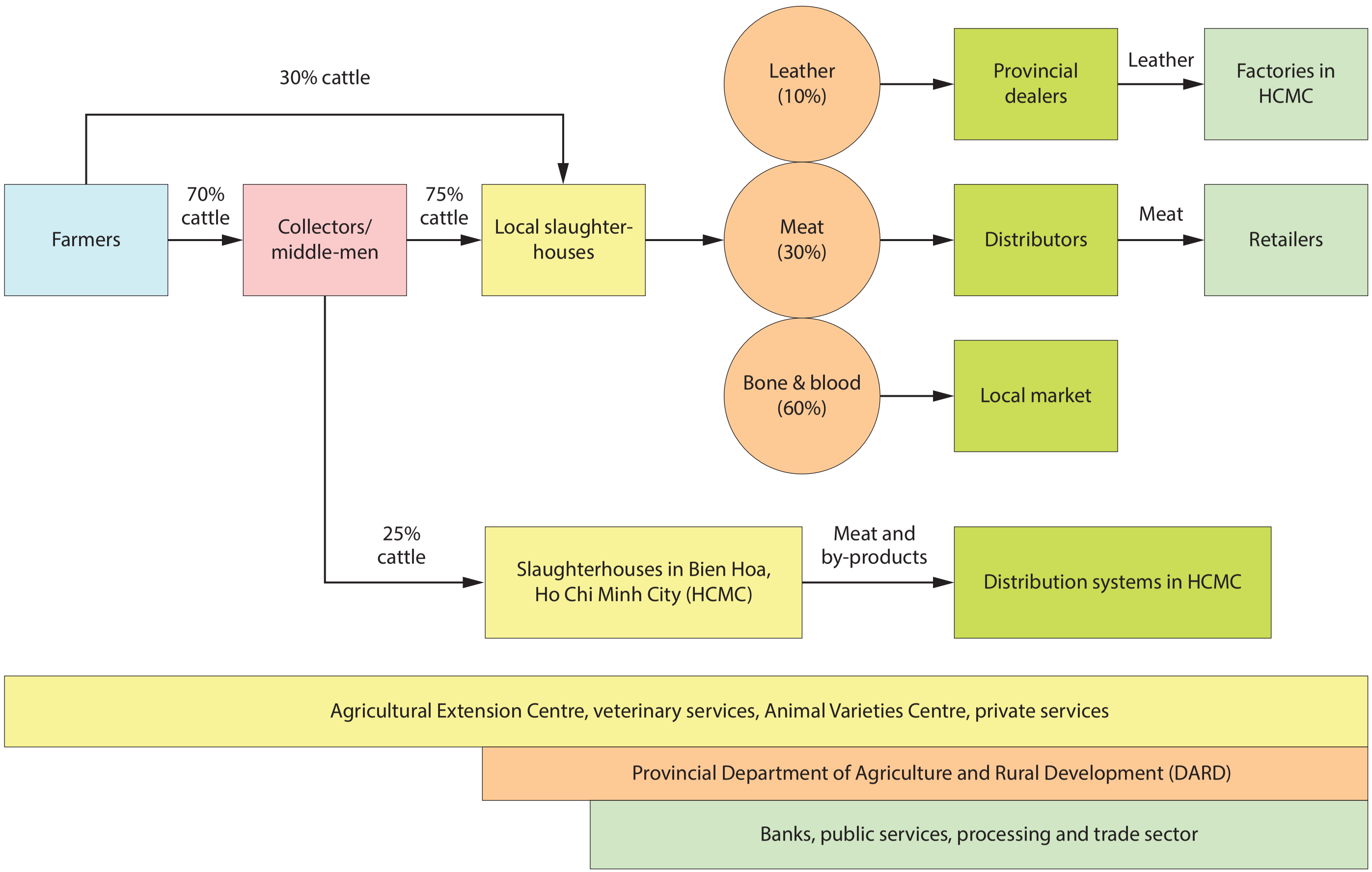

Figure 6. Beef cattle supply chain in south-central coastal Vietnam

Collectors and middlemen

Transactions between farmers and collectors/middlemen are spontaneous and the buying and selling price of live cattle is decided between them. The number of collectors and the structure of the network depend on region and are also influenced by purchasing power. Most transactions occur from December to the Tet festival (Vietnamese New Year—late January to early February). In all, 60–70% of live cattle are sold to local slaughterhouses and 25–30% are transported to the southern market. Demand for live cattle is influenced by the meat market demand in the south.

Local collectors often conduct both on-farm and off-farm activities and hence their income from purchasing and selling cattle accounts for nearly 20% of their total income (Table 4). One or two family members are engaged in the cattle business. They usually invest VND40–50 million for buying, transactions and to stock more head of cattle if they can buy at a lower price. Most of the clients are local farmers of the same village or nearby villages and payments are mainly made in cash.

Table 4. Financial analysis of collector agent, 2010–12

Item	Total (VND '000)	Proportion (%)
Total production (P)	4,500	100.0
Selling cattle	4,500	
Intermediate cost (IC)	4,000	88.9 (IC/P)
Buying cattle	4,000	
Value added (VA)	500	11.1 (VA/P)
Transportation & communication	180	
Brokerage commission	50	
Veterinary control	10	
Gross profit (GPr)	260	
Net profit (NPr)	260	

Source: project survey data

The average number of live cattle purchased monthly varies from 7 to 15, of which 20% are bought directly from farmers and 80% bought through middlemen. Cattle are then sold to wholesalers or local slaughterhouses during December and January (Lunar calendar). Sale and purchase prices are higher for the crossbred Sind cattle (60%) than the local breeds (*bò vàng*) due to their higher carcass weight. Most sales and purchases are based on verbal agreement and the delivery time from farmer's gate varies between 7 and 20 days. The price of cattle has been increasing at an average yearly rate of 3–5%.

Based on the transaction of one head of live cattle, a collector makes a profit of VND260,000 (Table 4) within 20 days. The average monthly profit for collectors is estimated to be about VND1.8 million. Value added by a collector comprises 11% of total production (P), of which 30% is from transportation costs and 10% from brokerage commission (Table 4).

Slaughterhouses

Small-scale slaughterhouses based in local areas are equipped with simple tools. They buy live cattle directly from farmers (30%) and local collectors (70%). The final products of slaughterhouses for beef meat are graded by provincial distributors for consumption in the southern region. By-products like bone, blood and intestine are sold in local markets. End users include leather dealers who are located in Ho Chi Minh City (HCMC) where they have their leather factories. At present, Binh Dinh, Phu Yen and Ninh Thuan have only small-scale slaughterhouses; hence, about 25% of live cattle are transported to slaughterhouses located in Bien Hoa (Dong Nai province, 25 km from HCMC) and HCMC itself.

After slaughtering an animal weighing 170 kg, a slaughterhouse makes VND5.3 million, of which 82% of production (P) is from meat products and the rest is from by-products (blood, tripe, bone, skin etc.). Intermediate costs (IC) make up 85% of P while agents create 15% of value added (VA) (Table 5). Net profit (NPr) represents 71% of VA.

Slaughterhouses of Bien Hoa city

The beef-meat market is very large and growing in southern Vietnam. The city of Bien Hoa, in Dong Nai province (in the south-eastern region) has slaughterhouses that have small- to medium-scale capacity to slaughter, supply and meet the demand for meat in surrounding areas of Ho Chi Minh City. These slaughterhouses act as external agents for the SCC beef-cattle value chain. There are six slaughterhouses (owned by Trung Dong slaughtering company) that can process 50–100 head of cattle per day (Trung Dong slaughtering company)[2] and they source cattle from different areas (the SCC region, Tay Ninh

[2] Bureau of Veterinary Services of Dong Nai issued the licence papers for 42 slaughterhouses and animal business enterprises in 2011.

province (south-eastern region), An Giang province (Mekong River Delta region), Cu Chi district and Cambodia). In 2011, approximately 12,300 cattle were imported from SCC Vietnam compared with 14,000 in 2010. This suggests that cattle husbandry in the SCC region is influenced by the beef market in the south.

Access to markets in the south and a good network with slaughterhouses and processing factories would help improve the value chain for SCC Vietnam. However, high transportation costs limit the expansion of the live-cattle industry in the SCC region.

Analysis of profit sharing in the value chain

The contribution of agents to value in the chain is as follows: farmers 61%, collectors 15% and slaughterhouses 24% (Table 6). Shares of profit are: slaughterhouses 54%, received in 1–5 days; collectors 25%, received in 7–20 days; and farmers, 22% received in 1–3 years. Cattle raising is an important part of the crop and livestock systems in this region as it generates extra income and its by-products (manure) are used for crop production. The farmer's family is the main labour force and manages both the livestock and the cropping systems.

Table 5. Financial analysis of slaughterhouse, 2010–12

Item	Total (VND '000)	Proportion (%)
Total production (P)	5,305	100.0
Main products	4,345	81.9
First-grade meat	1,540	
Second-grade meat	1,980	
Third-grade meat	825	
By-products	960	18.1
Blood and offal	555	
Bone, skin, horn, hoof etc.	405	
Intermediate costs (IC)	4,506	84.9 (IC/P)
Cattle	4,500	
Feedstuff	5	
Electricity and water	1	
Value added (VA)	799	15.1 (VA/P)
Labour	150	
Transportation and communication	80	
Gross profit (GPr)	569	
Depreciation	3	
Net profit (NPr)	566	

Source: project survey data

Table 6. Profit contribution of actors in the beef-cattle value chain

Value chain actor	Value added (VA)		Gross profit (GPr)		Net profit (NPr)	
	Value (VND '000)	Proportion (%)	Value (VND '000)	Proportion (%)	Value (VND '000)	Proportion (%)
Farmer/producer	2,047	61.2	247	23.0	230	21.8
Collector/middleman	500	14.9	260	24.2	260	24.6
Slaughterhouse	799	23.9	569	52.9	566	53.6
Total	3,346	100.0	1,076	100.0	1,056	100.0

Source: calculated from survey data, 2010–12

Strategies to improve the beef-cattle supply chain

Through the range of qualitative methods employed, including surveying the actors in the beef-cattle value chain in the SCC region, the problems in the chain became apparent. In Tables 7 and 8, we outline the problems and suggest solutions as well as identify the agents and agencies that would need to be involved to bring about those actions. The problems are categorised into technical (Table 7) and economic and market (Table 8) challenges.

Conclusions

From our study, overall we found that in SCC Vietnam:

- Cattle husbandry plays an important role and contributes to family income and helps to balance family budgets and cash flows for farming households throughout the year.
- The price of live cattle and beef meat has tended to increase due to relatively high demand in the market for beef meat, especially in large cities like Ho Chi Minh in the south of Vietnam, and hence has affected the overall beef-cattle value chain in the SCC region.
- The majority of farmers have become aware of cattle husbandry and have started investing capital to buy improved cattle breeds, feed, forage and in fattening the cattle.
- Lack of forage in the dry season is a constraint that influences scaling up of cattle herd size.
- Policies on installation of slaughterhouses, veterinary services, program of artificial insemination, and extension of pastures and forage areas etc. with support from government and private enterprises could improve the quality and quantity of the cattle herd in these provinces.
- Cattle husbandry uses cassava products and crop by-products as a source of feed in the dry season during shortage of feed and for fattening of cattle.
- Farmers also benefit from animals due to their by-product manure as it helps in maintaining soil fertility on sands that are a common feature of SCC Vietnam.

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Table 7. Technical challenges and proposed solutions to improve the beef-cattle supply chain in south-central coastal Vietnam

Problem	Solution	Relevant agents/agencies
Beef-cattle genetics and grass varieties	Improve performance of programs for breeding and artificial insemination Introduce high-biomass grass varieties adapted to extreme weather conditions	Extension services Veterinary services Media agencies Private enterprises Research institutes Universities Non-government organisations
Nutrition and feed	Apply nutrient-balance techniques, modify micronutrient and salt content in dry season; fatten using cassava flour and pulp, fermented rice straw and cassava leaf etc.	
Veterinary input	Increase ratio of vaccination and mapping for disease prediction	
Marketing skills and capacity	Train farmers in marketing skills and capacity	
Quality of beef meat	Apply husbandry techniques towards organic farming and good agricultural practices	

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Table 8. Economic and market challenges and proposed solutions to improve the beef-cattle supply chain in south-central coastal Vietnam

Problem	Solution	Relevant agents/agencies
Economic		
Capital	Introduce credit program for the beef-cattle husbandry (high loan and low interest rate, combined with technical support)	Credit agencies Bank for society welfare Self-help groups Private enterprises Department of Trade
Beef-cattle husbandry area	Devise a master plan for bovine husbandry in accordance with purchasing power and available resources (land, labour)	
Import of bovine meat	Implement quota on imported bovine meat, flexible tariff and non-tariff barriers to protect beef-cattle in domestic markets	
Coordination of agents	Organise contract farming and horizontal coordination to purchase input materials and encourage beef-meat consumption	
Slaughter and processing factories	Plan and build new slaughterhouses and processing factories	
Market		
Beef collection and distribution	Improve transparency in price and transaction methods between farmers and collectors, upload website to inform farmers of market-price information	Government Private enterprises Research institutes Universities Non-government organisations
Market fragmentation	Organise auction and distribution systems for beef cattle	
	Develop policies to encourage beef-cattle husbandry towards high quality, safety and competitive price compared with imported meat, target to high-income domestic market in Da Nang, Ho Chi Minh City, Ha Noi, Bien Hoa etc. and overseas countries	
Production strategy	Improve scale of herds and develop specialised farms	
Exports	Find new markets with competitive prices and high quality (organic-farming, natural grazing, no chemicals and industrial feeds)	

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Cashew value chain in south-central coastal Vietnam

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Abstract

The cashew value chain in south-central coastal (SCC) Vietnam was examined to offer appropriate solutions to improve the competitiveness of cashew production in the region. The key findings were: (i) the soil and climatic conditions in the provinces of the SCC region are favourable for cashew production; (ii) grafted cashew varieties that have good quality, high productivity, drought tolerance and pest resistance are in limited production; (iii) more support is needed for improved cultivation techniques in order for trees to fruit well; (iv) there are weaknesses on farms regarding preservation techniques and storage which make producers vulnerable to low selling prices; and (iv) appropriate government policies are needed to support trade promotion, market information, introduction of new techniques, quality management, tax incentives, credit etc. to help members of the cashew value chain develop their businesses and to develop cashew production sustainably in SCC Vietnam.

Introduction

Cashew is an important industry in Vietnam, as the country is the biggest supplier of cashew nuts to the international market. In 2012, 310 businesses exported about 220,000 tonnes (t) of cashew kernels, with a turnover of over US$1.45 billion. However, the cashew kernel industry of Vietnam is facing a lot of challenges (Nguyen Thai Hoc 2012).

The area for growing cashew has decreased gradually in recent years. In 2011, the total cashew-growing area was 360,300 hectares (ha), 5% lower than in 2010 and 10% lower than in 2009. The main reasons for this reduction were: (i) cashew orchards were old, with stunted trees causing reduced yield and lower profit; (ii) processing of cashew uses a lot of labour; and (iii) the distribution of returns was not equal among farmers, workers and processing companies.

The main aim of this study was to offer appropriate solutions to improve the competitiveness of production in the cashew value chain of the south-central coastal (SCC) region of Vietnam. The specific objectives were to:

- identify the actors in the existing domestic and export value chains, the decisive factors that affect the cashew purchasing price and farmers' opinions on the methods that may improve the value of cashew
- determine pre- and postharvest technology practices of the value chain and the quality of the products of these chain
- map the cashew value chain and its distribution channels
- propose solutions to improve the capacity of the overall cashew value chain and apply appropriate techniques in the future.

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Methodology

Relevant information was gathered directly from the Ministry of Agriculture and Rural Development (MARD), the Government Statistics Office and provincial government offices, such as the Department of Agriculture and Rural Development (DARD) in each province of SCC Vietnam.

Informal interviews were then carried out with actors in the cashew value chain. Questionnaires were developed, then completed by growers, collectors, wholesalers, packing houses, retailers and consumers. In addition, economic and financial analysis of the actors in the value chain was also determined.

Current and target cashew production in Vietnam

Although the total cultivated area for cashew in Vietnam in 2011 was 360,300 ha, the production area was lower than the cultivated area (Table 1), indicating that some cashew plantations were either old or not suited to the environment. The low yield (<1 t/ha) of cashew suggests that either the cashew variety is poor yielding or it was not being optimally managed. However, also note that productivity data obtained in this study varied between sources, so there are sometimes quite large differences between years in the cited data. According to the Vietnam Cashew Association (Vinacas), the long-term plan for cashew development to 2020 (with the vision of the Prime Minister to 2030) set optimistic targets for the cashew industry to achieve a cashew-production area of 350,000 ha with an average productivity of 2 t/ha giving total production of 700,000 t by 2020. These targets are based on policies to encourage agricultural expansion; however, specific plans for cashew have not yet been developed and deployed.

Table 1. Area, productivity and total production of cashew in Vietnam, 2010–11

Item	2010	2011	Percentage change
Cultivated area (ha)	379,300	360,300	–5.0
Production area (ha)	339,400	331,300	–2.4
Productivity (t/ha)	0.91	0.96	+5.5
Total production (t)	310,500	318,000	+2.4

Source: Vietnam Cashew Association (2012)

Global market information and product competitiveness

In 2008, there were 32 countries cultivating cashew, with a total area of 3.2 million ha and total production of 1.6 million tonnes (t), and the biggest producers were Vietnam, India and Brazil. Vietnam was in fact the top cashew kernel exporting country from 2006 to 2012, with output approaching double its nearest rival in 2012 (Table 2).

Table 2. Production of raw cashew in selected countries, 2012

Rank	Country	Output (t)	% of global	% change since 2009
1	Vietnam	1,159,600	32.3	+21.0
2	India	613,000	17.1	–11.8
3	Nigeria	594,000	16.6	+2.3
4	Côte d'Ivoire	370,000	10.3	+5.7
5	Brazil	174,300	4.9	–21.0

Source: FAO (2012)

The Vietnamese cashew market is unstable because more than 95% of cashew kernel production is exported and less than 5% is sold in the domestic market. Hence, the Vietnam cashew price depends on fluctuations in the international market. The international market price of cashew kernel dropped from around Vietnamese dong (VND)42,000/kg in 2011 to only VND28,000/kg in 2012. This led some farmers to remove their cashew trees and replace them with new crops.

In 2010, Vietnam had nearly 300 processing companies of different sizes, with a total processing capacity of about 800,000 t and employing 400,000 people. Vietnamese cashew kernels were exported to more than 90 different countries with major exports to the United States of America (USA), China and the Netherlands. In 2008, Vietnam had to import about 220,000 t of raw cashew nut valued at US$224.56 million from other countries to meet the export demand which was about 69% higher in price compared with 2007.

Cashew value chain in the SCC region

The cashew value chain involves production of cashew by farmers and collection from the farm by collectors to supply to the processing factories, after which cashew products are exported to other countries (Figure 1). The various products include fresh cashew nut, which is dried to reduce moisture content to produce raw cashew nut, from which the shell is removed to produce cashew kernel.

Actors in the cashew value chain include growers, collectors, wholesalers, purchasing and packing stations, processors, retailers and consumers (Figure 2).

According to surveys, interviews, market information and studying the whole system of the cashew value chain, the profit margin of the farmers was low compared with collectors, purchasers and processors even though they are the main members of the cashew value chain. It is necessary to make changes to the profit distribution system in the value chain to ensure that more of the profits go to the farmers if the government is serious about developing and establishing more cashew orchards to further support the cashew industry.

Of the three study areas of the SCC region, Binh Dinh province had the largest area under cashew compared with Phu Yen and Ninh Thuan provinces. Binh Dinh also had the largest system of collectors, purchasing stations and processing companies. However, the volume of raw cashew nut produced in the three provinces was not enough to supply and meet the processing companies' capacity, so factories had to import raw cashew from other provinces and countries.

Current techniques for processing cashew are heavily reliant on manual labour. Cashew-processing companies use the highest proportion of labourers (30–40%) in the whole cashew value chain. However, most of the workers are old, and young workers are reluctant to work in cashew factories. This may result in a lack of labour to process cashew in the future. Hence, it is necessary to find solutions to replace the manual labour requirement. It would also be worthwhile to identify by-products of cashew production that could be used to add value to whole of the cashew industry.

Figure 1. Some of the actors in the cashew value chain from farm to market

Economic analysis

One objective of this study was to analyse the value added at each phase of the cashew value chain. The analysis was carried out after considering the costs and the profits of the actors actors involved in the chain (from farmers to processors). Consideration was given to the processing costs of the farmers, the profits gained by the purchasing stations and the processors involved three different distribution channels (Figure 3):

i. Farmer → collector → purchasing station → processor
ii. Farmer → purchasing station → processor
iii. Farmer → processor.

In channel (i), farmers sell directly from their orchards to collectors, accounting for 25% of farmers in Binh Dinh and 75% in Ninh Thuan.

In channel (ii), farmers sell directly to purchasing stations. In Phu Yen province, 100% of households choose this channel, whereas only 50% opt for this in Binh Dinh.

In channel (iii), farmers sell directly to the processors. This channel is used by 25% of households in both Binh Dinh and Ninh Thuan.

The value-added analysis of the supply chain in these provinces shows that:

- The profit per kg of cashew that the farmers receive is VND7,971–12,150 depending on their input costs, annual costs, the price and total productivity.

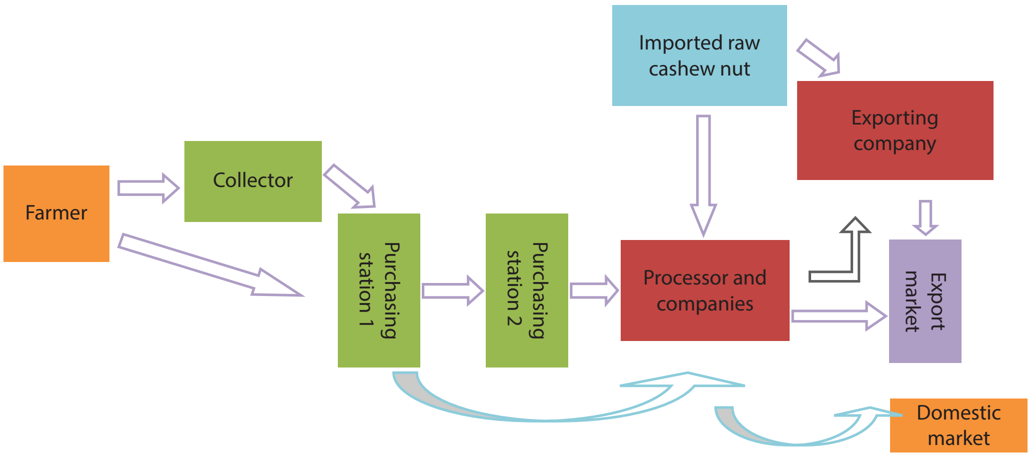

Figure 2. Cashew value chain of south-central coastal Vietnam

Figure 3. Alternative distribution channels in the cashew value chain

- The total profit that farmers make in 12 months on 1 ha of land by growing cashew varies between VND1,115,980 and VND12,257,971.
- The profit that the purchasing stations make by transacting 1 kg of cashew is VND1,167/kg, VND922/kg and VND115/kg in Binh Dinh, Phu Yen and Ninh Thuan, respectively.

The profit margin that farmers make from cashew is low, and their monthly average income is not adequate. According to the profit distribution system, farmers do not receive much from the value added to the cashew although they are the main production force. The purchasing stations and the processors play only a mediating role and find outlets for the products; however, most of the profit is concentrated in these phases. For this reason, there is a need to ascertain an appropriate method for purchasing stations and the processors to share part of their income to support farmers in further developing cashew production.

The decrease in cashew-growing area, cashew productivity and production in 2012 due to the decline in the cashew nut price is a worry and a challenge for the future of the cashew industry. MARD and the relevant boards and branch of the central government should urgently consider this and propose alternative solutions for maintaining and restructuring the cashew industry for it to be sustained.

As a result of declining production, many farmers and processors are looking at other options to make their living. Some farmers have even destroyed their cashew orchards and moved on to other types of farming. According to the Industrial and Commercial Establishment of Binh Phuoc province, in the first 6 months of 2012, 70% of processors met financial difficulties because of insufficient production. Some private processing facilities had to stop their cashew-processing business and even outsourced to foreign companies. The whole industry in the future is forecast to decrease significantly if no changes are made.

SWOT analysis of cashew value chain

A SWOT (strengths, weaknesses, opportunities and threats) analysis was carried out, the results of which are presented in Table 3.

Proposed solutions for improving the cashew value chain

The following solutions are suggested for increasing the value and efficiency of the cashew value chain and, in particular, for increasing profits margins for cashew farmers in the SCC region, and for the whole of Vietnam in general.

Variety

Currently, the national average productivity of cashew per hectare is low and the nut size is small. This means that nuts for export reach grade W240 and W320 at best, so the average price of Vietnam's exported cashew kernel is low. It is necessary to have an official, concrete and detailed plan for cashew-growing areas, emphasising intensive cultivation.

The intensive zones should be concentrated in areas that have fertile soil. To achieve high productivity of about 1.5–2.0 t/ha, besides finding high-productivity varieties like DDH66-14 and DDH67-15 to replace old and stunted varieties, farmers also need to apply fertilisers and pesticides to manage cashew trees to yield to their maximum potential. Further research should focus on developing new cashew varieties that have good-quality fruits and which are highly productive, pest-resistant and able to adapt to the changing climate of Vietnam.

Suitable harvesting and postharvest techniques for improving the quality of cashew kernels

It is necessary to set up programs to train farmers, traders, purchasing stations, processing companies and extension staff to use improved techniques to maintain the quality of cashew kernels and for harvesting through to drying raw cashew at orchards and purchasing stations before it is processed.

After harvesting, cashew nuts have to have their stems and outside matter removed in order not to interfere with cashew-kernel grading. Fresh cashew nuts may have a moisture content of about 17–19% which must be dried on the ground or passed through a drying system until the moisture content is lowered to about 11%. Then, before packing in gunny sacks, dried nuts must be cooled to ambient temperature to retain good quality and to avoid any fungal infections. In case of heavy rain or no drying yards, cashew nuts should be spread thinly and dried with a ventilating or forcing fan. The steps required are summarised in Figure 4.

Increasing mechanisation of cashew processing and utilising by-products

Because cashew-nut processing uses much manual labour, the productivity is low. It is necessary to find

Table 3. SWOT (strengths, weaknesses, opportunities and threats) analysis of the cashew value chain

Strengths	Weaknesses
Techniques for growing cashew are simple. Technology transfer is supported by the government, provincial Departments of Agriculture and Rural Development, science centres, research institutes and universities. Local active trading systems already exist. The cashew nut industry develops quickly and applies progressive techniques in processing. Given that Vietnam's raw cashew nut supply is too low to supply the processing industry, demand for domestic raw cashew nut is high, encouraging an increase in cashew production area. Some large-scale processors have improved significantly in mechanisation of the raw material processing phase (shelling, peeling, grading based on kernel colour or size) and in food safety issues (researching the material's origins).	Productivity is low due to an extensive cultivation approach and lack of fertilision, irrigation and branch pruning. Global climate change, changeable weather and rain during the flowering period cause low fruit bearing. Productivity is affected by insect pests. Crops are grown on infertile soils and barren hillsides with lack of water, leading to low productivity. Some plants are grown from seed, some orchards are over 20 years old, and need to be replaced. Crops are planted at excessively high density which reduces productivity. The application of a breeding program is still low and ineffective. The farmers disregard the importance of irrigation and fertiliser application for grafted cashew seedlings, so many seedlings die. Some members of the cashew value chain, mostly farmers, are not trained in the pre- and postharvest handling techniques and lack market information when required and are unable to focus on their cashew business.
Opportunities	**Threats**
Domestic cashew nut supply cannot fulfil the requirements of processors, hence there is high potential to expand production. Expansion of the cashew industry offers a major source of employment for the population in the SCC VN region. There is high demand for cashew nut exports.	Main market for cashew kernels is export of raw nuts, so the value of processing is low. Processors depend on the world market; consequently, cashew nut-processing returns are not stable. Negative practices do occur in competitive markets, e.g. mixing of poor-quality nuts, soaking nuts in lime water (calcium hydroxide) leading to quality reduction, and wide fluctuations in the price of raw materials—hence, the trading results of many enterprises are not stable and carry high risks. Because cashews are less economically profitable than the other trees, farmers are decreasing the area for cashew cultivation. Domestic cashew-nut supply is inadequate to fulfil the requirements of processors, so processors depend on imported cashew nut. Processors lack automation for cutting and splitting cashew shells, leading to a shortage of labour. Cashew production and trading still goes through many intermediate stages. Some farmers and processors do not focus on the quality of cashew kernels.

a way to replace this labour, as well as take advantage of by-products of the process, such as cashew fruit, in order to increase the value of the cashew value chain.

Prioritising mechanisation during the currently manual phases of cashew processing, such as shelling and splitting cashew nuts, and peeling and grading kernels (including colour grading) is a necessary step in order to reduce labour requirement and costs. Use of new steaming and drying equipment before shelling and splitting cashew nuts to help reduce the processing time and increase processing efficiency will allow large labour savings. Researchers at the Sub-Institute of Agricultural Engineering and Post-Harvest Technology have successfully applied heat-moisture treatment to raw cashew-nut processing to reduce the processing time (from 36–72 down to 18–22 hours from raw material to final product) and reduce breakage of kernels (see Figure 5).

At a cashew-processing equipment workshop in 2012, held in Binh Duong province by Vinacas, different cashew-processing machines were demonstrated, such as an automatic shelling and cutting machine (Khuon May Viet Co. Ltd and Son Viet Co. Ltd), KZ-type incineration boiler (Thien Phat Co. Ltd) and kernel-roasting machine (Figures 6–8, respectively).

An additional study was conducted to increase the value of the cashew supply chain by looking at possible by-products of cashew processing that could be used productively, which may include the cashew fruit, shell and testa (skin).

Marketing

The Vietnam cashew market was found to be unstable because more than 95% of cashew kernels were exported. For this reason, the Vietnam cashew price fluctuated a lot and depended on the international market. Hence, it is necessary to have a strategy to expand the market and to increase the competitiveness of Vietnamese cashew products through international and domestic trade fairs and advertising through the media. However, this requires the cashew processors and cashew export companies to improve the quality of products, comply with international standards and establish trademarks for Vietnamese cashews. Secondly, it is necessary to build the pricing system for potential markets, select loyal customers and protect the domestic market. Thirdly, it is vital to strengthen the management of transport, shorten supply times and increase turnover. Finally, the state should have a policy to support members of the

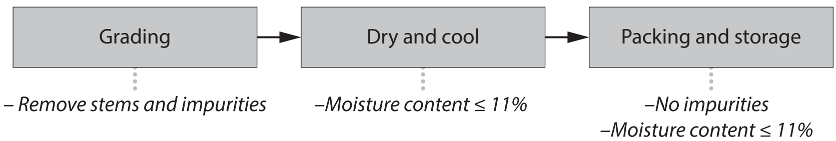

Figure 4. Essential steps for optimal harvesting, drying and packing of raw cashew nuts at the farmer level

Figure 5. Equipment for heat-moisture treatment of raw cashew (capacity 1 t/hour) using steam-drying technology designed by Sub-Institute of Agricultural Engineering and Post-Harvest Technology (shown from either end of the machinery)

supply chain with, for example, technical support (varieties, fertilisers, irrigation, pesticides etc.) and low-interest loans for companies to purchase processing equipment. In hard times, the state could reduce taxable income to help businesses survive and grow.

Conclusions and recommendations

The soil and climatic conditions in the provinces of the SCC region are favourable for cashew production. Seasonal harvesting of cashew in these provinces is later than in the Mekong Delta River and south-eastern regions and this could be a competitive advantage for supply of cashew to the market in the off-season. Cashew production in Binh Dinh, Phu Yen and Ninh Thuan provinces is on a large scale; however, lack of investment results in low productivity and low profit. The linkages between actors in the value chain (cashew growers, collectors, wholesalers and retailers) are weak and limit the ability of all involved to further improve the chain. Farmers' profit margin is low, even though they are the main contributors, and they rely on climate to maximise cashew production, whereas the collectors, purchasers and processors are secondary players but are able to make better profits than the farmers.

The provinces under cashew production in the SCC region should plan and develop strategies for improvement of the cashew value chain by establishing cashew cooperatives for farmers to create large-scale production areas. In addition, training should be provided to farmers to adopt new technologies with special reference to plant protection and harvesting techniques. Provision of market information, especially in regard to the price of cashew nut and its by-products, is essential for farmers to maximise their profits.

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Figure 6. Machine for cutting and splitting cashew nuts

Figure 7. KZ-type incineration boiler

Figure 8. Machine for roasting and salting cashew nuts

Analysis of the value chain of mango in south-central coastal Vietnam

Luong Ngoc Trung Lap and Nguyen Minh Chau[1]

Abstract

Analysis of the mango value chain in south-central coastal (SCC) Vietnam was carried out to offer appropriate solutions to improve competitiveness of mango production in this region.

The key findings regarding the mango value chain in the SCC region were: (i) the soil and climatic conditions in the provinces of the region are favourable for the expansion of mango production—seasonal harvesting has a competitive advantage to supply mango in the off-season (compared with the Mekong River Delta region); (ii) the number of fruit traders is low and linkages between mango growers, collectors, wholesalers and retailers are still limited; (iii) mango growers contribute the largest proportion of added value in the chain and the spread of profits along the chain seems reasonable.

Introduction

Analysis of the mango value chain in south-central coastal (SCC) Vietnam was an activity of component 1 ('Value chain analysis for sustainable and profitable farming systems on the south-central coast') of the Australian Centre for International Agricultural Research (ACIAR) Project SMCN/2007/109 (*Sustainable and profitable crop and livestock systems for south-central coastal Vietnam*). The Southern Horticultural Research Institute (SOFRI) was selected to implement the investigations on the mango value chain in the SCC region. The main objectives of the study were to offer appropriate solutions to improve the competitiveness of mango production in the SCC region by:

- analysing relevant information from growers through to consumers on current farming and marketing practices of mango in three SCC provinces—Binh Dinh, Phu Yen and Ninh Thuan
- identifying essential actors in the mango value chain and evaluating the role of each
- identifying technical, financial and political constraints/problems and proposing appropriate solutions to support and implement pathways for improvements in the chain.

Methodology

Relevant information on mango was collected from the Ministry of Agriculture and Rural Development (MARD), the Government Statistics Office (GSO) and provincial government offices such as the Department of Agriculture Research and Development (DARD) by:

- informal interviews of the actors in mango value chain;
- organising surveys using questionnaires developed for value-chain actors (growers, collectors, wholesalers, packing houses, retailers and consumers)
- analysing economic factors for the main actors involved in the mango value chain.

Current mango production in the agricultural zones of Vietnam

Mango is grown widely in Vietnam and is dominated by the Mekong River Delta region which represents

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61% of the total produce. In 2010, the total area and production of mango in Vietnam were 86,418 hectares (ha) and 686,700 tonnes (t), respectively. The SCC region ranked third in both area and production, contributing 10.2% and 7.6%, respectively (Figures 1 and 2).

Area and production of mango in three SCC provinces

From 2000 to 2010, the mango-growing area increased significantly in Binh Dinh province, but much less in Ninh Thuan and Phu Yen provinces

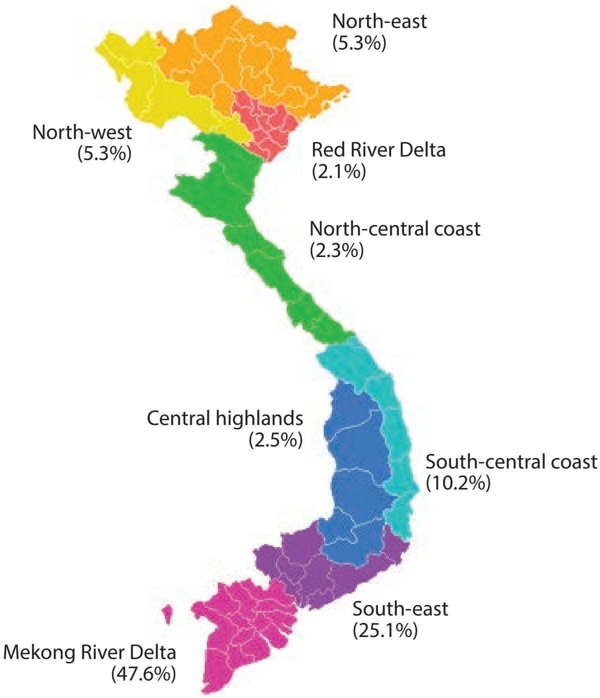

Figure 1. Mango-growing area in Vietnam's eight agricultural zones, 2010

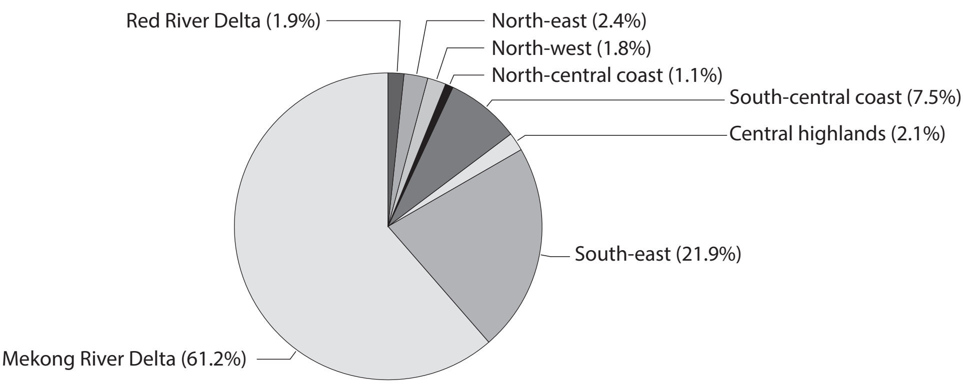

Figure 2. Mango production in Vietnam's eight agricultural zones, 2010. Source: National Institute of Agricultural Planning and Projection (unpublished data, 2012)

(Figure 3). In 2000, the areas planted to mango in Binh Dinh, Phu Yen and Ninh Thuan were 1,020 ha, 90 ha and 495 ha, respectively, increasing by 2010 to 1,727 ha, 98 ha and 565 ha, respectively (Figure 3). Phu Yen province remained a small player during the period.

Increases in mango-growing area and production led to the formation of cooperatives in Binh Dinh and Ninh Thuan provinces which played an important role in the development of mango cultivation and production in SCC Vietnam. If production in Binh Dinh and Ninh Thuan are to be further increased, large-scale infrastructure investments are required to improve irrigation, harvesting and provision of market information. Interestingly, even though the area under mango cultivation in Binh Dinh is nearly three times higher than in Ninh Thuan (Figure 3), the amount of mango produced is not much different between the two provinces (Figure 4).

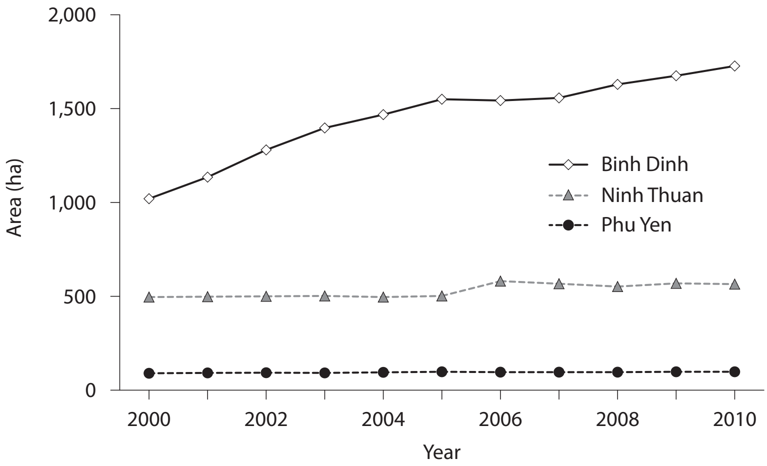

Figure 3. Mango-growing area in three south-central coastal provinces. Source: Binh Dinh, Phu Yen and Ninh Thuan Statistical Offices (2011)

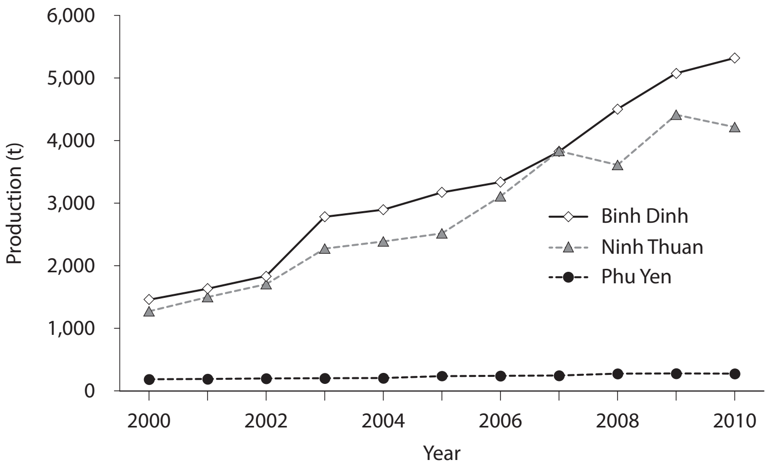

Figure 4. Mango production in three south-central coastal provinces. Source: Binh Dinh, Phu Yen and Ninh Thuan Statistical Offices (2011)

Market information and product competitiveness

In 2010, nearly 3% of all mango produced in the world was exported. The remaining 97% was consumed in the producing countries (own calculations based on FAO 2011). The world's mango exports increased from 541,000 tonnes (t) with a value of US$372 million in 2001 to 1.0 million t (Mt) valued at US$950 million in 2011. The average annual growth rate of production and value of exported fresh mango increased by 5.5% and 6.2% per year, respectively, during 2009–2011. The world's mango exporters are mostly concentrated in Latin America and the Caribbean, accounting for over 50% in both quantity and value of global fresh mango exports. India is the largest exporter in the world. However, Thailand, Pakistan and the Philippines remain the most important mango suppliers in the Asian region.

According to Vietnam's Ministry of Industry and Trade, in 2012, about 1,500 t of mangoes were exported at valued of US$6.2 million, contributing about 1.7% of the total fruit export value of the country.

Domestically, mango is consumed in various regions/cities of the country. Ho Chi Minh City and Hanoi are the two biggest cities and also the biggest consumers of fresh mango in Vietnam. Mango produced in the SCC region is mainly consumed locally and in neighbouring provinces; however, it has made its way to Ho Chi Minh City and Da Nang city as well. The timing of the mango harvest is later in the SCC region than in other regions, which provides an opportunity for SCC mangoes to be sold in Ho Chi Minh and Da Nang cities as the mango season comes to an end in the Mekong River Delta region.

Mango value chain in the SCC region

The actors and processes in the mango value chain in SCC Vietnam are shown in Figure 5. Currently, mango in the SCC region is mainly consumed in the domestic market as fresh fruit. Processed mango products are not readily available. The value chain comprises two main pathways:

- farmers → collectors → wholesalers (local/out-of-province) → retailers → consumers
- farmers → local wholesalers → out-of province wholesalers → retailers → consumers

The main difference between the two pathways is whether farmers deal directly with local wholesalers, or if they work through collectors; however, either way the produce eventually makes its way through retailers to consumers.

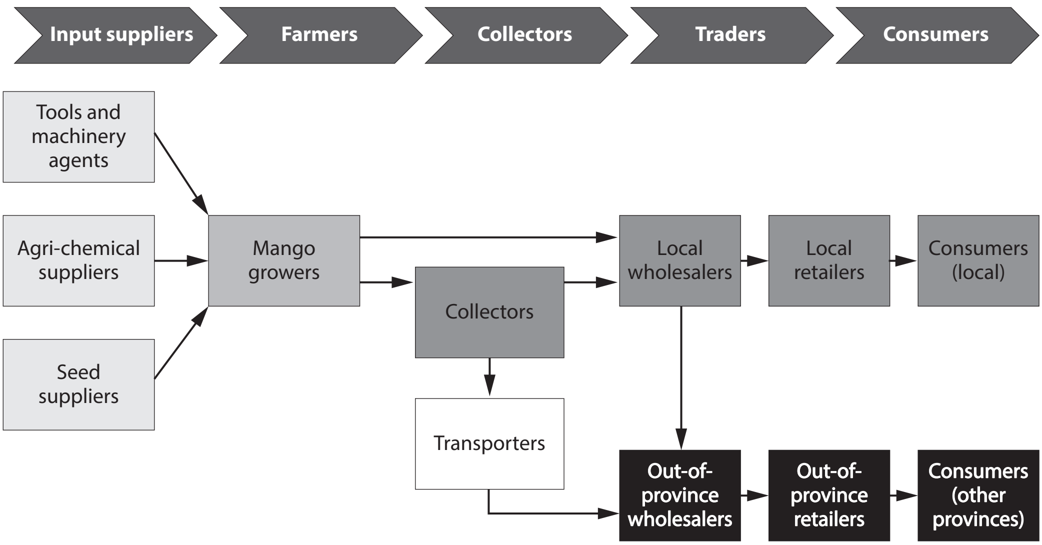

Figure 5. Schematic diagram of the stages involved in the mango value chain in south-central coastal Vietnam

Description of the mango value-chain actors

Producers (farmers)

Mango in Binh Dinh, Phu Yen and Ninh Thuan provinces is almost all grown by farming households. Farmers play the key role in organising all stages of the mango value chain from land preparation and planting to selling to collectors/wholesalers. The area of agricultural land planted to mango is 1–2 ha for 50% of farmers in Binh Dinh, followed by 76% in Phu Yen and 46% in Ninh Thuan. The largest and smallest areas of mango are 11.0 ha and 0.1 ha, respectively. Cat Hoa Loc is the most widely planted variety in Binh Dinh, Phu Yen and Ninh Thuan, grown by 68%, 43% and 45% of households, respectively. Other varieties of mango, such as Kieusavoi (from Thailand), Cat Chu and Tu Quy, are also gaining popularity. Local mango varieties, such as Cat Moc, Da Trang and Queo, are grown by only 20% of households. Even though they require low investment, they are becoming unpopular because of their low yields and quality. Farmers are now switching from local varieties to new varieties and are following new planting techniques and, hence, the new mango varieties in the SCC region are mostly 5–10 years old. Mango yields vary markedly between households in SCC Vietnam: 14% produce <1 t/year; 46% produce 1–5 t/year; 31% produce 5–10 t/year; and 9% produce >10 t/year. About 82% of total households sell their produce directly to collectors at the farm gate. Most of the farmers have no grading system and sort their fruits just before marketing (if they are dealing directly with wholesalers).

Collectors

Collectors play the role of middleman between farmers and wholesalers in many cases. They also provide feedback to farmers on market demand and price in a timely manner. The collectors harvest mango fruit themselves and sort it into four grades. Mango is harvested from early morning till noon. The collectors are immediately paid in cash after purchase by the wholesalers/retailers and make 10–20% of the total revenue (Vietnamese dong (VND)1,000–2,000/kg). They involve their own family as a source of labour. Their capital investment is as little as around VND5–15 million. They buy and sell fruit within a day and, hence, such trading does not require large capital investment. Motorcycles are mainly used to transport mango from the farm to wholesalers.

Local wholesalers/packing agents

The local wholesalers/packing agents play an important role and potentially have large amounts of capital for investment. They are mostly local people, are well experienced (2–20 years) and have been running businesses for the past 5–10 years. They trade 3–5 different types of fruit (mango, banana, dragon fruit, orange, pomelo etc.). The business scale varies between local wholesalers and ranges from tens of VND million to hundreds of VND million. In all, 67% of wholesalers fall into the category of VND100–500 million, with only 8% running over VND500 million for their wholesale business.

During the harvesting season, 50% of the local SCC wholesalers trade 2–4 t mango/day (50–100 t/year) with only 8% trading over 300 t/year. The profit margin for local wholesalers is about 5–15% of the total revenue. Most local wholesalers involve their own family members or relatives in their business. About 2–3 extra labourers may be hired during the peak season for sorting, packing, loading and other labour. The owners exclusively perform work that directly relates to business management and most business exchanges are made in cash.

The local wholesalers have to bear all costs of collecting, sorting, transport and tax to the point where the mango arrives at the external wholesaler destination. If they are dealing directly with farmers, they pay a lower price than if they're buying from collectors The reason for this is that mangoes collected from farmers need to be sorted, whereas collectors have already done this. Hence, local wholesalers prefer to buy from mango collectors than directly from farmers.

Out-of-province wholesalers

Out-of-province wholesalers carry out their business mainly at the fruit wholesale markets in Ho Chi Minh, Nha Trang and Da Nang cities. Their business is specific to a particular fruit. The business activities are similar to those of local wholesalers/packing agents. Their main customers are retailers in those cities.

Their business expenditure includes the costs of hiring a fruit shop in the wholesale market, handling and transport, and labour for sorting, packaging etc. Most of them operate as commission agents, charging a fee of around 10–15% of total revenue after all costs are deducted from the total revenue.

Retailers

Retailers supply both domestic and imported fruits directly to customers. Retailers sell fruits in many locations, such as wet markets, fruit markets, street markets and street shops. There are two groups of retailers: local retailers and retailers in other provinces. Local retailers collect grade 2 and 3 mango from local wholesalers and then supply to consumers within the province. Their profit margin is around VND3,000–5,000/kg. Retailers in other provinces collect fruit from wholesalers then sell to consumers in their provinces. The selling price is nearly double because they have to pay the middlemen.

There are large numbers of retailers, and their capital investment and selling volumes are low. The business capital for 42% of retailers is approximately VND5–10 million and only 8% exceed VND10 million. However, their selling and buying cycle is fast. They buy 20–40 kg of mango and other fruits at a time, and repeat the cycle within 2–3 days. The mangoes are sold within 3–5 days, at an average rate of 5–10 kg/day. Mango quality remains high within 2 days, but after 2–3 days, the quality starts to deteriorate and consequently the price is reduced. To balance this, retailers usually sell mangoes to customers at a higher price initially, when the fruit quality is good, and charge lower price as quality deteriorates.

Consumers

Usually consumers evaluate mango by its look and by hand feeling. The selection criteria applied are: size, maturity, shape, ripeness, colour, taste and flavour. Most consumers (78%) buy fruit from retailers or street shops that are closer to their home due to its convenience, while others buy fruit from the supermarket because they believe this assures good quality and price. About 90% of consumers cannot identify mango varieties and rely on retailers to name them. Consumers buy 1–2 kg of mango at a time, 1–2 times a week. Consumers have no concerns about the food safety and most of prefer the fresh fruit. Most consumers prefer buying the Cat Hoa Loc variety if it is moderately priced.

Economic analysis of mango production in the three provinces

Binh Dinh province

The Kieusavoi (Thai) variety had the highest profit margin of VND36.1 million/ha, followed by Cat Hoa Loc with VND29.6 million/ha (Table 1). Local mango varieties had the lowest profit margin of VND9.7 million/ha due to low investment, productivity and quality.

Phu Yen province

In Phu Yen, the Cat Hoa Loc variety had the higest profit margin (VND26.9 million/ha), whereas local mango varieties had low profit margins of VND5.6 million/ha (Table 2) due to low investment, productivity and quality.

Table 1. Economic analysis of mango production in Binh Dinh province

Item	Cat Hoa Loc variety	Kieusavoi variety	Local varieties
Output (kg/ha)	4,650	4,800	2,400
Average price (VND/kg)	11,500	13,500	6,000
Total revenue (VND million/ha)	53.5	64.8	14.4
Total cost (VND million/ha)	23.9	28.7	4.7
Profit (VND million/ha)	29.6	36.1	9.7

Table 2. Economic analysis of mango production in Phu Yen province

Item	Cat Hoa Loc variety	Local varieties
Output (kg/ha)	4,200	1,800
Average price (VND/kg)	11,500	5,000
Total revenue (VND million/ha)	48.3	9.0
Total cost (VND million/ha)	21.4	3.4
Profit (VND million/ha)	26.9	5.6

Ninh Thuan province

The mango farmers in Ninh Thuan made investments in mango plantations due to favourable weather conditions and, in 2011, mango productivity in this province was the highest in SCC Vietnam. The profit margins for the Thai Kieusavoi and Cat Hoa Loc varieties were VND42.1 million and VND35.6 million/ha, respectively. The local mango varieties had a profit margin of only VND7.0 million/ha.

Economic analysis of the mango value chain

The results of an economic analysis of the value chain in Binh Dinh province based on 1 t of mango being sold locally, including all of the actors involved, are given in Table 4. Input costs are the biggest expense incurred during the whole process. The costs, profits and margin for each actor are detailed in Table 5 and Figure 6.

Table 3. Economic analysis of mango production in Ninh Thuan province

Item	Cat Hoa Loc variety	Kieusavoi variety	Local varieties
Output (kg/ha)	5,400	5,500	2,200
Average price (VND/kg)	11,500	13,500	5,000
Total revenue (VND million/ha)	62.1	74.3	11.0
Total cost (VND million/ha)	26.5	32.2	4.0
Profit (VND million/ha)	35.6	42.1	7.0

Table 4. Cost of value added by actors in the mango value chain (VND ’000/t)

Cost	Farmer	Collector	Wholesaler	Retailer
Inputs	5,120	11,000	13,500	16,000
Labour		20	20	20
Transport		450	700	350
Packaging		30	50	400
Loading		100	100	60
Rent			40	30
Tax			50	25
Power, fuel			10	10
Marketing		15	20	10
Depreciation		35	10	10
Total	5,120	11,650	14,500	16,915

Table 5. Cost, profit and margin for each actor in the mango value chain

Particulars	Farmer	Collector	Wholesaler	Retailer	Total
Total cost (VND ’000)	5,120	11,650	14,500	16,915	
Value added (VND ’000)		650	1,000	915	2,565
Value added (%)	67	8	13	12	100
Price (VND ’000)	11,000	13,500	16,000	21,000	
Profit (VND ’000)	5,880	1,850	1,500	4,085	13,315
Profit (%)	44	14	11	31	100
Margin (VND ’000)	11,000	2,500	2,500	5,000	21,000
Price (%)	52	12	12	24	100
Cost:price ratio	47	86	91	81	
Profit:price ratio	53	14	9	19	

The results indicated that the biggest contribution of actors in the mango value chain in Binh Dinh province was by farmers (67% of total value added), followed by wholesalers (13%), retailers (12%) and collectors (8%). Farmers received the highest profit (44% of total profit) and contributed the most in the total value added. Therefore, the distribution of profit to farmers in mango value chain in the Binh Dinh province is reasonable. Retailers received about 31% of total profit, followed by collectors (14%) and wholesalers (11%). However, the actual total profits of wholesalers are underestimated given that the quantity of sales of wholesalers are several times higher than the other actors in the chain.

Opportunities and challenges for the mango value chain in SCC Vietnam

The results of a SWOT (strengths, weaknesses, opportunities and threats) analysis and a summary of possible means to improve the mango value chain in the SCC region are detailed in Tables 6 and 7, respectively.

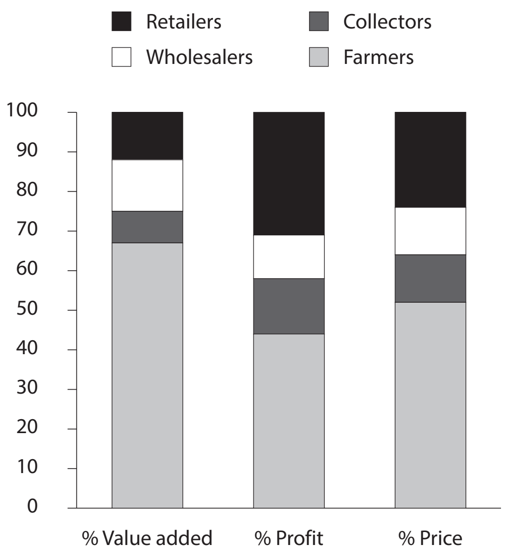

Figure 6. Distribution of cost, profit and margin in value chain of mango

Conclusions and recommendations

Conclusions

- The soil and climatic conditions in the three focal provinces of SCC Vietnam are favourable for development of mango production.
- Late harvesting of mango in the SCC region as against the Mekong Delta River and south-eastern regions can be of advantage in the market.
- Mango production in Binh Dinh, Phu Yen and Ninh Thuan provinces could be increased but lack of investment, low productivity and low profit margins restrict such expansion.
- The number of fruit traders is low and linkages between mango growers and others (collectors, wholesalers and retailers) are still limited.
- Mango growers contribute the most value added to the chain and profits they receive are reasonable.

Recommendations

- Develop plans and strategies for the SCC region to improve the mango value chain based on the solutions recommended in Table 7.
- Develop projects for funding to further research and development strategies to improve the value chain of mango for the region.
- Establish mango cooperatives to create large-scale production areas.
- Train and educate farmers on the latest technological methods to move away from traditional farming systems.
- Provide market information to farmers (demand, supply, price etc.) and develop marketing strategies for SCC produce.

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Table 6. SWOT analysis of the mango value chain in south-central coastal (SCC) Vietnam

Core problem	Strengths	Weaknesses
Varieties	Various and abundant mango varieties are available. There are many good-quality mango varieties.	Farmers have limited knowledge of mango varieties, so suboptimal choices are made. Supply of of good seedlings (right variety, good quality) is lacking.
Soil and weather	Weather conditions are favourable for developing mango production. Seasonal harvesting of mango in SCC is later (off-season) than in the Mekong River Delta region.	Frequent changes of weather (rain in February and March) negatively affect flowering and hence mango productivity. Fast growth of industrialisation in SCC region has somewhat influenced land capital, agricultural land prices and farming environment.
Quality of product	High-quality mango can be produced naturally (sweet, yellow flesh, delicious flavour).	Production of mango is scattered, which makes it difficult to administer and control product quality and safety. Farmers follow traditional mango production methods. There is no trademark to distinguish SCC mango in the marketplace.
Prices	Mango is often priced higher than other fruits. Supermarkets pay a higher price than other retailers.	Prices in local markets are not stable. There is competition from other fruits during the harvest season and with fruits imported from China andThailand. Cooperatives have not operated effectively.
Relationships in the value chain	Link model has been established (farmer–farmer; farmer–company/ supermarket). Government supports farmers through agricultural extension, i.e. technical training, financial support for demonstration model etc. Agencies (DARDs, Industry and Trade Departments, ASISOV, SOFRI) play an important role in providing technical knowledge and training to farmers.	Policies to assist and stimulate actors in the value chain aside from farmers are limited. Linkages between farmers, collectors, wholesales and traders in the value chain are limited.
	Opportunities	**Threats**
Market demand	High demand for mango exists in the local and neighbouring markets in Vietnam. There are potential export markets, such as Korea, Japan, Hong Kong, Europe and New Zealand.	Domestic market: inability to meet requirements for large quantities and stable supply. Export market: inability to meet requirements regarding large quantities, uniform quality, seasonality and especially quarantine restrictions (e.g. pests) and pesticide residues.
Products/ competition	Mangoes are easily transported to other provinces and cities. Mango in SCC is produced later than in the Mekong River Delta and south-eastern regions.	Different kind of fruits are available (durian, rambutan, longan, pomelo) in the market in May–July, which affects demand for mango. Mango from SCC has to compete against mango imported from Cambodia, and Thailand (cheaper).

Note: DARD = Department of Agriculture and Rural Development; ASISOV = Agricultural Science Institute for Southern Central Coast of Vietnam; SOFRI = Southern Horticultural Research Institute

Table 7. Solutions to improve the mango value chain in south-central coastal (SCC) Vietnam

Factor	Main difficulties	Solutions	Who solves?	How to solve?
Farm inputs				
Seedlings	Lack of good seedlings Poor management of seedlings	Transfer mango-breeding techniques to farmers Increase research to develop new mango varieties Provide better quality seeds and saplings	SOFRI, DARDs, agricultural seed centres	Provide training to farmers on mango-breeding techniques Provide farmers with better quality seeds Find the funding for research
Capital	Lack of capital	Support the policies for developing the mango value chain	Banks, farmers' unions	Provide low-interest loans to farmers
Extension	Lack of fruit extension staff	Enhance the knowledge of extension staff	Institutes (DARDs, SOFRI, ASISOV)	Train and transfer new technologies
Information	Farmers passive in finding market information	Improve farmers' skills in sourcing market information	Institutes (as above), farmers	Provide training on obtaining market information
Farmers				
Cultivation	Irregular irrigation Low investment, productivity and profit	Improving the farm scale and investment	Government, institutes (as above), privatecompanies	Plan areas of mango production and build projects on fruit development
Cultivation techniques	Most farmers grow mango traditionally Farmers lack experience in growing fruit trees. Low productivity Quality is not stable	Improve cultivation techniques Change farmers' ways of thinking and working Provide model of GAP standards for mango	Institutes, DARDs, companies, farmers	Provide training and workshops on GAP standards Build the model of mango GAP standards
Markets				
Trademark	No trademark exists for SCC mango	Update knowledge in marketing and branding Improve quality and reliable supply of local product Promote local product	Farmers, companies	Register the trademark Promote product at fairs and exhibitions Progress mango production compliance with GAP standards
Marketing	Product is not well known by customers and consumers			
Domestic market	Product quantity and quality are not stable Lack of information market			
Export market	Mango is not still exported as it does not meet export requirements (quantity, quality and standards)			

Note: SOFRI = Southern Horticultural Research Institute; DARD = Department of Agriculture and Rural Development (provincial); ASISOV = Agricultural Science Institute for Southern Central Coast of Vietnam; GAP = good agricultural practices

Market and economic analysis of sesame production in south-central coastal Vietnam

Nguyen Thanh Phuong and Nguyen Van Duong[1]

Abstract

Market and economic analysis of sesame was carried out to assess its suitability for inclusion in the farming systems of south-central coastal (SCC) Vietnam. The analysis included conducting a survey of farmers, collectors, transporters and consumers in three provinces of the SCC region—Binh Dinh, Phu Yen and Ninh Thuan.

Sesame is a high-value, short-duration crop that has the potential in this region to fit in well between staple crops. The benefit:cost ratio of sesame production was found to be greater than 1 in Phu Yen province, reflecting its potential for expansion as a crop in the region. However, lack of good varieties and infrastructure restrict adoption of sesame as a viable option to improve farmers' incomes. This study outlines the constraints limiting expansion of sesame cropping in SCC Vietnam.

Introduction

Sesame (*Sesamum indicum* L.) is considered the most ancient of oil crops, supplying edible oil, seeds for confectionery purposes, paste (tahini), meal and flour. Sesame probably arose in Africa and was domesticated in India around 2000 BC. It has long been naturalised in many tropical countries.

Sesame is a high-value, warm- and short-season annual crop. It is considered drought tolerant and capable of growing well on stored soil moisture. Researchers at Texas A&M University and Auburn University have found that sesame reduces nematode populations in the soil, particularly the root-knot nematode that attacks peanuts. Sesame is a fairly high-value food crop, being harvested both for whole seed used in baking, and for the cooking oil extracted from the seed. It is primarily adapted to areas with long growing seasons and well-drained soils. Although drought tolerant once established, it requires good soil moisture initially.

Sesame seeds have high nutritional value. They are unusually high in oil (50%)—i.e. around 50% of the seed weight, compared with 20% seed oil in soybeans. Sesame seeds also contain 20–25% protein, 8–11% sugar, 5% water and 4–6% ash. The major sesame fatty acids are oleic (45.3–49.4% of oil) and linoleic (37.7–41.2%). Sesame meal, left after the oil is pressed from the seed, is an excellent high-protein (34–50%) feed for poultry and livestock.

Sesame is mostly consumed as oil. Unlike other oils, sesame oil does not oxidise and develop an unpleasant smell because the oil contains sesamol, a compound that inhibits the oxidation process.

World production and trade

In 2010, 7.8 million hectares (Mha) of sesame were cultivated, producing a world average yield of 0.49 tonnes (t)/ha. India Burma and China were the main sesame producers (Table 1). World sesame prices have ranged from US$800/t to US$1,500/t between 2008 and 2010.

World trade in sesame has been increasing rapidly over the past decade. In 2010, it was worth over US$1 billion. India is the largest sesame exporter, followed by Ethiopia and Burma. Japan is the world's

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largest sesame importer. Sesame oil, particularly from roasted seed, is an important component of Japanese cooking and traditionally the principal use of the seed. China is the second-largest importer of sesame, mostly oil-grade sesame. China exports lower priced food-grade sesame seeds, particularly to South-East Asia. Other major importers are the United States of America, Canada, the Netherlands, Turkey and France.

Table 1. Major sesame-producing countries in 2010

Country	Production (million t)	Yield (t/ha)
India	0.89	0.43
Burma	0.87	0.53
China	0.59	1.31
Ethiopia	0.33	0.85
Sudan	0.25	0.19
Uganda	0.18	0.66
Nigeria	0.15	0.46
Burkina Faso	0.09	0.72
Niger	0.09	0.50
Somalia	0.07	0.90
World	4.39	0.53 (av.)

Source: FAO (2014)

Oilseed production in Vietnam

In 2004, the Ministry of Industry made a decision approving the planning and development of Vietnam's edible oil sector, with targets for 2010 (Ministry of Industry 2004). This set out the targets for oilseed plants including sesame, among others (Table 2).

Objectives of the study

The aim of this research was to ascertain whether sesame production was a viable option for farmers in the three focus provinces of SCC Vietnam to include in their cropping systems, using a combination of surveys of actors in the sesame value chain and information sourced from a variety of sources, including government agencies such as the Department of Agriculture and Rural Development (DARD) in each province.

Methods and materials

In 2011, production and market surveys for sesame were carried out in three SCC provinces of Binh Dinh, Phu Yen and Ninh Thuan. While a full sesame value-chain analysis was not undertaken, much of the methodology of M4P (2008) was followed. The analysis was designed to determine whether farmers in this region could switch to sesame and achieve market competitiveness. Actors at each stage of the sesame value chain were interviewed to collect information on sesame from farm to consumer.

Sesame production in Vietnam

National context

In Vietnam, sesame can be grown in most regions due to its wide adaptation, ease of production and low capital requirement, short growth duration and fast recovery of capital, making it suitable for poor farmers to sustain their livelihood.

Table 2. Proposed expansion of the cropping area for production of oil in Vietnam

Source crop	2005		2010	
	Area cultivated ('000 ha)	Oil processing volume ('000 t)	Area cultivated ('000 ha)	Oil processing volume ('000 t)
Soybean	169.1	29.2	205.0–400.0	31.4–433.2
Peanut	302.4	15.9–17.8	368.6	32.9–47.2
Sesame	49.9	10.8–17.7	58.1	28.5–35.1
Coconut	151.0	39.3	159.1	39.4–53.3
Rice bran	–	150.0	–	300.0
Rice husk	–	1.8	28.0	12.6

Source: Ministry of Industry (2004)

The total area for sesame in Vietnam in 2010 was around 45,000 ha, with an average yield of 480 kg/ha to achieve an overall production of 22,000 t of sesame for oil processing. Sesame in the southern provinces accounted for more than 60% of the total area in 2010 and was focused mainly in the SCC (9,000 ha), south-eastern (7,400 ha) and Cuu Long (Mekong) River Delta (6,900 ha) regions.

An Giang province along the Mekong River is well suited to the cultivation of sesame and the area there has increased to 16,000 ha. Higher than average yields (500–600 kg/ha) have been observed in the Chau Phu district of An Giang. There is potential to increase sesame yield to 1 t/ha if appropriate varieties and production practices are adopted. A propagation model for high-yielding sesame was one of the most important agricultural extension initiatives of the national extension program implemented in An Giang province in 2010. With this model, the An Giang Agricultural Extension Centre developed a project covering 50 ha. Farmers were able to achieve returns of Vietnamese dong (VND)15–20 million/ha in a short span of 2–3 months. This model had an impact on rice cultivation as it encouraged production of other crops such as sesame to be included in crop rotations that may consist of a combination of two rice crops and one cash crop, or two cash crops and one rice crop and one other crop. Such strategies can lead to high economic returns and may prove to be more sustainable than current practices (National Agricultural Extension Center 2010).

Sandy soils in Nghe An province (north-central coastal region) account for about 7,000 ha of sesame production. Districts such as Dien Chau (3,050 ha), Nghi Loc (3,600 ha) and Quynh Luu (586 ha) are the main areas for sesame cultivation in this province (Vy 2003).

Production in the SCC region

Among the three provinces studied in the 2011 project, Phu Yen had the largest area under sesame cropping (Table 3) and coincided well with the area under rice and mungbean, indicating that sesame—because of its short duration—fits in well between rotations of those crops to take full advantage of intensive cropping (Department of Agriculture and Rural Development (DARD) 2010, unpublished provincial reports for 2010 and planning for 2011, DARD Binh Dinh, DARD Phu Yen and DARD Ninh Thuan). Yields in Binh Dinh and Phu Yen were much higher than the average for Vietnam (Table 3). Of the total area sown to crops in 2010, sesame accounted for less than 10% of the total area (Table 4).

Factors important for growing sesame

Climatic conditions

Sesame is considered drought tolerant, due in part to its extensive root system. However, it requires adequate moisture for germination and early growth and a minimum rainfall of 500–600 mm/season is necessary for reasonable yields. Soil-moisture levels before planting and flowering have the greatest impact on yield. Sesame is intolerant of waterlogging and salinity. Rainfall late in the season prolongs growth and increases shattering losses. Wind can cause shattering at harvest and is cited as one reason for the failure of commercial sesame production throughout the world.

Table 3. Area and yield of sesame in the three study provinces of south-central coastal Vietnam, 2011

Province	Area (ha)	Yield (kg/ha)	Districts
Binh Dinh	1,687	740	Phu My, Phu Cat, Hoai An, Hoai Nhon, Van Canh, Tay Son
Phu Yen	2,000	710	Song Hinh, Son Hoa, Dong Xuan, Tuy An
Ninh Thuan	432	760	Ninh Hai (250 ha), Bac Ai (140 ha), Ninh Son (120 ha), Ninh Phuoc (70 ha), Thuan Bac (20 ha)
Total SCC	9,000	–	
Total Vietnam	45,000	480 (average)	

Note: official data from the Department of Agriculture and Rural Development in each province

Table 4. Area of main crops of surveyed households in three provinces, 2008–2010 (m^2/household)

Crop	Binh Dinh			Phu Yen			Ninh Thuan			Average[a]		
	2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010
Sesame	714	926	896	9,280	10,158	9,571	2,958	4,510	1,708	4,317	5,198	4,058
Rice	2,686	2,697	2,660	9,651	10,606	9,965	5,000	5,947	6,021	5,779	6,417	6,215
Peanut	2,408	2,380	2,359	–	–	–	–	–	–	2,408	2,380	2,359
Mungbean	–	–	–	9,390	10,334	9,737	20,071	13,714	22,071	14,731	12,024	15,904
Watermelon	1,100	700	620	–	–	–	–	–	–	1,100	700	620
Cassava	3,211	3,247	3,283	9,840	10,115	9,501	17,241	20,429	26,464	10,097	11,264	13,083
Sugarcane	–	–	–	9,192	10,054	9,477	–	–	–	9,192	10,054	9,477
Tobacco	–	–	–	–	–	–	11,000	12,667	12,500	11,000	12,667	12,500
Maize	–	–	–	–	–	–			5,000			5,000
Total crops	10,119	9,950	9,818	47,353	51,267	48,251	56,270	57,267	73,764	37,914	39,495	43,944

[a] Average among provinces that grew that crop

Soils

Sesame is adaptable to many soil types, but it thrives best on well-drained, fertile soils of medium texture and neutral pH. Sesame, which has an extensively branched root system, appears to improve soil structure.

Characteristics of different sesame varieties

The main varieties of sesame widely grown in Vietnam are Dien Chau (yellow sesame), Huong Son (black sesame) and V6 (white sesame) (Vy 2003). In particular, yellow sesame and black sesame are local varieties with some good characteristics, such as adaptation to local climatic and soil conditions, and low production costs and good pest resistance. However, the productivity of these varieties is low and the oil content is not as high as V6. Sesame variety V6 is native to Japan and has a relatively high yield. However, it has some disadvantages, such as susceptibility to certain pests and diseases, especially bacterial wilt. Selected plant characteristics appear unstable because seed purity is not high. The varieties grown in the SCC provinces are detailed in Table 5.

Upon ripening, sesame capsules split, releasing the seed. Because of this shattering characteristic, sesame has been grown primarily on small plots that are harvested by hand. Although researchers have made significant progress in sesame breeding, harvest losses due to shattering continue to limit domestic production.

Cropping season

Sesame is grown in almost all seasons (Table 5); however, the preferred season is spring–summer, when it does not overlap the two main rice seasons. Hence, the main advantage of sesame is that it can be grown in between other cash crops, making use of its short duration (75–80 days) to increase farmers' incomes.

Sesame value chain in SCC Vietnam

In general, the sesame value chain in the SCC region followed the steps shown in Figure 1. The process, however, differed between the provinces (Figure 2). For example, in Binh Dinh, over 90% of collectors deal directly with farmers to set the purchase price of sesame, while in Ninh Thuan, only 38% of collectors negotiate directly with the farmers.

Limitations to sesame production in the study provinces

Reasons for limited sesame production in the three provinces vary. Sesame production in Ninh Thuan depends on rainfall as most of the crops grown in this region are rainfed due to limited availability of irrigation water. High cassava prices seem to drive cropping patterns in Ninh Thuan. Sesame production in Binh Dinh is more dependent on the market and

Table 5. Cropping seasons and varieties of sesame in the three study provinces of south-central coastal (SCC) Vietnam

Province	Cropping seasons	Varieties	Cropping pattern
Binh Dinh	Summer–autumn, 1,500 ha; winter–spring, 300 ha	Local black sesame, V6 (white), V36, V10 (black)	Peanut–sesame – dry-sown rice
Phu Yen	Spring–summer (February–June)	Local black sesame	Cassava–sesame, maize–sesame–maize
Ninh Thuan	Winter–spring, summer–autumn	VD 10 (black sesame) occupying 60–70%, V6 (white sesame), local black sesame	Sesame–sesame
SCC region, whole country		New varieties: VDM1, VDM2, VDM3, VDM5, VDM6, VDM 12, VDM11, VDM 9, Indian white sesame, DT-04 white, Thailand red sesame, VD 10, V6, V36, V10 etc.	

Figure 1. General process of the sesame value chain in south-central coastal Vietnam

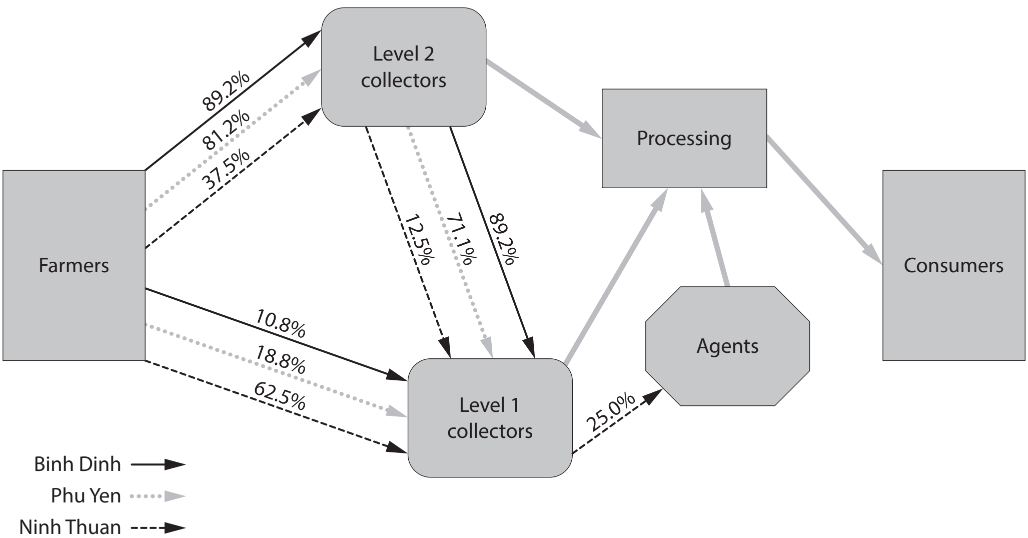

Figure 2. Variations in the sesame value chain between the three study provinces. Note: Level 2 collectors go to rural areas to buy product directly from farmers; farmers and level 2 collectors must take the product to the office of the level 1 collectors.

government policy, and farmers have the option of growing other cash crops, which are more profitable, such as peanut. In Phu Yen, rice, vegetables and mungbean seem to accommodate sesame as a short-duration rotation crop which adds to profitability. However, overall lack of water, poor choice of available varieties and low yield—as well as other reasons such as extensive farming, reluctance to change cropping patterns, limited postharvest technology and poor market structure—seem to limit sesame production in all three provinces (Table 6).

Information from a survey conducted along the value chain (farmers, collectors, transporters, processors and consumers) in the three provinces showed that suboptimal varieties and lack of capital topped the list of limitations preventing farmers from producing sesame or expanding sesame production. Other limitations identified by chain actors were lack of pre- and postharvest technology, product grading standards, market information and options, seed moisture measurement, transport, and processing options, as well as high transport costs.

Markets for sesame in Vietnam

A proportion of the sesame produced throughout Vietnam is purchased by enterprises based in Ho Chi Minh City at an agreed price. The price for white sesame in the market is around VND25 million/t. The short growing season of only 75–80 days allows white sesame to be grown between the two rice-crop seasons. Households growing black sesame are able to get a larger return as demand for black sesame in the market is high and the price was as high as VND35 million/t. Even with high sesame prices and a good benefit:cost ratio, fluctuations in demand and the collectors' decision to fix their selling prices play a major role in the decision-making for farmers considering whether to produce sesame.

Sesame is already in production in each of the three focus provinces with better than the national average yield (Table 3). The yield and benefit:cost ratio in Ninh Thuan province is the lowest of the three provinces, mainly due to the lack of available irrigation water. Phu Yen performed best of the three provinces in terms of yield and benefit:cost ratio (Table 7).

Table 6. Major limitations to sesame production in the three study provinces

Province	Major limitations
Binh Dinh	Risk of adverse weather conditions, lack of water, lack of capital and information; low prices
Phu Yen	Lack of technical knowledge, varieties suboptimal for local conditions, low yield, lack of market information, unstable markets leading to uncertain prices, extensive production
Ninh Thuan	Suboptimal varieties, climate (rainfed production), labour costs, harvest losses, low product quality, low yield, lack of technical knowledge, unreliable buying enterprises, lack of capital

Table 7. Production income and expenses for 1 ha of sesame in the study provinces

Items	Binh Dinh	Phu Yen	Ninh Thuan	Average
A. Gross expenses (I+II+III+IV) (VND '000)	13,299.0	11,728.0	4,001.8	9,676.4
I. Materials	5,319.0	3,484.0	1,075.8	3,293.0
II. Labour costs	7,980.0	6,904.4	2,926.0	5,936.8
III. Transportation (VND '000/t)	0.0	143.2	0.0	47.8
IV. Interest	0.0	1,196.4	0.0	398.8
B. Gross income (VND '000)	20,383.6	26,572.6	4,819.2	16,300.4
Yield (kg/ha)	802.0	973.0	240.0	672.0
Selling price (VND '000/kg)	25.42	27.31	20.08	24.27
C. Net profit (VND '000)	7,084.6	14,844.6	817.4	6,624.2
Net revenue (VND '000)	15,064.6	21,749.0	3,743.4	12,561.0
Benefit:cost ratio	0.53	1.27	0.20	0.68

Conclusions

As a short-season crop, sesame can be grown in crop rotations between cropping seasons for other crops in SCC Vietnam. However, limitations to expansion of sesame production arise, according to farmers, from lack of high-yielding varieties, unsuitable weather/climatic conditions, lack of irrigation water (in Ninh Thuan) and price fluctuations. Given that the benefit:cost ratio for cropping sesame is favourable for Phu Yen province, efforts should be made to improve the whole sesame value chain for the benefit of the farmers. Even though policymakers made a decision in 2009 to encourage sesame as part of the cropping system in the SCC region, little research and extension have been undertaken to develop sesame as a viable option for the farmers in the region.

There are many issues that need attention. The main ones, according to farmers, are availability of capital, availability of high-yielding varieties, and appropriate pre- and postharvest technology. The profitability of sesame compared with other crop options should be assessed and, if favourable, a plan for the development of sesame production in SCC Vietnam should be developed by relevant Vietnamese government agencies.

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Issues and opportunities for garlic producers in Ninh Thuan province, Vietnam

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Abstract

This rapid value-chain assessment was prepared to report on the situation of the garlic sector in Ninh Thuan province. It specifically focused on better understanding current farming techniques, production, and analysis of input supplies, as well as overall financial viability of smallholder farmers. The study assessed value-chain aspects that link growers and traders to customers with the aim of determining competitive advantages as well as constraints. Suggestions were made of appropriate strategies, interventions and actions that will improve the sector's value chain, primarily focused on improving profitability of smallholders as well as other chain actors.

Introduction

Garlic (*Allium sativum*) is an important cash crop in the sandy soils of Ninh Thuan province, Vietnam. By late 2011, value-chain analysis of five key crops (peanut, cassava, cashew, mango and sesame) plus beef cattle in the focus provinces of south central coastal (SCC) Vietnam were studied and reported as part of an Australian Centre for International Centre for International Agricultural Research (ACIAR)-funded sustainable farming systems project SMCN/2007/109 (*Sustainable and profitable crop and livestock systems for south-central coastal Vietnam*) with funding from the Australian Government. These analyses are included in this section of these proceedings.

Garlic was added as a focus crop following a consultative agreement between the project proponents and the Ninh Thuan Department of Agriculture and Rural Development (DARD). This rapid assessment of Ninh Thuan garlic was undertaken to investigate garlic production and its value chain and to report the impediments to profitable production and marketing and to suggest strategies to improve profitability and market engagement for smallholders.

Garlic is a member of the Alliaceae plant family and is closely related to onions, shallots, chives and leeks. In the past 20 years, world consumption of garlic has increased. It is used mainly as a flavouring for other foods and as a health food. Garlic contains alliin which is converted to allicin, a natural antibiotic compound, when garlic is cut or crushed. Various health claims have been made relating to allicin, including the ability to improve cardiovascular health.

Garlic is native to central Asia. Plants produce only a few flowers which are sterile and do not produce seed. The mature garlic bulb consists of modified storage leaves that contain 6–30 segments or cloves, held together by outer skins. Cloves are used as planting material and about 15% of the crop needs to be retained to plant the same area the following season.

World production of garlic was 23.7 million tonnes (Mt) in 2011, with China by far the largest producer, with 80% of global production (FAO 2013). China also dominates world trade in garlic, having exported 1.66 Mt in 2011 (Global Trade Information Services 2013). The main markets for Chinese garlic were Indonesia, Brazil, Vietnam, the United States of America, Malaysia and Thailand. According to trade

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data, in 2011, China exported 162,000 t of garlic to Vietnam valued at US$189.5 million or US$1.17/kg.

The approach

This study used a combination of methods, including value-chain analysis approach of the Making Markets Work Better for the Poor project (M4P 2008) funded by the United Kingdom Department for International Development and the International Institute for Environment and Development (Vermeulen et al. 2008). SWOT (strengths, weaknesses, opportunities and threats) analysis was used for the situational analysis and a logical framework was used for suggested strategies, interventions, actions and predicting impacts.

During 2012, data and information were generated through interviews with growers and local agency staff, trader interviews, focus group discussions, site visits, secondary data collection and a literature review. Interviews were conducted with 33 garlic growers in three communes, namely Nhon Hai (Ninh Hai district), Van Hai (Phan Rang city) and An Hai (Ninh Phuoc district). Meetings were held with local sector management, extension and technical staff of DARD, Commune People's Committees and District Agriculture Sections. Other meetings and interviews were held with local collectors, and traders in and outside the province (28 people). A workshop was held on 2 November 2012, with 16 local authority staff, extension officers, growers and traders to share results and findings to key stakeholders for feedback and recommendations. Consensus was sought on proposed strategies, intervention and actions.

Results and discussion

No garlic industry data were available in the Ninh Thuan province statistics books and data in this report are from historical data recorded by DARD of Ninh Thuan province.

Vietnam is relatively a small garlic production country and according to the official statistics reports, annual average planted area, production and yields for 2007–2011 were 725 hectares (ha), 6,647 t and 8.6 t/ha, respectively. World average yields for garlic are around 15.7 t/ha, while the garlic yield in China averages close to 20.0 t/ha.

Vietnam has a long history of garlic production. Presently, commercial and specialised garlic eco-agriculture areas include Bac Giang (a northern province), Quang Ngai and Ninh Thuan provinces, which between them account for more than 80% of area and nearly 90% of the total national production reported for 2007–2011. Bac Giang had the largest cultivation area of 225 ha (31.0%) with a production of 2,955 t (44.5%) in 2011. During 2007–2011, Bac Giang had steady growth both in area and production while Ninh Thuan's garlic sector tended to decline.

There are no statistics for domestic consumption of garlic in Vietnam. However, according to the import figures of 2010 from China, nearly 120,000 t of garlic was imported into Vietnam, representing 99% of the total imported volume and further increased to 162,000 t in 2011.

It is reported that about 2,000 t/year of garlic was exported from Vietnam in recent years. This research is unable to validate whether the exported garlic was of Vietnamese origin or re-export of Chinese garlic. However, big traders in Ho Chi Minh City as well as the trade association shared that there were large volumes of Vietnamese garlic (and onions) ordered by foreign importers from countries including Japan, Korea, the Middle East and European region and that there was a preference for Vietnamese garlic. The current supply is reported to be far below export demand. Additionally, a large proportion of Vietnamese garlic does not yet meet export quality standards. This indicates that a focus on producing garlic for export markets should be encouraged by improving production, yield and quality.

In 2011, Ninh Thuan produced garlic on 126 ha of land, representing only 18.7% of the 673 ha of national total. Ninh Hai district and Phan Rang city had the largest areas, with 44 ha and 70 ha, accounting for 35% and 56% of the area, respectively (Table 1). However, in 2012, the garlic area in Phan Rang city dropped to 16 ha. Available data from DARD for 2007–2011 showed a declining trend in area, production and yield, at –21.2%, –28.2% and –6.6%, respectively. The biggest area reduction was between 2008 and 2009, representing a –65% decline. Based on data collected and interviews during this study, causes for the decline included: (i) low and unstable yields; (ii) intrusion of salinity that decreased productivity, especially in Van Hai commune; (iii) high input costs causing reduced profits; (iv) increased diseases and difficulty in managing them; and (v) unstable market prices. These problems encouraged farmers to shift to other crops. Factors associated with these problems will be discussed in more detail later in this chapter.

Table 1. Garlic plantings (ha) in districts of Ninh Thuan province

District	2007	2008	2009	2010	2011	2012 (estimate)
Phan Rang	NA	81	49	35	44	16
Ninh Hai	NA	128	77	67	70	91
Ninh Phuoc	–	–	–	–	–	3
Thuan Bac	–	23	14	12	12	6
Thuan Nam	–	–	–	–	–	3
Total	200	232	140	114	126	119

Note: NA = not available
Source: Department of Agriculture and Rural Development, Ninh Thuan province, 2012

The average garlic yield reported for Ninh Thuan for 2007–2011 was 7.9 t/ha. In 2011, the Ninh Thuan yield was the highest at 8.6 t/ha. Local officials and farmers reported that the higher yield was likely due to suitable weather and increased soil fertility as a result of the serious flood of November 2010.

The main results and findings of this study are:

- Ninh Thuan province has a long tradition of planting garlic and, together with Bac Giang and Quang Ngai, is one of the major garlic production areas in Vietnam. In Ninh Thuan in 2007–2011, the annual planted area averaged 162 ha, with production of 1,034 t/year, with an average yield of 7.9 t/ha. This yield is somewhat lower than national average yield (8.6 t/ha).
- In 2011, Ninh Thuan had a planted area of 126 ha and produced 1,082 t of garlic, representing 15.4% of national production. Garlic is grown in small plantings on household farms, at about 0.2 ha on average in sandy districts, including Ninh Hai (56% of area), Phan Rang (34% of area), Thuan Bac and others (10%). Garlic production has declined in recent years. The average reductions of planted area and production within the period 2007–2011 were –21% and –28%, respectively. Yield has been unstable and has been falling.
- In 2011, the garlic sector in Ninh Thuan was valued at about Vietnamese dong (VND)55 billion, representing 1.0% of provincial gross domestic product (GDP) and 2.5% of gross output of the agriculture sector. Garlic has been an important crop that can be grown on sandy soils in Ninh Thuan. It contributed about 35% of household income per year in the surveyed households. Garlic, together with onion and other vegetables, were major sources of income for smallholders in these communities on sandy soils.
- Growers in Ninh Thuan have had long experience in growing garlic. They are becoming more aware of the roles of nutrients, irrigation, mechanisation and cultivation knowledge, which was considered as a positive signal for further investments and for suggested actions on raising awareness of improved farming practices and quality control. The climate in Ninh Thuan has led to a diverse range of crop options for rotation and intercropping. There have been technology-transfer programs—for example, demonstrating improved garlic cultivation and storage systems—and these are considered as strengths for improved production. However, many weaknesses are apparent, including low yields, lack of quality control, overuse of pesticides and poor irrigation management. Many of these have resulted in low productivity and hence high production costs and low profits along with negative environmental impacts.
- The average yield of Ninh Thuan garlic was about 80% of the national average and has been declining in recent years. Production costs on small farm holdings were 30% higher due to cultivation techniques compared with those promoted by current ongoing programs and similar garlic production areas in the region (Table 2). This situation reflects growers' lack of good agricultural practice and farm management ability to cope with emerging and changing conditions, such as climate change or new pests and disease resistance. Planting material also appears to be degrading as a result of current farming practices. The use of uncertified seeds and, until recently, a lack of breeding improvement were the main factors. The virus status of planting material also needs to be tested as a matter of priority.

- Despite the area, production and yield all declining, garlic was still an important crop on the sandy soils of Ninh Thuan. Local authorities estimated that about 40% of households in the major garlic-growing communes of Nhon Hai, Thanh Hai and Vinh Hai planted garlic and onions. The average income of small households surveyed was VND65 million, of which income from garlic accounted for about 35%. The remaining income was from crops such as onion, watermelon and chillies. In Nhon Hai, the contribution to income from garlic and onions was higher, representing 79% of annual household income. Garlic and onions were important crops for the livelihood of smallholder farmers in these communities.
- Ninh Thuan garlic has long been considered to be a speciality product. It receives strong preference and loyalty from a group of customers who have high income and/or look for good quality and flavour. The main markets for Ninh Thuan's garlic are the central coast, the highlands and parts of south-eastern region provinces. Large markets such as Ho Chi Minh City have declined due to the high price of Ninh Thuan garlic and competition from cheap Chinese garlic. The price of Ninh Thuan garlic is 2.5–3.0 times higher than other garlic. The product still has good presence in some modern supermarkets and demand in this sector is strong. There is also demand from export markets but these require certain standards in terms of quality as well as large supply volumes. Current supply is relatively small and has not yet met domestic demand. Low uniformity, mediocre quality and high prices are impediments to the long-term market expansion and development of the garlic sector in Ninh Thuan.
- Along with the history of garlic production, Ninh Thuan has experienced collectors, traders and networks that link local communities to the market. Presently, there are individuals and traders who are pioneering and promoting safe production and safe products to market.
- The value distribution within the chain appears fair except for a deduction ratio that has long been applied to growers. Review and improvement in this deduction system are recommended.
- Many initiatives and programs have been undertaken by local authorities to strengthen the agriculture sector and some of these have focused on garlic. These have included support for safe vegetable production, cultivation techniques, extension training, increased competitive advantage for

Table 2. Garlic production costs in major garlic production provinces of Vietnam

	Production costs (VND/kg)				Cost comparison (%)[a]		
	Ninh Thuan, farmer practice (FP)	Ninh Thuan, ACP[b]	Quang Ngai	Bac Giang	FP/ ACP	FP/ Quang Ngai	FP/ Bac Giang
Average yield (kg/0.1 ha)[c]	789	789	789	1,264			
Seed[d]	5,703.4	5,703.4	5,703.4	2,076.7	100.0	100.0	274.6
Fertiliser	4,820.7	2,400.3	2,799.8	1,551.1	200.8	172.2	310.8
Pesticide	5,069.7	1,267.4	1,267.4	791.1	400.0	400.0	640.8
Other (fuel + electricity)	2,117.1	1,494.8	1,534.8	790.0	141.6	137.9	268.0
Equipment	2,534.9	2,534.9	2,534.9	1,582.3	100.0	100.0	160.2
Labour	9,550.1	9,550.1	9,550.1	5,961.2	100.0	100.0	160.2
Other costs (interest etc.)	592.2	392	404.8	198.6	151.1	146.3	298.2
Total cost per kg	30,388.1	23,342.9	23,795.2	12,951.0	130.2	127.7	234.6
Price	45,000	45,000	45,000	27,000			
Gross margin	14,612.1	21,657.2	21,204.9	14,048.9	67.5	68.9	104.0
Profit (%)	32.5	48.1	47.1	52.0			

[a] Percentage difference in cost between farmer practice in Ninh Thuan (FP) and the alternative
[b] Following Agricultural Competitive Program (ACP) technical guidelines
[c] Based on 2011 average yield for Ninh Thuan and Quang Ngai, and 2008–2011 average yield for Bac Giang
[d] Seed prices in Quang Ngai and Ninh Thuan are the same (same variety), but the seed price is lower in Bac Giang (different variety).
Note: rates for labour, equipment, loan interest costs are same or similar in each province

agriculture, technology transfer, marketing and business development. These efforts are highly regarded as valuable strengths and opportunities for sector development.

- The current decline in area, production and quality, seed variety degradation, unstable prices and growers' difficulties in farm management imply that there has been a long absence of a platform to connect growers and growers to traders, technical expertise and research for the sector. As Ninh Thuan's garlic has been considered a specialty, local culture needs to build on this, and it requires collective action. In addition, the value-chain concepts involving diverse stakeholders require someone to take a coordinating role to facilitate dialogue and mobilise and coordinate resources.

Figure 1 describes the product flow for Ninh Thuan garlic. It is quite simple as it deals with a small volume. Every year, farmers in Ninh Thuan used about 8% of provincial garlic production for seed. Half was self-stored seed and half was purchased from local traders. The rest (92%) was traded directly from growers to collectors while only 4% went directly to wholesalers in communes and districts. The provincial domestic market was small, accounting for 4% of volume. About 88% of Ninh Thuan garlic was sold out of province—76% was for the fresh market and 12% for food-processing industry. Out-of-province traders handled 68% of volume. Supermarkets took 8% with the expectation that this proportion will rise rapidly given the rapid growth in this market channel.

In terms of consumption channel (route to market), there are four basic channels as below:

1. Farmer → Local collector → Local trader → Farmer (garlic seed)
2. Farmer → Local collector → Local trader → Local retailer → Consumer
3. Farmers → Local collector → Local trader → National wholesale trader → Retailer → Consumer
4. Farmers → Local collector → Local trader → National wholesale trader → Supermarket

One critical issue raised by the growers was that of the deduction ratio applied to their produce by collectors, which ranged between 3 and 10%, and was based on the somewhat arbitrary quality classification of garlic bulbs. Bulb grading relied on collectors' judgment, highlighting the need for more objective bulb specifications. Interestingly, the deduction ratio that wholesalers applied to collectors was lower, at about 1%. Using the same unit cost (based on 2011 yields) and selling price in March 2012, Table 3 was constructed to present costs and profit of each actor along the chain with average current loss and deduction figures. With a 5% average deduction ratio, growers lost 4% of their profit margin, which is shifted to the collectors (Table 3). Other costs such as transport and the labour of retailers inside and outside the province (at traditional markets) are only estimates.

Conclusions

Many opportunities related to the Ninh Thuan garlic sector were identified. These include different cropping seasons, crop rotations and inter-cropping, low-cost efficient technology (e.g. sprinkler irrigation), further research and opportunities to increase yield and reduce costs of production. In terms of market improvement, rapid development of supermarkets means more consumers expect higher quality products produced under safe food-quality assurance systems. The export market is also promising. Current research relating to cultivation techniques and fertilisation is available for adoption by garlic farmers. Based on the situation outlined above, we suggest key strategies and related interventions and actions to improve the sector in future. These are:

- Improving productivity is the top of priority for the sector. The interventions and actions should be based on basic studies of soils, nutrients, breeding, healthy planting material and cultivation techniques and larger demonstration to, and training support for, growers.
- Increase the production scale to maximise resources and potential, by expanding planted area based on assessment on land and water resources, land-use planning, a sector loan program for growers to expand production, and development of investment policy for growers and investors.
- Improve quality standards and increase market coverage. Quality assurance should be a requirement for marketing Ninh Thuan garlic to support its market position as a premium product. Collective action by growers, traders and enabling actors is required to achieve this objective. Quality can be enhanced by improving farming techniques and management as well as through better handling and packaging.
- Register and build a trademark and certification of geographical origin, along with support for the private sector in quality-control training and

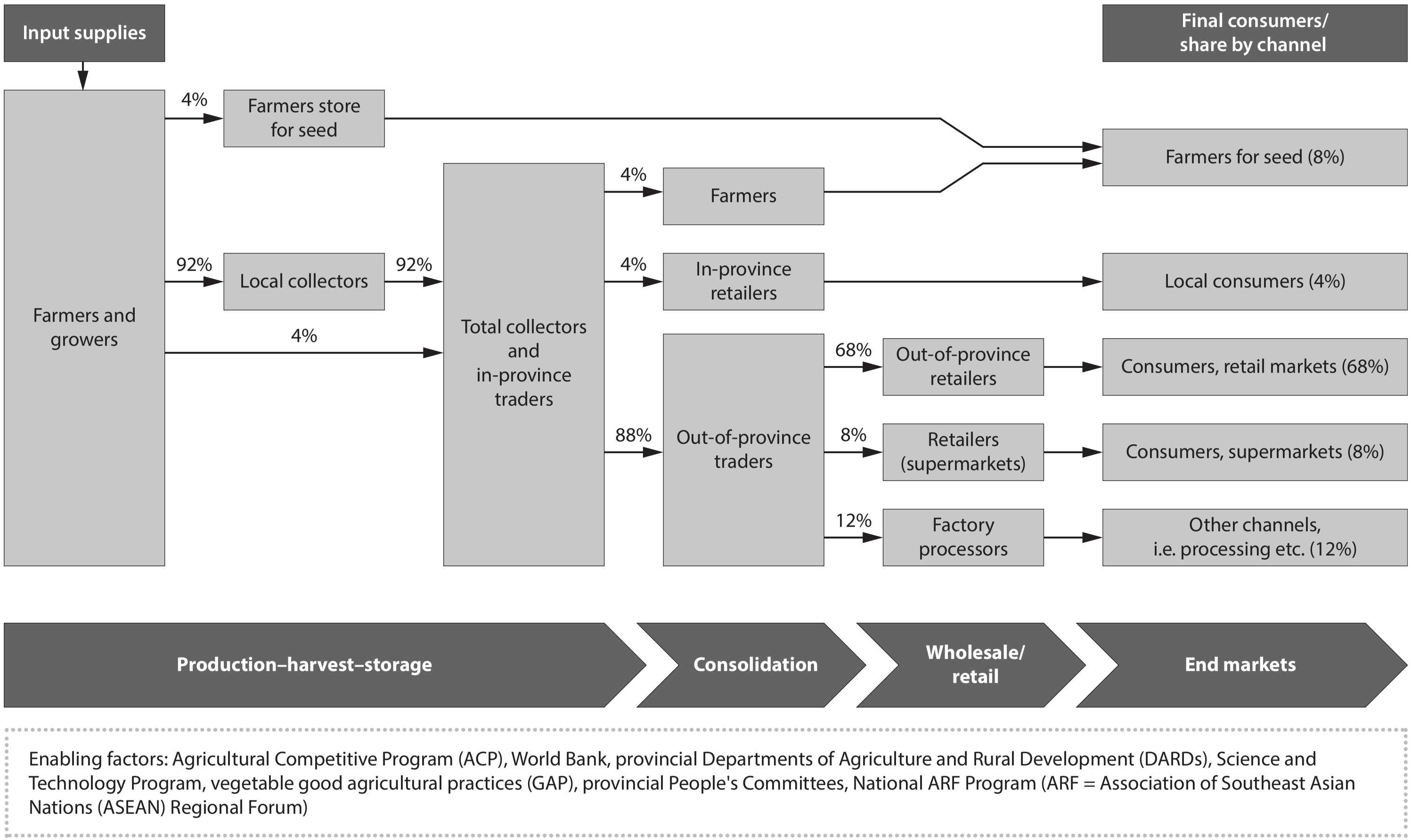

Figure 1. Product flow for Ninh Thuan garlic as percentage of volume

Table 3. Value-chain analysis for Ninh Thuan garlic

Item	Units	Farmer	Local collector	Local wholesale trader	Local retailer	National wholesale trader	National retailer: market	National retailer: supermarket
Production costs	VND/kg	30,388	46,450	50,650	52,960	55,300	60,800	61,000
Capital cost	VND/kg	–	45,000	47,500	52,000	52,000	60,000	60,000
Material, equipment cost	VND/kg	20,246	–	200	–	500	–	–
Labour cost	VND/kg	10,142	500	1,000	500	1,000	500	500
Transport cost	VND/kg	–	500	1,000	200	500		500
Cost on loss (price × loss ratio)	VND/kg	–	450	950	260	1,300	300	–
Selling price	VND/kg	45,000	47,500	52,000	56,500	60,000	65,000	69,000
Net margin	VND/kg	14,612	1,050	1,350	3,540	4,700	4,200	8,000
Profit margin	%	32.5	2.2	2.6	6.3	7.8	6.5	11.6
Return on investment (ROI)	%	48.1	2.3	2.7	6.7	8.5	6.9	13.1
Loss ratio	%		1.0	2	0.5	2.5	0.5	0
Deduction ratio (DR)	%	–5	4.0					
Loss/gain with deduction ratio (RR)	VND/kg	–2,250	1,900					
Net margin after DR	VND/kg	12,362	2,950	1,350	3,540	4,700	4,200	8,000
Profit margin	%	27.5	6.2	2.6	6.3	7.8	6.5	11.6
Return on investment (ROI) after applying DR	%	40.7	6.4	2.7	6.7	8.5	6.9	13.1

initiatives to strengthen packaging, distribution channels and attending trade fairs, which would greatly strengthen the 'brand' and hence market opportunities.

- Improve networking among growers to facilitate the exchange of knowledge and skills on farming techniques and market information. A growers' association would be an appropriate organisation to build the culture relating to the specialty product and to increase market power.
- Improve coordination, and develop enabling policies to facilitate sector development: an effective and dynamic enabling environment is needed to underpin and stimulate growth of the sector. Successful models in other regions—including growers' associations, and think tanks that consist of extension practitioners, researchers and policymakers—should be emulated to build local knowledge. Regular dialogue is needed to discuss and share issues and opportunities within the sector plus available incentive policies need to be developed for this sector similar to those for investors in other agriculture sectors.

While the above strategies, interventions and actions are suggested to stimulate short- to long-term development, many specific issues need to be tackled through extension of currently available technology and improved practices. Table 4 outlines the recommended actions for improving the Ninh Thuan garlic value chain.

The strategies and interventions for the garlic value chain suggested in this study should be supported by research and technology development. For the market-related aspects, further research is recommended to build a comprehensive understanding of the garlic sector in Ninh Thuan, including: (i) the potential for export; (ii) research into processed and other products, e.g. medicine, oil; (iii) trends in per capita consumption; and (iv) customer preferences in key domestic and export markets. In addition, the Farm Economic Model (FEM; Summers et al. 2013) could be used for economic analysis of various cropping scenarios, to give a clearer view of the role of garlic cropping in the profitability of farming systems on sandy soil in Ninh Thuan.

Table 4. Recommended actions for garlic value-chain improvement in Ninh Thuan

Problem or priority need	Suggested action and extension activities
Overuse of pesticides and fungicides that result in high production costs, low yields and poor-quality products and damage to soil and water resources	Conduct extension training and awareness raising for growers though communication material such as posters, leaflets, field days and radio spots. Develop and print leaflets on common diseases, treatment and management to increase grower knowledge
Poor crop nutrition, resulting in high production costs, waste of resources and possible impacts on diseases or farm management	Conduct extension training for growers Produce leaflets or brochures on cultivation techniques to disseminate to small-farm garlic producers
Flood irrigation is still popular but more-efficient sprinkler irrigation is available and used by some leading growers	Conduct training on efficient irrigation systems and irrigation scheduling Simultaneously, develop a finance support scheme to facilitate expansion of sprinkler irrigation
Seed quality	Develop and implement seed standards Develop extension material to increase knowledge and awareness among growers
Absence of a grading system for garlic	Agree on quality standards and encourage adoption by farmers and marketers Produce printed extension material as reference for growers
Facilitate information-sharing and promote the advantages of collective action	Form grower associations and train leaders to improve their capacity to run such associations Design social activities to create a cultural environment among growers aligned to producing a specialty product

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Section 4: Forage and cattle production

Growing demand for beef consumption in Vietnam has led to cattle raising as an opportunity for small landholders to raise their incomes. However, intensive grazing on marginal farmlands, especially on sandy soils, was identified as a limitation. This section covers the management options for livestock, with an emphasis on forage production as a source of feed for cattle.

Improved forage cultivars for smallholder cattle farmers in south-central coastal Vietnam

Nguyen Xuan Ba[1], Nguyen Huu Van[1], David Parsons[2] and Peter Lane[2]

Abstract

An on-farm forage assessment was conducted on sandy soils of three provinces (Binh Dinh, Phu Yen and Ninh Thuan) of south-central coastal (SCC) Vietnam from May 2010 to December 2011. The on-farm trial had two purposes. The first was to evaluate the biomass yield and nutritive value of each forage species in sandy soils (*Megathyrsus maximus* (previously *Panicum maximum*) cv. TD58, *Brachiaria* hybrid cv. Mulato II, *Pennisetum purpureum* cv. VA06, *Paspalum atratum* cv. Terenos and *Stylosanthes guianensis* cv. CIAT 184). The second purpose was to introduce these five forage species to farmers for adoption.

Although there were significant differences in biomass and quality between species and between planting areas, all of the forage types may be suitable for growing in these provinces. The greatest yields were obtained from TD58 (34–50 t dry matter (DM)/ha/year) and Mulato II (25–38 t DM/ha/year). There were significant differences ($p < 0.05$) in crude protein (CP) concentration between species and time of cutting. CP concentration tended to decrease in the dry and hot season. Stylo had the greatest CP concentration (14.7–17.9%). Of the grasses, Mulato II had the greatest CP (10.5–13.7%). This research was the first time that most of these species had been introduced in the sandy areas of the SCC region, and all species may be usefully grown by farmers. For waterlogged areas, the best potential grass was paspalum due to its high vigour and low mortality.

We recommend that farmers plant a mixture of forage varieties, including grasses and legumes, to diversify cattle diets and to build resilience to cope with variable environmental conditions that prevail in SCC Vietnam.

Introduction

Beef production has traditionally been an important component of smallholder farming systems in Vietnam and production has increased steadily in recent years, from approximately 100,000 tonnes (t) liveweight in 2001 to 290,000 t liveweight in 2011 (General Statistics Office 2012). Many smallholder farmers use a combination of supervised grazing and cut-and-carry methods to feed their cattle. Cut-and-carry fodder is collected from communal land, waste areas on roadsides and crop margins, and from crop residues. There is a significant opportunity for smallholder crop–livestock farmers in south-central coastal (SCC) Vietnam to improve their overall household income by changing the balance of their farming systems in favour of beef cattle. However, the availability of labour and competition for traditional feed resources, particularly communal grazing land, are major impediments to farmers realising this opportunity and progressing from cattle keepers to cattle producers.

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Cattle production in the SCC region is further constrained by low-fertility sandy soils, and harsh climatic conditions. The dry season is long and hot, and flooding regularly occurs in the wet season. The limited quantity and quality of feeds, and poor husbandry practices, lead to low cattle productivity and efficiency. Improving feeding options by making better use of locally available feed resources and introducing specialist forages suited to the region and farming system is a key strategy for improving beef-cattle production in SCC Vietnam (Nguyen Xuan Ba et al. unpublished project report 2010).

Numerous high-yielding forage species have been imported and evaluated for adaptation, biomass yield and quality across Vietnam (Phan Thi Phan et al. 1999; Truong Tan Khanh 1999) although there is little evidence of their widespread adoption by farmers. Involving smallholder farmers in applied research projects through participatory research methods, such as the best-bet approach (Lisson et al. 2010), increases the likelihood of adoption of research findings in the community. The forage-development study reported here was conducted to: (i) assess the on-farm seasonal production and quality of a range of promising forage species in three locations in SCC Vietnam; and (2) facilitate farmer assessment and preferences of the forage species.

Materials and methods

Climatic conditions in the three provinces

Three provinces in SCC Vietnam—Binh Dinh, Phu Yen and Ninh Thuan—were chosen. The average annual rainfall and average daily maximum and minimum temperature in the three provinces from 2003 to 2012 are shown in Figure 1. Temperature ranges are similar (26–27 °C) but the mean annual rainfall is higher in Binh Dinh and Phu Yen (1,710 mm and 1,540 mm, respectively) than Ninh Thuan (1,160 mm). Rainfall occurs predominantly from September to December.

Forages

Five improved perennial forage species (four grasses and one legume) were introduced to farmers, initially by way of on-farm trials managed by the project team in selected locations in the three study communes. The five forage species were: *Pennisetum purpureum* cv. VA06, *Megathyrsus maximus* (previously *Panicum maximum*) cv. TD58, *Brachiaria* hybrid cv. Mulato II, *Paspalum atratum* cv. Terenos and *Stylosanthes guianensis* cv. CIAT 184.

Soil characteristics

Soil samples were collected for chemical analysis before growing the forages. Samples were collected

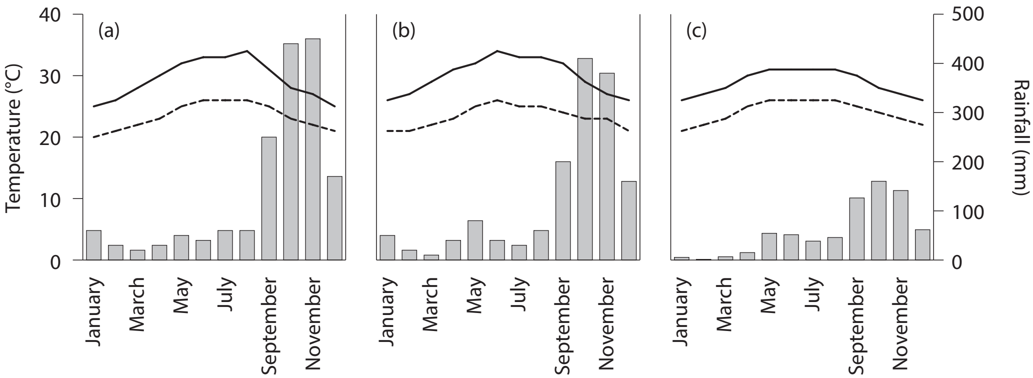

Figure 1. Average annual rainfall and average maximum (solid line) and minimum (dotted line) temperature in (a) Binh Dinh, (b) Phu Yen and (c) Ninh Thuan provinces for the period 2003–2012. Source: Weatherbase (2012)

from each household at five different locations within the forage plot area to a depth of 15 cm. A representative subsample was taken for analysis at the Laboratory of Soil Resource and Environment Faculty, Hue University of Agriculture and Forestry. The main soil characteristics at each experimental location are given in Table 1. The data presented here are the average of the four farm sites from each province.

Soils in Binh Dinh and Phu Yen had lower pH (pH_{KCl} 4.46 and 4.81, respectively) than in Ninh Thuan (pH_{KCl} 5.72) (Table 1). Organic carbon levels were low in Binh Dinh and Ninh Thuan (0.84% and 1.16%, respectively), but higher in Phu Yen (1.78%). The total nitrogen (N), phosphorus (P) and potassium (K) concentrations were low in all three provinces. Thus, the sandy soils in these provinces were not ideal for adequate plant development.

On-farm forage experiments

Between May 2010 and December 2011 in Binh Dinh, Phu Yen and Ninh Thuan, the five forage species detailed above were evaluated for yield and chemical composition. Four farms in each province were selected as trial sites (blocks) and planted with the forage species (treatments).

Each treatment plot was 5 m long by 1 m wide, with 0.5 m between plots. King grass (Napier grass) was grown as buffer rows to separate the plots. Each site was managed in a similar manner, with regular inputs of fertiliser (NPK 16:8:8, applied at a rate equivalent to 600 kg/hectare (ha)/year and urea applied at a rate equivalent to 200 kg/ha/year). The NPK and urea fertilisers were applied alternately after each cutting and plots were irrigated during the dry season, to approximate potential yields under typical farm conditions.

Forage measurements

The forages were harvested 60 days after establishment, and subsequently at approximately 40-day intervals, for a total of eight harvests over the length of the trial. The four grasses were harvested at a stubble height of 15 cm and the stylo at 20 cm. Forage samples for chemical analysis were collected twice, once in March 2011 during the dry season and once in September 2011 during the rainy season. The samples were dried at 60 °C, and crude protein (CP) analysis of the samples was conducted using the method of AOAC (1990) at the laboratory of the National Institute of Animal Sciences. Analysis for neutral detergent fibre (NDF), acid detergent fibre (ADF) and ash were conducted at the laboratory of the University of Tasmania, Australia.

Evaluation of waterlogging resistance of the forage species

At the end of 2010, there was an extended wet period in the three study provinces. Waterlogging resistance was observed in the forage species throughout this period. After 1 month of heavy rain, with waterlogging observed at all sites, we recorded plant vigour and survival ratings for all plots using the rating scale below:

1. all plants are dead
2. major plant damage, but not all dead
3. moderate damage, including some plant death, chlorosis, necrosis
4. minimal damage, some chlorosis or necrosis
5. virtually no damage—all plants are alive and healthy.

Survival was measured as the number of plants in each plot that had green tillers or leaves (alive) divided by the total number of plants (alive and dead) in the plot.

Table 1. Average soil characteristics of forage trials at the three provincial sites

Province	pH_{KCl}	Organic carbon (%)	Nitrogen (%)	Phosphorus (P_2O_5) (%)	Potassium (K_2O) (%)
Binh Dinh	4.46 ± 0.22	1.16 ± 0.29	0.026 ± 0.003	0.029 ± 0.014	0.098 ± 0.055
Phu Yen	4.81 ± 0.73	1.78 ± 0.37	0.035 ± 0.004	0.048 ± 0.010	0.075 ± 0.024
Ninh Thuan	5.72 ± 0.12	0.84 ± 0.22	0.028 ± 0.005	0.027 ± 0.004	0.103 ± 0.021

Note: measurements are average ± standard deviation; pH_{KCl} = pH measured in 1M potassium chloride; P_2O_5 = phosphorus oxide; K_2O = potassium oxide

Farmer forage assessment

Fifteen farmers were selected in each province to assess the new forage varieties. This assessment was done using a 'best-bet' approach under typical farming conditions in each province (Lisson et al. 2010). Forage assessment activities were conducted by farmers with guidance from researchers. These activities were: (i) new forage introduction and development; (ii) improved management practices for existing and new forages; and (iii) more effective utilisation of other available feed resources.

An improved supply of forage was an important first step in the best-bet process (see Ho Le Phi Khanh et al. 2015), due to its ability to make a rapid impact at the farm level. Farmers were provided with seed or tillers of the new forage cultivars to establish small nursery areas, then encouraged to expand the area of those that they preferred. Group discussions, workshops and individual household visits were used to assess available resources, constraints and opportunities for increasing the productivity and profitability of each farm. Farms were visited regularly to work through technical problems, provide training in planting, fertilising, cutting management and feeding, and record qualitative and quantitative data. Farmer preferences for forage species were evaluated in workshops and through questionnaires. In the analysis of farmer preference, farmers were able to 'like' as many forage species as they wanted.

Statistical analysis

Forage assessment data were analysed using a general linear model (GLM, Minitab 14.0) and one-way analysis of variance (ANOVA) with species and provinces as fixed effects and farms (blocks) as a random effect. Differences were considered significant at $p < 0.05$. The results were expressed as means with standard error of the mean (SEM) or standard deviation (SD) as indicated.

Results and discussion

On-farm forage assessment

Growth rate and yield of experimental cultivated forage species

Cutting interval, canopy height, plant height, leaf fraction, biomass and protein yield are important indicators to express the growth and potential of a forage species. The results of observing these indicators in this experiment are shown in Tables 2, 3 and 4, and Figure 2.

The forages were harvested eight times per year. The cutting intervals were variable between seasons and ranged from 31–60 days (Table 2). In the rainy season (which is also the coldest season), the cutting interval was longer than in the spring–summer season. The cutting intervals in this experiment were similar to the prior work of Bui Quang Tuan and Le Hoa Binh (2004), Nguyen Xuan Ba et al. (2010) and Nguyen Thi Mui et al. (2011).

Table 2. Average, maximum and minimum cutting intervals in the three provinces over 1 year

Province	Average ± SD (days)	Maximum (days)	Minimum (days)
Binh Dinh	44 ± 5.5	53	35
Phu Yen	44 ± 6.9	60	37
NinhThuan	43 ± 9.0	60	31

Note: SD = standard deviation

The canopy height and height of tallest plants at harvesting time varied between species and between cutting intervals (Figure 2). The canopy height of species in this experiment was similar to that reported in other trials (Bui Quang Tuan and Le Hoa Binh 2004; Nguyen Xuan Ba et al. 2010).

Leaf-to-stem ratio (LSR) is an important indicator of the nutrient and feeding value of the grass species. The leaf is the most palatable and digestible part of the forage. The LSR is variable depending on the cutting interval and the grass species. Results in Table 3 show that LSR varied from 64 to 81%. Among the four grass species, Mulato II and paspalum had higher LSRs than TD58 and VA06 ($p < 0.05$). The results presented here are consistent with those reported by several authors (Bui Quang Tuan and Le Hoa Binh, 2004; Nguyen Xuan Ba et al. 2010) where they conducted similar studies in other provinces in Vietnam.

Dry matter (DM) content of the forages is heavily reliant on the cutting interval and climate. The average cutting interval was 44 days (Table 2), and the DM content varied between 17 and 21%, depending on the species and location (Table 3).

Data from the eight cuttings (December 2010 to December 2011) showed that there were significant

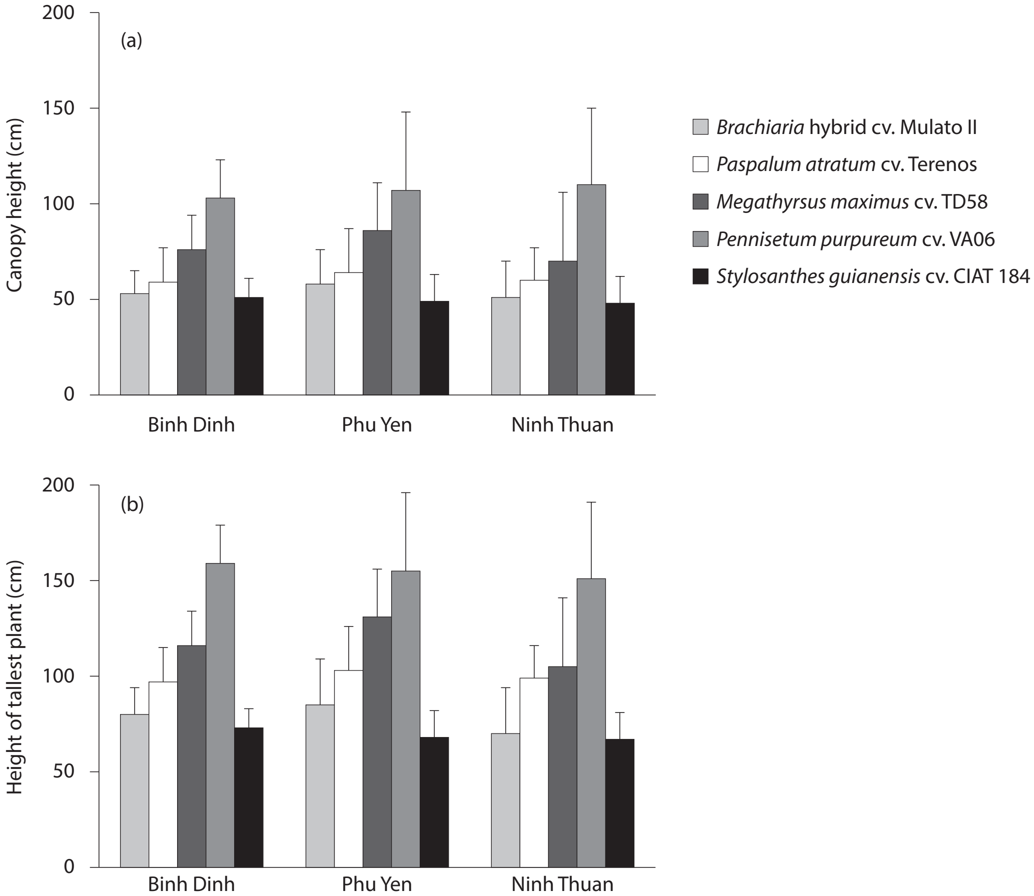

Figure 2. Average (± standard deviation) canopy height (a) and tallest plant of each forage variety (b) at harvesting time over 1 year in the three provinces

Table 3. Average leaf-to-stem ratios (LSRs) and dry matter yields of different forage species in the three study provinces

Species	Leaf fraction (% ± SD)	Dry matter (% ± SD)			Probability
		Binh Dinh	Phu Yen	Ninh Thuan	
Mulato II	81.3 ± 3.2 x	18.2 ± 0.2 a xyz	18.6 ± 0.2 ab xyz	19.3 ± 0.1 b x	*
Paspalum	80.5 ± 3.7 x	17.3 ± 0.2 a y	18.0 ± 0.2 a xyz	20.0 ± 0.2 b xy	**
TD58	70.7 ± 6.1 y	18.3 ± 0.2 a xyz	18.9 ± 0.2 a xyz	21.2 ± 0.2 b y	**
VA06	63.7 ± 14.4 y	16.8 ± 0.2 a xy	17.3 ± 0.2 ab xy	18.6 ± 0.2 b x	**
Stylo	–	19.3 ± 0.2 a z	19.5 ± 0.2 a z	21.2 ± 0.2 b z	**
Probability	***	***	**	***	

Note: full species names are *Brachiaria* hybrid cv. Mulato II, *Paspalum atratum* cv. Terenos, *Megathyrsus maximus* cv. TD58, *Pennisetum purpureum* cv. VA06, *Stylosanthes guianensis* cv. CIAT 184; SD = standard deviation; averages within rows with different letters (a,b) differ significantly ($p < 0.05$); averages within columns with different letters (x,y,z) differ significantly ($p < 0.05$); significance for p values: *** = < 0.001, ** = < 0.01, * = < 0.05, NS = not significant differences ($p < 0.05$) in the yields of DM and protein between species at the same location in all three provinces (Table 4). In Binh Dinh, the average DM yield of the four grass species ranged from 25.7 to 40.0 t/ha/year, while stylo yielded an average of 11.5 t/ha/year. Among the grass species, TD58 had the greatest DM yield ($p < 0.05$). In Phu Yen, there was no significant difference in DM yield among the four grass species (although the DM yield varied from 37.3 to 50.3 t/ha/year), while stylo yielded 17.0 t/ha/year. In Ninh Thuan, the greatest DM yield was from VA06 (39.0 t/ha/year).

Protein yield was significantly different ($p < 0.05$) among species in Binh Dinh and Phu Yen, while there was no significant difference ($p = 0.269$) among species in Ninh Thuan (Table 4). The highest CP yield was from TD58 in all provinces (Table 4), largely due to its high yield.

In general, most of the grass species performed better in Phu Yen province compared with other provinces, with Ninh Thuan performing the poorest, indicating that low rainfall could be one of the limiting factors for their poor performance.

Although the field sites featured sandy soils with difficult climatic conditions, good management (fertiliser, irrigation and cutting interval) meant that the forages yielded similar levels to forage trials in more fertile parts of Vietnam (Nguyen Ngoc Ha et al. 1995; Truong Tan Khanh 1999 in Dak Lak province; Nguyen Thi Mui et al. 2011 in Red River Delta, central coast and south-east; Nguyen Van Quang et al. 2011 in two areas of Lai Chau province; and Nguyen Ngoc Anh and Nguyen Thi Mui 2009).

Chemical composition of different forage species

Chemical composition of forage is an important indicator of nutritive value. The results of chemical analyses are shown in Tables 5 and 6.

There were significant differences in the CP concentrations in different forage species and in the different provinces ($p < 0.001$) (Table 5). CP concentrations tended to be lower during the dry season. The greatest average CP concentrations were observed in stylo (14.7–17.9%). Of the four grass species, Mulato II contained significantly higher levels of CP (10.6–13.7%). These results are similar to other reports in Vietnam (Truong Tan Khanh 1999; Vu Kim Thoa and Khong Van Dinh 2001; Ba et al. 2005; Vu Chi Cuong et al. 2009; Nguyen Xuan Ba et al. 2010).

Regarding NDF, ADF and ash, the chemical analyses for all species were similar to results from other regions in Vietnam (Truong Tan Khanh 1999; Vu Kim Thoa and Khong Van Dinh 2001; Ba et al. 2005; Vu Chi Cuong et al. 2009; Nguyen Xuan Ba et al. 2010). The NDF concentrations were as expected—relatively high in the grass species (64–71%), and lower in stylo (55%) (Table 6). NDF is a measure of cell wall content, which is influenced by species characteristics, temperature, and leaf and stem age. Among the grasses, Mulato II had the lowest levels of NDF and ADF. Ash concentrations were similar among species.

Waterlogging resistance

In 2010, SCC Vietnam experienced high rainfall at the end of the year (e.g. Phu Yen's November rainfall was 1,224 mm). Most areas were waterlogged for

Table 4. Average dry matter (DM) and crude protein (CP) yields of different forage species in three provinces (t/ha/year)

Species	Province					
	Binh Dinh		Phu Yen		Ninh Thuan	
	DM	CP	DM	CP	DM	CP
Mulato II	25.7 a	3.5 a	37.3 a	4.6 abc	24.4 ab	2.6
Paspalum	27.2 a	2.9 a	42.1 a	4.0 abc	38.6 a	2.7
TD58	40.0 b	5.0 b	50.3 a	5.2 b	33.9 a	3.3
VA06	26.4 a	3.4 a	39.4 a	4.4 abc	39.0 a	3.2
Stylo	11.5 c	2.0 c	17.0 b	3.0 c	15.8 b	2.3
Probability	***	***	***	*	**	NS

Note: full species names are *Brachiaria* hybrid cv. Mulato II, *Paspalum atratum* cv. Terenos, *Megathyrsus maximus* cv. TD58, *Pennisetum purpureum* cv. VA06, *Stylosanthes guianensis* cv. CIAT 184; averages within rows with different letters differ significantly ($p < 0.05$); significance for p values: *** = < 0.001, ** = < 0.01, * = < 0.05, NS = not significant extended periods. A lot of forage plants died or had low growth rates. Waterlogging resistance of the forage cultivars was measured using plant vigour and survival ratings (Table 7).

Paspalum had the greatest resistance to waterlogging and continued to persist and grow under waterlogged and inundated conditions. Mulato II, TD58 and VA06 had less resistance to waterlogging, and stylo had poor waterlogging tolerance (Table 7).

Farmer forage assessment

Most farmers preferred two or three species (Table 7). These preferences were based on observation of field trials where forage varieties were fed to cattle. The three main factors that influenced farmer choice were species yield, palatability to cattle and ease of establishment (stem or tiller versus seed). Generally, farmers operating cow–calf systems preferred Mulato II and TD58 because they appeared more palatable and had higher leaf-to-stem ratios. However, farmers operating fattening systems often preferred VA06 because it provided bulk to complement concentrate feeding.

By the end of the project, 95% of the best-bet farmers were using the improved forages and 90% had expanded beyond their original planted area. The area of forage grown varied considerably between farmers and between provinces as determined by the availability of land, the aspirations of the individual farmers, and the interest and support from extension personnel.

Table 5. Average crude protein (CP) concentration of forage species in three provinces of south-central coastal Vietnam

Species	CP concentration (% dry matter)								
	Binh Dinh			Phu Yen			Ninh Thuan		
	Rainy season	Dry season	Average	Rainy season	Dry season	Average	Rainy season	Dry season	Average
Mulato II	15.34 a	12.07 a	13.70 a	14.03 a	10.78 a	12.41 a	10.44 a	10.70 a	10.57 a
Paspalum	12.03 b	9.40 a	10.72 b	10.10 b	8.95 b	9.52 b	7.71 b	6.09 b	6.90 b
TD58	13.49 ab	10.72 a	12.10 b	11.47 b	10.34 b	10.91 b	10.31 a	8.76 b	9.53 c
VA06	13.23 b	11.00 a	12.12 ab	11.48 b	9.07 ab	10.28 ab	8.50 ab	8.01 ab	8.25 bc
Stylo	19.65 c	15.34 b	17.49 c	20.01 c	15.69 c	17.85 c	14.96 c	14.51 c	14.73 d
Probability	***	***	***	***	***	***	***	***	***

Note: full species names are *Brachiaria* hybrid cv. Mulato II, *Paspalum atratum* cv. Terenos, *Megathyrsus maximus* cv. TD58, *Pennisetum purpureum* cv. VA06, *Stylosanthes guianensis* cv. CIAT 184; averages within rows with different subscripts differ significantly ($p < 0.05$); significance for p values: *** = < 0.001, ** = < 0.01, * = < 0.05

Table 6. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and ash content of forage species

Species	*n*	NDF (% DM)	ADF (% DM)	Ash (% DM)
Mulato II	21	63.6 ± 3.5	34.1 ± 2.7	11.3 ± 0.9
Paspalum	24	65.5 ± 4.1	38.5 ± 3.9	11.2 ± 1.6
TD58	22	71.1 ± 2.6	41.6 ± 2.2	11.4 ± 1.4
VA06	17	67.0 ± 4.0	37.5 ± 2.7	10.4 ± 1.5
Stylo	21	55.0 ± 5.5	42.0 ± 5.8	10.2 ± 1.9

Note: the values presented here are averages (± standard deviation) across all provinces; DM = dry matter; full species names are *Brachiaria* hybrid cv. Mulato II, *Paspalum atratum* cv. Terenos, *Megathyrsus maximus* cv. TD58, *Pennisetum purpureum* cv. VA06, *Stylosanthes guianensis* cv. CIAT 184

Table 7. Waterlogging resistance and farmer preference for the five forage species

Species	Vigour rating[a] (1–5)	Plant death (% of plants)	Farmer preference (% of farmers)
Mulato II	3.1	1.4	92
Paspalum	4.8	0.2	46
TD58	3.7	3.1	85
VA06	3.5	16.6	82
Stylo	2.9	Not recorded	36

[a] 1 = all plants are dead; 2 = major plant damage, but not all dead; 3 = moderate damage, including some plant death, chlorosis, necrosis; 4 = minimal damage, some chlorosis or necrosis; 5 = virtually no damage—all plants are alive and healthy

Note: full species names are *Brachiaria* hybrid cv. Mulato II, *Paspalum atratum* cv. Terenos, *Megathyrsus maximus* cv. TD58, *Pennisetum purpureum* cv. VA06, *Stylosanthes guianensis* cv. CIAT 184

Conclusions and recommendations

In the irrigated sandy areas of Binh Dinh, Phu Yen and Ninh Thuan provinces, the DM biomass yield from the five forage species tested was relatively high, and similar to previous studies in other regions of Vietnam. Although there were significant differences in biomass and protein concentration between species and between planting areas, all these five forage species are suitable for growing in these sandy soil areas. This research was the first time that most of these species had been introduced to SCC sandy areas. The yield and quality results suggest that *Brachiaria* hybrid cv. Mulato II and *Panicum maximum* cv. TD58 are excellent new forage options for SCC Vietnam. For waterlogged areas, *Paspalum atratum* cv. Terenos has great potential to persist and produce high-quality forage. We recommend that farmers plant a mixture of forage varieties, including grasses and legumes, to diversify the diet of their cattle and to build resilience to the variable environmental conditions in the SCC region.

Development of the beef-cattle industry in Vietnam has been constrained by limitations in forage supply and quality. Improved knowledge regarding growing, managing and feeding new and existing fresh forages, utilisation of crop residues and use of feed supplements will encourage greater intensification of beef-cattle production. A video of newly introduced forage species was aired on Vietnamese national television (Channel VTV2), and communicating such findings through television offers the opportunity to reach a wider audience of farmers.

Balanced intensification of cattle farming has the potential to improve the livelihoods of smallholder farmers. The research presented here provides the basis for further investigation into forage management (stubble height, nutrition management) and cattle performance on these varieties.

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Cattle production in south-central coastal Vietnam

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Abstract

Growing demand for beef in Vietnam provides an opportunity for smallholder farmers to improve their incomes and livelihoods. Current systems of production range from extensive production utilising common land, to intensive systems with high levels of purchased inputs. A semi-intensive system, where farmers combine grazing with cultivation of forages and use of crop by-products, is potentially both profitable and resilient. A key challenge for farmers is knowledge of nutrition, and how to best utilise available feed resources. Nutrition has been the focus of Australian Centre for International Agricultural Research (ACIAR)-funded beef cattle projects in Vietnam. Optimal levels of supplementation are now established for Laisind and yellow cattle of different weights. Cassava powder is a cheap and readily available supplement, and can be used in mixes; however, intake should be limited to between 0.7 and 1.0% of liveweight. For finishing Vietnamese cattle, a concentrate containing 16% crude protein is recommended. The greatest opportunities for farmers to improve the diet include high-quality cultivated forage and locally available concentrate ingredients.

The importance of cattle production in the south-central coastal region

South-central coastal (SCC) Vietnam is one of the eight regions of Vietnam (Figure 1). It consists of the independent municipality of Da Nang and seven other provinces. The two southern provinces Ninh Thuan and Bình Thuan are sometimes included as part of the south-eastern region.

The growing demand for beef in Vietnam, driven by increased disposable incomes and tourism, is providing an opportunity for smallholder crop–livestock farmers in some Vietnamese provinces to improve their income through beef-cattle production. Cattle numbers and beef production for the whole country since 2000 are shown in Figure 2. Cattle numbers increased from 4,127,900 head in 2000 to 6,724,700 head in 2007, but then decreased to 5,194,200 head in 2012, and appear to be stabilising. However, beef production steadily increased during this period, from 93,800 tonnes (t) in 2000 to 304,400 t in 2013.

According to the General Statistics Office (2014), 22% of Vietnam's estimated 5.1 million cattle were found in the SCC region, with the majority in Quang Ngai, Binh Dinh and Phu Yen provinces (Figure 3). As in the other regions of the developing world, and other regions in Vietnam, cattle production in this region plays an important role in the agricultural and rural economies. People breed and raise cattle for multiple purposes, including draught power, meat production, manure, as a form of saving and investment, and as security against crop failure.

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Sustainable generation of income for smallholder farmers in the central provinces is a major development priority for Vietnam. Demand for beef is increasing, particularly in the major urban centres, as a result of both tourism and the increasing disposable income of the local population. Increasing cattle production is an opportunity to help alleviate poverty in central Vietnam. Furthermore, cattle rearing and finishing was recently identified as the most desirable income-generating activity of households in this region (MARD 2013). Therefore, the local governments of Quang Ngai, Binh Dinh and Phu Yen provinces placed greater priority on policies to support and improve cattle production. In line with local government policies, the Australian Centre for International Agricultural Research (ACIAR) collaborated with Vietnam research institutions to carry out a series of projects in this region, such as ACIAR Project LPS/2002/078 (*Improved cattle production in central Vietnam*) and ACIAR Project SMCN/2007/109 (*Profitable and sustainable crop and livestock systems for south-central coastal Vietnam*).

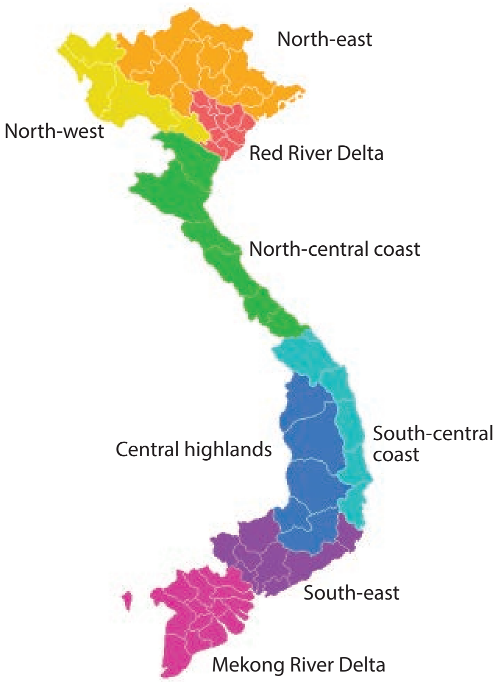

Figure 1. Map of ecological regions in Vietnam

Systems of cattle production in SCC Vietnam

In 2009, three communes, one from each of three provinces (Binh Dinh, Phu Yen and Ninh Thuan), were selected as broadly representative of the area for a baseline survey (Parsons et al. 2013). The cattle populations for these provinces are shown in Figure 3. The selected communes were Cat Trinh in

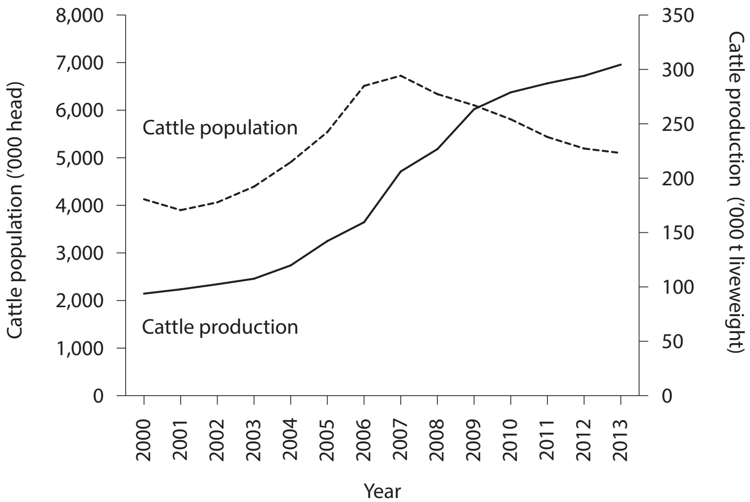

Figure 2. Cattle population and production in Vietnam from 2000 to 2013. Source: General Statistics Office (2014)

Phu Cat district (Binh Dinh), An Chan in Tuy An district (Phu Yen) and Phuoc Dinh in Ninh Phuoc district (Ninh Thuan). From each commune, a number of villages were selected for survey, comprising: Phu Kim and An Duc (Cat Trinh commune); Phu Quy, Phu Thanh and Phu Phong (An Chan commune); and Son Hai 1, Son Hai 2, Bau Ngu and Tu Thien (Phuoc Dinh commune). Using a stratified sampling method, 180 households from the three study communes were chosen, all of which were located on lowland sandy soils. Some results have already been presented in Hoang Thi Thai Hoa et al. (2015).

Managing cattle production

Examination of management techniques and procedures indicates the intensity of cattle production. The hours of grazing for cattle in Ninh Thuan are two to four times longer than Binh Dinh and Phu Yen (Table 1), confirming the importance of grazing in Ninh Thuan. Procedures such as bathing cattle, supplementing with vitamins and salt, supplying water and recording mating also indicate the level of intensity. More households in Phu Yen and Binh Dinh conduct these activities than in Ninh Thuan, confirming the more extensive production practices in Ninh Thuan province.

Households that bathe cattle, use salt, supply water and record mating have lower cattle numbers (Table 2). This confirms that intensive and semi-intensive cattle production generally involves smaller herds than extensive production. The trend is the same for all procedures except vaccination, which is undertaken through government extension programs.

Method of insemination is an indicator of the intensity of cattle production. Results showed that 100% of households in Ninh Thuan used natural mating without control of when this occurs, reflecting the extensive production system. In comparison, in Binh Dinh and Phu Yen, only 31% and 22% of households, respectively, used natural mating without control. In these provinces, the majority of households used controlled natural mating, with a minority using artificial insemination. The source of semen is Zebu purebred, such as Red Sindhi, or crossbred Brahman genotypes.

The breed of bull is an additional indicator of the level of extensive cattle production. In Ninh Thuan, the proportion of households using yellow cattle bulls is 69% and Red Sindhi or cross Red Sindhi make up 31%. In Binh Dinh and Phu Yen, a third of households use yellow cattle bulls and the remainder practise crossbred matings using Limousin, Simmental, Red Sindhi or other Brahman genotype sires.

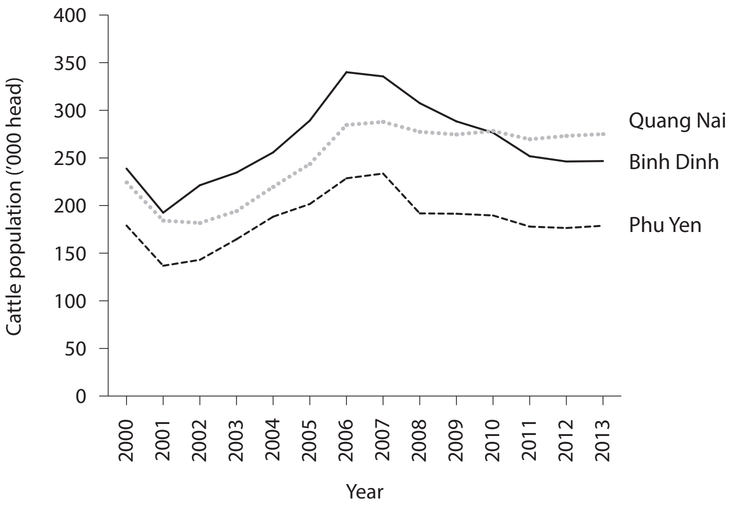

Figure 3. Cattle populations for selected coastal provinces, 2000 to 2013. Source: General Statistics Office (2014)

Table 1. Indicators of cattle management and procedures for households surveyed in Binh Dinh, Phu Yen and Ninh Thuan provinces

Activity	Province		
	Binh Dinh	Phu Yen	Ninh Thuan
Grazing time in rainy season (hours ± SD)	2.3 ± 2.6	2.2 ± 2.3	8.7 ± 2.4
Grazing time in dry season (hours ± SD)	3.5 ± 3.0	4.8 ± 3.8	9.3 ± 2.3
Parasite prevention (%)	77.4	51.7	56.3
Bathing cattle (%)	90.3	96.6	39.4
Vitamin supplementation (%)	38.7	41.4	6.1
Water supply to housed cattle (%)	93.6	96.6	75.8
Salt supplementation (%)	96.8	75.9	6.1
Vaccination (%)	100.0	96.6	90.9
Recording time at insemination (%)	41.9	34.5	0.0
Estimating calving date (%)	54.8	44.8	9.1

Note: SD = standard deviation

Table 2. Average numbers (± standard deviation) of cattle in households surveyed adopting the nominated production technology procedures compared with those not adopting

	Cattle per household		Probability
	Adoption	Non-adoption	
Parasite prevention	6.3 ± 8.5	7.9 ± 10.1	0.106
Bathing cattle	5.9 ± 7.5	10.5 ± 12.7	0.033
Vitamin supplement	4.2 ± 4.6	8.2 ± 10.3	0.060
Water supply	6.2 ± 8.1	13.4 ± 14.2	0.016
Salt supply	4.3 ± 6.7	11.0 ± 10.9	0.001
Vaccination	7.2 ± 9.4	4.5 ± 2.7	0.571
Recording time at insemination	3.4 ± 2.1	8.3 ± 10.3	0.028
Estimating calving date	5.4 ± 6.0	8.0 ± 10.6	0.192

The decision to supplementary feed cattle affects the expression of the genetics and the efficiency of production. Many criteria can be used by farmers to decide when to provide concentrate, including age, sex, season and purpose of cattle production. In Ninh Thuan, due to the lower rainfall and the predominance of grazing, the season is a very important criterion for offering concentrate. Cows and fattening cattle are the priority classes for receiving concentrate. However, the number of households that offer concentrate to cattle is low, and cattle production relies mostly on other available feed resources, including grazing, crop residues, and cut and carry.

Constraints to cattle production

There were numerous perceived constraints to cattle production of surveyed households including lack of capital, cattle breeds, nutrition, labour availability, diseases, knowledge, and marketing (Table 3). We acknowledge that constraints to production can be complex, and that farmers' perceptions of constraints may not completely explain the situation. Capital was the constraint most frequently (69%) identified by farmers as very important. Other constraints such as lack of feed, diseases, breed and labour were listed as important or very important by just under half of the surveyed households.

Feed for cattle production in SCC Vietnam can be constrained by a general lack of quantity but can depend on the season and the source of feed. This constraint is not always recognised by farmers, as only 18% of farmers felt that lack of feed was a very important limitation (Table 3). In order to solve the feed-supply problem, many farmers have adopted solutions such as planting grasses, storing crop residues, offering concentrates, cutting natural grass and reducing the cattle numbers. Depending on the province, 41–77% of surveyed households stored agricultural by-products. In all provinces, approximately 60% of farmers collected and fed natural grass. Supplying concentrate was most commonly reported (55%) by farmers in Binh Dinh. In comparison, cultivating grass was a more common way (59%) for farmers in Phu Yen to deal with feed shortages. Reducing cattle numbers was a less commonly reported solution to feed shortages (15–20% of farmers). Farmers also reported that selling cattle when there were feed shortages results in lower prices, due to the influx of cows on the market.

Nutrition research for improved beef production

Effects of cassava powder as a supplement for Laisind cattle

An experiment (Nguyen Xuan Ba et al. 2008a) was conducted at the Hue University of Agriculture and Forestry (HUAF) farm to examine the effect on intake and gain when Laisind cattle were fed basal diets supplemented with cassava powder on a dry matter (DM) basis of up to 2% of liveweight (LW)/day. There were five treatments (four animals per treatment, blocked by LW): a basal diet of elephant grass (organic matter (OM) 89.0%, neutral detergent fibre (NDF) 7.15%, crude protein (CP) 10.8%) fed at 1.25% of LW and rice straw (OM 88.0%, NDF 77.1%, CP 5.1%) fed ad libitum, or this diet supplemented with cassava powder (OM 97.0%, NDF 8.3%, CP 1.7%), containing 2% urea, at rates of approximately 0.3, 0.7, 1.3 or 2.0% LW. The cattle fed cassava powder at about 2.0% LW did not consume all of the supplement, with actual intake similar to the 1.3% LW treatment. OM, digestible OM and digestible energy intakes increased ($p < 0.001$) curvilinearly as the amount of cassava powder consumed increased (Table 4). Rice straw intake declined curvilinearly with increasing intake of cassava powder ($p < 0.001$), and there was a small linear decline ($p = 0.01$) in grass intake. The substitution rate of cassava powder for forage was between 0.5 and 0.7 kg DM reduction in forage intake per kg DM supplement consumed, with no difference between treatments. Apparent digestibility of organic matter increased ($p < 0.001$) in a curvilinear manner, while digestibility of neutral detergent fibre declined ($p < 0.001$) in a curvilinear manner as the amount of cassava powder consumed increased. LW gain increased ($p < 0.01$) linearly as the amount of supplement consumed increased (Table 5).

Although forage intake decreased with increased cassava supplement, the quality of the total diet was improved, providing increased digestible energy intake to improve LW gain. This is consistent with similar studies in ruminants where forages have been supplemented with starch-containing feeds (Mulholland et al. 1976; Thomas et al. 1988). Results show that cassava powder with added urea is a useful supplement for beef production in central Vietnam to increase LW gain. Increasing responses can be expected when offered up to a level of 1.0–1.3% LW but higher rates would probably be wasteful and could cause rumen dysfunction and depressions in forage digestion. This supplement would be better incorporated in mixtures with maize or rice bran which are more slowly digested.

Table 3. Householders' views on limitations to cattle production in south-central coastal Vietnam

Factor	Unimportant (%)	Less important (%)	Important (%)	Very important (%)
Capital	4	10	17	69
Breed	28	29	30	13
Lack of feed	29	25	28	18
Labour	30	26	27	17
Diseases	30	28	24	18
Technical knowledge	33	41	22	4
Marketing	47	26	14	13

Table 4. Dry matter (DM), organic matter (OM), crude protein (CP) and neutral detergent fibre (NDF) intake and digestibility when Laisind bulls were fed elephant grass and rice straw supplemented with different amounts of cassava powder

	Treatment						Relationship	Significance[b]
	0.0	0.3	0.7	1.3	2.0	SED[a]		
Cassava powder intake (kg DM/day)	–	0.55	1.04	2.16	2.21			
Elephant grass intake (kg DM/day)	1.80	1.86	1.79	1.80	1.58	0.159	$Y = 1.81 + 0.07C$	$p < 0.02$
Rice straw intake (kg DM/day)	1.75	1.47	1.43	0.48	0.48	0.195	$Y = 1.72 – 0.18C – 0.18C^2$	$p < 0.01$
Substitution rate (kg DM/kg DM)	–	0.6	0.5	0.7	0.7	0.25		
OM intake (kg/day)	3.13	3.49	3.87	4.13	3.98	0.156	$Y = 3.10 + 0.96C – 0.24C^2$	$p < 0.03$
OM digestibility (%)	56.5	63.2	64.4	68.8	67.2	1.25	$Y = 56.9 + 11.1C – 2.8C^2$	$p < 0.01$
Digestible OM intake (kg/day)	1.76	2.21	2.49	2.84	2.67	0.116	$Y = 1.75 + 0.98C – 0.24C^2$	$p < 0.01$
Energy digestibility (%)	54.2	60.6	61.7	66.0	64.3	1.28	$Y = 54.6 + 10.6C – 2.7C^2$	$p < 0.01$
Digestible energy intake (MJ/day)	61.4	67.4	73.7	76.3	73.2	2.91	$Y = 60.9 + 16.5C – 4.6C^2$	$p < 0.05$
CP intake (kg/day)	0.28	0.32	0.35	0.40	0.38	0.014	$Y = 0.28 + 0.09C$	$p < 0.001$
CP digestibility (%)	49.1	59.1	55.0	58.0	57.3	1.62	$Y = 50.3 + 11.0C – 3.6C^2$	$p < 0.01$
NDF intake (kg/day)	2.64	2.51	2.47	1.83	1.68	0.100	$Y = 2.61 + 0.01C – 0.18C^2$	$p < 0.01$
NDF digestibility (%)	62.3	61.3	58.5	46.2	41.3	2.04	$Y = 62.2 + 1.0C – 4.4C^2$	$p < 0.01$

[a] SED = standard error of the diffence between two treatment means
[b] Significant relationships between cassava powder intake (C) and different parameters are given

Table 5. Liveweight (LW), LW change, and nitrogen (N) intake, excretion in faeces and urine and apparent retention when Laisind bulls were fed elephant grass and rice straw supplemented with different amounts of a cassava powder

	Treatment						Relationship	Significance[b]
	0	0.3	0.7	1.3	2.0	SED[a]		
Cassava powder intake (kg dry matter/day)	–	0.55	1.04	2.16	2.21			
N intake (kg/day)	0.045	0.051	0.056	0.064	0.061	0.0022	$Y = 0.045 + 0.014C$	$p < 0.001$
Faecal N (kg/day)	0.023	0.021	0.025	0.027	0.026	0.0013	$Y = 0.022 + 0.001C$	$p < 0.001$
Urinary N (kg/day)	0.009	0.009	0.008	0.009	0.008	0.0009		
Apparent N retention (kg/day)	0.013	0.021	0.023	0.029	0.027	0.0018	$Y = 0.013 + 0.001C –0.003C^2$	$p < 0.01$
Initial LW (kg)	172	164	160	159	163	14.8		
Final LW (kg)	185	189	196	203	195	17.7		
LW gain (kg/day)	0.22	0.35	0.43	0.59	0.47	0.079	$Y = –26.5 + 259.2C$	$p < 0.001$

[a] SED = standard error of the diffence between two treatment means
[b] Significant relationships between cassava powder intake (C) and different parameters are given

Effects of concentrate supplementation in yellow cattle

Two experiments (Nguyen Xuan Ba et al. 2008b) were conducted on the HUAF farm to examine the effect on intake and LW gain when yellow cattle were fed basal diets supplemented with a concentrate comprising (all fresh basis) rice bran (45%), maize (49%), fish meal (3%), urea (2%) and salt (1%), when offered at rates up to 2% of LW (kg DM/day). In both experiments, there were five treatments, namely a basal diet of fresh grass fed at 1.25% of LW (experiment 1, elephant grass, *Pennisetum purpureum*; experiment 2, native grass) and rice straw (*Oryza sativa*) fed ad libitum, or this diet supplemented with concentrate at about 0.3, 0.7, 1.3 or 2.0% LW. There were four male growing cattle per treatment in experiment 1, and three in experiment 2. Cattle were fed for 44 (experiment 1) or 49 (experiment 2) days, with feed intake recorded daily, LW measured weekly and digestibility measurements made over 7 days commencing on day 24 (experiment 1) or day 10 (experiment 2). The elephant grass and native grass had NDF concentrations of 82 and 73% DM, respectively, and nitrogen (N) concentrations of 1.3 and 1.8% DM, respectively. The rice straw used had a NDF concentration of 79–84% DM and N concentration of 0.8% DM. The concentrate had NDF and N concentrations of 33 and 2.8% DM, respectively.

In both experiments, DM intake increased ($p < 0.001$) linearly as the amount of concentrate consumed increased. Rice straw intake declined ($p < 0.001$) (experiment 1: 1.24 to 0.48 kg DM/d; experiment 2: 0.95 to 0.50 kg DM/d) as concentrate intake increased. Grass intake was not significantly affected by concentrate intake in either experiment. The lowest amount of concentrate supplement increased forage intake, but at higher amounts of concentrate, substitution increased as the amount of concentrate consumed increased. However, substitution rates at the highest amount of concentrate consumed were modest at 0.3 to 0.5 kg DM reduction in forage intake/kg DM supplement consumed. In both experiments, digestible OM intake increased linearly ($p < 0.001$) (experiment 1: 1.16 to 2.38 kg/day; experiment 2: 1.30 to 2.49 kg/day) as the amount of supplement consumed increased, as did LW gain (experiment 1: 0.15 to 0.81 kg/day; experiment 2: 0.15 to 0.77 kg/day). This was associated with significant ($p < 0.01$) linear increases in OM intake and apparent OM digestibility. NDF digestibility declined as concentrate intake increased, but the effect was just short of significance ($p = 0.051$) in experiment 2.

An economic analysis based on the results from experiment 1 (Table 6) indicates that the profitability of finishing cattle in central Vietnam can be substantially increased by appropriate use of well-formulated concentrates. The benefits accrued from a reduced time to achieve the target weight are most likely due to increased partitioning of energy from the concentrate to LW gain. Faster growth reduces the proportion of the total energy that is used for maintenance compared with growth. The implications of labour costs on profit were significant (Table 6). In many circumstances in developing countries, labour costs are not included in such analyses. It is also important that labour efficiencies would be gained where more than one animal is finished at one time. The resources available within a household have a marked impact on the economics of finishing cattle in these smallholder systems and may determine the number of cattle a farmer is prepared to finish and the time of year when they will finish animals. Cash flow and access to credit are primary constraints to increased cattle production in rural households, underscoring the need to fully utilise feed resources available within the farm. The response relationships generated in this research enable extension staff and farmers to design feeding strategies that meet the needs of farmers with different financial positions. Reducing the cost of protein supplements, which are not available within the farm, is likely to increase the implementation of feeding strategies using formulated concentrates in this region. Hence, further work defining the requirement for protein in the supplement, and how this is affected by the characteristics of forages in the basal diet, is warranted.

In conclusion, traditional practice involves feeding low amounts of either cassava powder, maize or rice bran once a day. Formulating concentrates based on a mix of these ingredients, feeding increased quantities (up to 2% LW) and more frequent feeding will increase growth rates, reducing the time taken to achieve target LW, and reduce labour inputs. Therefore, household income and profit from cattle finishing can be increased through better use of concentrates.

Table 6. Economic evaluation of feeding a concentrate supplement comprised of rice bran, maize, fish meal, urea and salt at 1% or 2% liveweight (LW) for a LW gain of 50 kg (120–150 kg LW) in yellow cattle

Cost	Secondary labour			Primary labour	
	Concentrate				
	0	1% LW	2% LW	1% LW	2% LW
Sale price (VND million)	3.40	3.40	3.40	3.40	3.40
Purchase price (VND million)	2.40	2.40	2.40	2.40	2.40
Time taken to 170 kg LW (days)	278	88	52	88	52
Labour costs (VND million)	0.56	0.18	0.10	0.44	0.26
Supplement fed (kg fresh)	–	136	161	136	161
Supplement costs (VND million)	–	0.36	0.43	0.36	0.43
Grass fed (kg fresh)	2,431	763	453	763	453
Grass costs (VND million)	0.49	0.15	0.09	0.15	0.09
Straw fed (kg fresh)	482	137	57	137	57
Straw costs (VND million)	0.05	0.01	0.00	0.01	0.00
Total feed costs (VND million)	0.53	0.53	0.52	0.53	0.52
Net profit (VND million)	–0.10	0.30	0.37	0.03	0.22

Note: All prices and costs (at 2008) are in Vietnamese dong (VND million). Primary labour (adults) was costed at VND5,000/day, and secondary labour (children under 16 years and adults over 60 years of age) was costed at VND2,000/day.

Effect of crude protein in yellow cattle diets

Two experiments (Dinh Van Dung et al. 2013) were conducted at the HUAF farm to determine the effects of CP level in concentrate (experiment 1) and concentrate level (experiment 2) on feed intake, nutrient digestibility, N retention, ruminal pH and ammonia nitrogen (NH_3-N) concentration and average daily gain (ADG) of Vietnamese yellow fattening cattle. Animals (24 cattle, initial LW 150.3 ± 11.8 kg in experiment 1 and 145.1 ± 9.8 kg in experiment 2) were allotted based on LW to one of four treatments in a randomised complete block design. In experiment 1, concentrate with four levels of CP (10, 13, 16 and 19%) was fed at 1.5 % of LW. In experiment 2, concentrate was fed at 1.0, 1.4, 1.8 and 2.2 % of LW. In both experiments, roughage consisted of 5 kg/day of native grass and ad libitum rice straw. Results showed that the CP level in concentrate significantly affected DM intake ($p < 0.05$), N retention, ADG and ruminal NH_3-N concentration ($p < 0.01$). However, it had no significant effect on DM, OM and NDF digestibility ($p > 0.05$), whereas CP digestibility increased ($p < 0.001$) along with the CP level. DM intake, N retention and ADG increased ($p < 0.001$) linearly with concentrate intake. DM and CP digestibility were not significantly affected by concentrate intake ($p > 0.05$). OM digestibility and NH_3-N concentration increased linearly ($p < 0.05$), whereas NDF digestibility and ruminal pH declined linearly with increased concentrate consumption ($p < 0.01$). The results indicated that feeding a concentrate containing 16% CP at a rate of 2.2% of LW could be recommended for finishing local cattle.

Effect of supplementation on growth of yellow–Brahman bulls

A feeding experiment (Quang et al. 2011) was undertaken at the Institute of Agricultural Science for Southern Vietnam (IAS) Ruminant Research and Training Centre in late 2010 and early 2011. The aim of the research was to assess the responses in growth and nutrient digestibility when Brahman-cross cattle were given concentrate supplementation. Twenty Brahman-cross bulls (~200 kg) were fed a basal diet (rice straw and guinea grass) and supplemented at rates of 0–2.4% of LW. The supplement consisted of cassava chips, rice bran, crushed rice, fish meal, urea and salt.

Intake of rice straw and guinea grass decreased with increasing levels of supplementation (Figure 4). Total intake flattened above 1.2% of LW.

LW (Figure 5) increased rapidly with supplementation of up to 1.2% of LW, but there was no further significant increase at greater levels of supplementation. A simple economic analysis of the data suggested that 1.2% ration was a good balance between animal response and cost and consequently resulted in the greatest net profit. All concentrate treatments were more profitable than the control treatment.

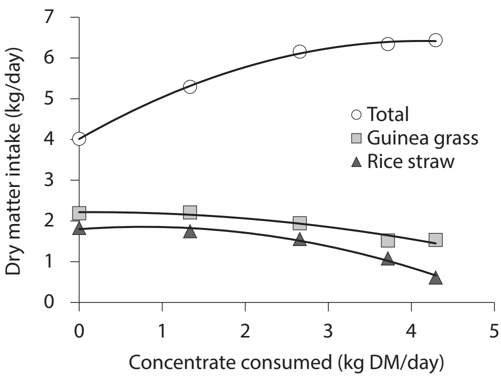

Figure 4. Effects of amount of concentrate consumed on intake of total dry matter (DM), rice straw and guinea grass

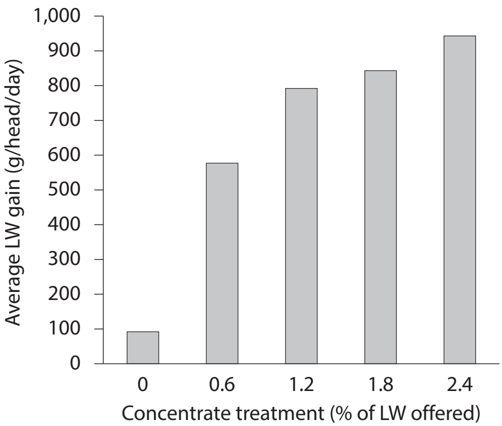

Figure 5. Average daily liveweight (LW) gain of Brahman-cross cattle fed increasing levels of supplement

Utilisation of high-protein concentrates for finishing Brahman-cross cattle

Sixteen F1 (Brahman × yellow) cattle from 20 to 24 months of age were assigned to four treatments in a completely randomised experiment (Nguyen Huu Van et al. 2012). The experiment was conducted over 84 days in Quang Ngai province to investigate the possibility of using high-protein concentrates during the finishing period. The animals were individually penned in the same house, fed elephant grass ad libitum, and had free access to drinking water. Concentrate ingredients comprised:

- treatment I—rice bran 49%, corn powder 30%, cassava powder 20% and salt 1%
- treatment II—rice bran 20%, corn powder 48.5%, cassava powder 20%, fish meal 10%, salt 0.5% and urea 1%
- treatment III—rice bran 20%, corn powder 39%, cassava powder 20% and fish meal 21%
- treatment IV cattle were fed a factory-made concentrate (Lai Thieu feed company) comprising corn, rice bran, peanut cake, cassava, fish meal, shell powder, methionine, lysine, minerals, vitamins and enzymes.

CP was 9.4% DM in concentrate of treatment I, and about 15.5% DM in other treatments. The level of concentrate offered was periodically increased from 1.0% of liveweight from day 1 to day 15 followed by 1.5% from day 16 to day 33 and then 2.0% from day 34 to the end of the experiment of 84 days.

Results showed that increasing CP in the concentrate from 9.4% to 15.5% did not influence the feed intake but significantly increased the digestibility, feed conversion efficiency and weight gain of the animals (Table 7).

The economic analysis of the results (Table 8) showed that a small extra cost for high protein concentrates (treatments II, III and IV) may produce a greater economic return when finishing cattle. In addition, profit can be maximised if using locally available concentrates with or without urea (treatments II and III) rather than commercial concentrates (treatment IV) (Table 8).

Table 7. Feed intake, digestibility and liveweight (LW) gain during the finishing period when Brahman-cross steers/bulls were given various supplements to increase protein intake

	Treatments				SE	Probability
	I	II	III	IV		
Mean feed intake (kg DM/day)	5.65	5.99	5.78	6.01	0.42	0.915
DM digestibility (%)	66.24[a]	76.55[b]	75.96[b]	77.43[b]	1.29	0.001
OM digestibility (%)	68.63[a]	78.97[b]	78.36[b]	79.83[b]	1.14	0.001
NDF digestibility (%)	45.25[a]	62.00[b]	60.99[b]	68.03[b]	2.65	0.001
CP digestibility (%)	63.85[a]	74.77[ab]	73.98[ab]	77.51[b]	3.17	0.048
GE digestibility (%)	65.94[a]	77.05[b]	75.80[b]	79.56[b]	1.57	0.001
FCR (kg DM/kg LW gain)	7.51[a]	4.35[b]	4.45[b]	4.58[b]	0.36	0.001
Average initial weight (kg/head)	223	222	227	222	17.9	0.99
Average finished weight (kg/head)	279	328	322	321	22.3	0.42
LW gain (g/day)	667[a]	1,259[b]	1,125[b]	1,184[b]	109	0.01

[ab] Values with different superscripts within rows are significantly different
Note: SE = standard error; DM = dry matter; OM = organic matter; NDF = neutral detergent fibre; CP = crude protein; GE = gross energy; FCR = feed conversion ratio; see text for treatment details

Table 8. Economic analysis of supplementing Brahman-cross cattle during the finishing period

	Treatments			
	I	II	III	IV
Expenditure ('000 VND)	32,798	33,991	34,290	35,220
Buying cattle	25,450	25,340	25,900	25,280
Concentrate	5,576	6,910	6,666	8,172
Elephant grass	1,284	1,323	1,305	1,321
Veterinary	221	151	152	180
Cattle shed and equipment	267	267	267	267
Return ('000 VND)	37,650	44,250	43,350	43,350
Profit per treatment ('000 VND)	4,852	10,259	9,060	8,130
Profit per head ('000 VND)	1,213	2,565	2,265	2,032

Conclusion

The growing demand for beef in Vietnam is providing an opportunity for smallholder crop–livestock farmers in central Vietnam to increase household incomes through more-productive beef breeding and growing systems. The most limiting constraints are those regarding supply of good-quality feeds. The greatest opportunities for farmers to improve the supply of feed include high-quality cultivated forage and locally available concentrate ingredients. Research has established that ingredients such as cassava powder, rice bran, corn meal, fish meal and peanut cake can improve the diets and hence the productivity and economic efficiency of growing and finishing beef cattle in this environment.

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The best-bet participatory approach and its impact on smallholder livelihoods

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Abstract

Key issues for cattle production in south-central coastal Vietnam include feed quantity and quality, and poor feed management. We tested a 'best-bet' research approach to overcoming these limitations where selected farmers were introduced to improved options, namely: new forage species coupled with improved grass management; better management and use of existing feed resources (including crop residues, fresh forages and supplements); better animal feeding practices, including strategic use of available and potential feed sources to meet specific nutritional and/or production needs; and better management of the seasonal breeding cycle to lift calving percentage and reduce the calving interval. This paper concentrates on new forage introduction and management, reviews the approach applied and examines the impact of this best-bet option on the livelihoods of smallholders. To achieve this objective, household interviews using a questionnaire, as well as in-depth interviews, were conducted to collect information. The results indicated that the participatory approach increased the level of engagement of farmers in practising best-bet activities and the level of forage cultivation. In addition, the process improved the livelihoods of smallholder farmers through increased income, reduced labour time and enhanced social networking among farmers.

Introduction

Livestock production in general, and cattle production in particular, play an important role in rural development (Steinfeld and Mack 1995). Livestock production can have positive effects on the diet, health, income, financial security, sustainable crop yields, employment opportunities and the social status of households (ILRI 2003). For this reason, raising livestock can enhance the economic viability and sustainability of a farming system (Steinfeld and Mack 1995). According to De Haan (1995) and Devendra (2007), improving cattle production can increase rural growth, reduce poverty and improve the livelihoods of farmers. Furthermore, the agricultural system can be more productive and sustainable if animal production is well managed (ILRI 2003).

In Vietnam generally and in the south-central coastal Vietnam in particular, livestock production has been viewed as an important tool for poverty reduction, because crop production has not been well developed due to the prevailing harsh climatic conditions (Tong Vinh Trung 2010). However, the fundamental issue faced by farmers has been low productivity of cattle raising caused by constraints such as limitations in quantity and quality of feed, especially during the dry season (Hoang Manh Quan 2009). Other constraints include traditional husbandry practices, lack of infrastructure to support and improve cattle management, animal diseases and market issues (Hoang 2011). Among these constraints, the limitation of feed supply and quality is the most important factor restricting improved cattle production in smallholder mixed crop–livestock households in the SCC region (Le Thao Nguyen 2008). A 2010 baseline survey indicated that many

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households in three SCC provinces of Vietnam rely substantially on native grasses, either cut-and-carry or grazed, to overcome dry-season cattle feed shortages (Parsons et al. 2013). Few crop–livestock small farmers in this region grow specific fresh forages such as elephant grass (*Pennisetum purpureum*) to feed their cattle. This has contributed to the high level of labour required for feed gathering, and high costs for provision of alternative feeds (e.g. supplements).

Various interventions have been applied to improve animal husbandry generally and more intensive cattle production in particular. Many such interventions focused on improving feed quality through use of supplements and improving cattle reproduction management via controlled seasonal mating and/or early weaning to reduce the calving interval and increase calving percentage. Others concentrated on improving cattle quantity and quality via crossbreeding and introduction of better genetic resources, especially via artificial insemination (AI). However, research projects have often suffered from a lack of active farmer participation, and thus 'ownership', at critical stages. The present study aimed to test a participatory approach to achieving greater farmer engagement with improved cattle productivity. It was carried out within an Australian Centre for International Agricultural Research (ACIAR)-funded project titled *Sustainable and profitable crop and livestock systems for south-central coastal Vietnam* (SMCN/2007/109), the broader aim of which was to help understand and tackle the major constraints to improved cattle production within smallholder mixed crop–livestock communities in the SSC region of Vietnam.

Participatory approach in 'best-bet' activities

The project employed a farming systems participatory adaptive research (PAR) approach similar to that used by Lisson et al. (2010) in eastern Indonesia. This approach combined three main elements: (1) use of farming systems methodology to capture existing constraints to improved livestock production and identify intervention opportunities to address these constraints within target smallholder communities; (2) selection of a small number of representative farmers within each target community (in this case, commune) for intensive real-farm testing and adaptation of various 'best-bet' intervention options, using stepwise PAR methods for implementation, monitoring and evaluation and capacity building; (3) use of successful 'best-bet' farmers as primary agents for communication and dispersion of new technologies and management options to other farmers.

This approach differs from previous studies such as Ashley et al. (2001) and Morton et al. (2002) in its focus on adaptation of often generic 'best-bet' interventions to individual farmer circumstances, to encourage ownership and uptake via practice application within the existing farming system. Farmers are the centre of the process while others (researchers and extension agency staff) are the facilitators. Farmers engaged in this PAR approach simultaneously enhance their understanding and knowledge while also improving their decision-making skills. This in turn enables them to take the actions necessary to change their farming practices to benefit from the opportunities brought about by application of best-bet options. Knowledge for the sake of knowing is de-emphasised while 'knowing' is linked to concrete action. This enhances the quality of knowledge acquired and informs their action.

Villages were selected in 2009 for intensive study in: Cat Trinh commune, Binh Dinh province; An Chan commune, Phu Yen province; and Phuoc Dinh commune, Ninh Thuan province. Ten potential best-bet study farmers were initially selected for each of the three study communes and interviewed in depth in June 2010, following completion of commune-scale benchmarking and initial farmer workshops. Several farmers from the original cohort of farmers dropped out, mainly because they were initially not well chosen, and were not committed to the best-bet process. Consequently, a further cohort of new farmers was selected for inclusion in the 'best-bet' program in March 2011, bringing the numbers to 15 study farmers per study commune, or 45 in total.

As described above, the study applied a PAR approach similar to that employed by Lisson et al. (2010) in eastern Indonesia. Tools employed included village-scale benchmarking; farmer group discussions; in-depth household interviews leading to shared development of best-bet intervention options with selected study farmers; and, most importantly, interactive, continuous learning techniques to transfer knowledge and build capacity with both farmers and local extension staff. Project team members and commune staff also captured independent data on the available forage resource, cattle feeding and management, cattle housing conditions etc. throughout the life of the project, to cross-check against farmer-supplied information.

The best-bet program involved a stepwise process, starting with system understanding through collection and analysis of benchmark data on climate, soil condition, seasonal crop and livestock production patterns, and household livelihoods and labour use patterns. Results from this step were used to identify current constraints to improved cattle performance and productivity within targeted smallholder communities and likely generic best-bet intervention options to address these constraints.

The next step was to test the practical application of these best-bet options in real farm situations. For each study farmer, a range of likely forage and animal management interventions drawn largely from step 1 were identified to help overcome current constraints to cattle production on their farm. These best-bet options fell into four broad categories:[4]

- new forage introduction and management
- better management and use of existing feed resources (including crop products and residues, fresh forages and supplements)
- better animal feeding practices, including strategic use of available and potential feed sources to meet specific nutritional and/or production needs
- better management of the seasonal breeding cycle to lift calving percentage and reduce the calving interval.

The actual suite of best-bet activities thus differed slightly among farmers, though most reflected a similar pattern of constraints and opportunities. Best-bet activities for each farmer were introduced in a stepwise manner starting with less 'risky' options and progressing to options that required a greater commitment of resources by the farmer. This process occurred according to individual farmer readiness and capacity to embrace each step in the best-bet process. Typically, best-bet activities started with new forage species introduction for three main reasons: feed supply and quality were usually identified as the primary constraint; the opportunity to obtain new forage species was a significant attraction for farmer engagement in best-bet activities; and new forage introductions were seen by farmers as relatively low-risk options involving only small initial commitment of land (usually backyards) and labour.

With regard to the first two best-bet categories, smallholder farmers have traditionally relied on native grass, both through grazing and/or cut-and-carry approaches. More recently, many farmers have grown local varieties of elephant grass to enhance fresh forage supply. However, poor management (lack of nitrogen, irregular cutting practices) has often resulted in poor-quality forage (high stem:leaf ratio, old, rank material) being fed to cattle.

To overcome this, the best-bet program used two complementary approaches. The first involved the introduction of selected improved grass and legume forage varieties to increase the supply and quality of the available on-farm forage resource. New grass varieties introduced included *Brachiaria* hybrid cv. Mulato II, *Panicum maximum* cv. TD58, *Paspalum atratum* cv. Terenos and *Pennisetum purpureum* cv. VA06, while legumes included *Stylosanthes guianensis* cv. CIAT 184 and the tree legume *Leucaena leucocephala* cv. Taramba. Taramba in particular was seen to have great potential for improving dry-season feed quality due to its ability to access subsoil moisture long after herbaceous grasses and legumes had exhausted moisture reserves within their root zone.

The second activity focused on better management and use of existing feed resources with special emphasis on management and use of local king or elephant grass, including better fertiliser and cutting management (both cutting interval and cutting height). These improved management techniques were applied equally to existing grasses and new forage varieties in the course of best-bet implementation. Alongside better use of existing fresh forages, the best-bet program also sought to make better use of crop residues generated following harvest. Suggested activities focused on conservation and strategic feeding of selected residues at critical times in the feed cycle and/or to specific classes of cattle. This option was more relevant in some locations than others due to variation in reliance on field cropping, and also the crop mix from which residues were derived. The other best-bet options were focused on more strategic use of limited feed resources via preferential feeding of particular animal classes, such as freshly calved cows or males for fattening; early weaning of calves and controlled seasonal mating to help improve cow condition and reduce calving intervals; and better cattle housing to improve sanitation and reduce cut-and-carry feed wastage.

[4] Note: improved cattle housing infrastructure best-bet activities were associated with the third and fourth categories, e.g. better sanitation, feed troughs, segregation facilities etc.

Project field team members (field staff from the Research and Development Centre for Animal Husbandry and commune extension officers) worked closely with the study farmers to ensure they gained the necessary knowledge, skills and confidence required to implement agreed best-bet activities. To complement this, the project team also conducted a series of farmer workshops carefully timed to target particular knowledge and skills that the farmers needed to successfully implement the next step in their best-bet activities. These practical interactive workshops were a critical element in the successful uptake of best-bet options. Group discussions/interviews were integrated into these training workshops to explore farmers' perceptions regarding the progress of best-bet activities and their impact on household livelihoods. Best-bet progress was monitored via collection of qualitative and quantitative data on metrics such as land use, labour requirements, cost of cattle production, cattle herd structure, level and diversity of best-bet activities practised, and impact on household livelihoods. In-depth interviews or questionnaire-based surveys of best-best farmers were conducted every 2 months throughout the life of the project.

Results and discussion

Best-bet activity adoption

Best-bet farmer survey results revealed that the number of farmers who had tried and adapted various best-bet options increased significantly across all three communes since the project began. There has been a recognisable increase in farmer understanding and application of new knowledge and skills, reflecting a continuing increase in capacity building. However, the percentage of farmers practising best-bet activities differed among the three target communes. For instance, Cat Trinh had the lowest percentage of farmers (80%) who grew the new forage varieties offered, and only 73% of those who did try them have since expanded their initial plantings (Figure 1). By contrast, 100% of Phuoc Dinh and An Chan best-bet farmers had achieved this after 2 years of engagement. One factor contributing to the lower uptake of new forages in Cat Trinh might be limitations on the availability of suitable land for forage development for some farmers due to smaller backyards and lack of protection from uncontrolled grazing in spare land adjacent to cropping areas.

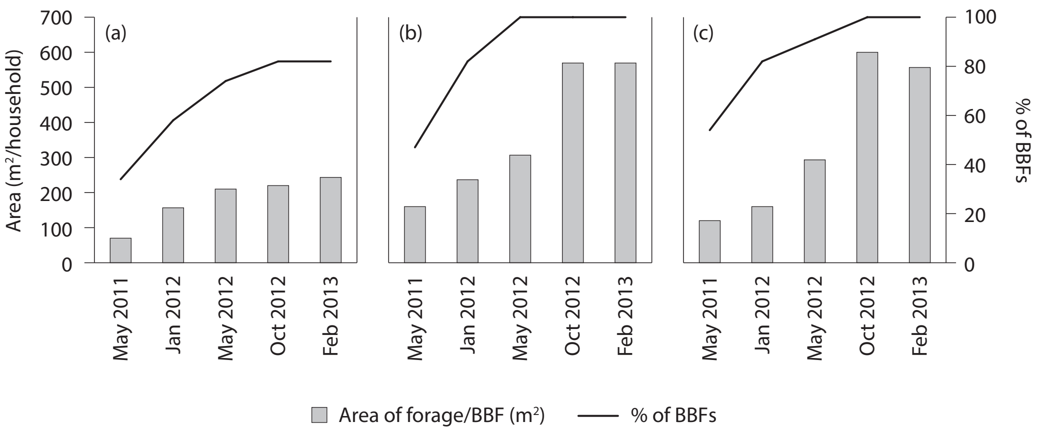

Figure 1. The percentage of best-bet farmers (BBFs) planting new forages and area for new forage cultivation in three study communes: (a) Cat Trinh, (b) An Chan and (c) Phuoc Dinh. Source: household interviews

Other factors, both on-farm and external, may be involved but have not been defined.

In both Cat Trinh and An Chan, 100% of best-bet farmers planted some Taramba as individual plants or hedgerows, while 85% of best-bet farmers in Phuoc Dinh took up this best-bet option. The farmers in Phuoc Dinh who had not planted Taramba reported that they understood its usefulness, but so far had insufficient time to establish and look after the seedlings. Two or three of the Phuoc Dinh best-bet farmers initially commented that they had no experience of feeding Taramba to cattle and so were unsure about its feed value.

Despite the high percentage of farmers who initially planted Taramba, only a small number (20–27% across all three communes) have expanded their initial plantings to date. This is likely to be in part due to the lead time between initial plantings and the time necessary for those plants to start producing seed necessary for further plantings. Other reasons for slow growth and expansion of Taramba plantings include difficulty in controlling chicken and goat grazing of seedlings, poor weed control and competition for light and nutrients with other trees along fence lines.

Increased household income

To explore the impact of best-bet activities on household income, data on the cost of cattle production were collected monthly, focusing on various items such as fresh and conserved forages fed (including crop residues), vaccinations used, parasite control measures and other veterinary costs, use of hired labour etc. The results indicated that the cost of cattle production—predominantly focused on purchases of concentrates and crop residues—had been reduced by 72% and 65% in An Chan and Cat Trinh, respectively, compared with the first survey in January 2011 (Figure 2); whereas this cost remained stable in Phuoc Dinh commune. Note that the cost of cattle production in Phuoc Dinh was almost half that of the to other two communes initially as the farmers hardly use concentrate for feeding cattle; therefore the development in new forage varieties does not impact to reduce the cost of production but does include the other benefits such as labour time, knowledge transfer and networking among farmers.

The baseline survey indicated that more than 85% of farmers across the three communes had to buy rice grain, rice straw and peanut residue for feeding cattle, especially in the dry season. While some farmers had elephant grass in their gardens, they needed to buy concentrates and crop residue because the grass was not enough for feeding their cattle. Mr Hai, a farmer at Cat Trinh, mentioned that:

> I used to buy rice straw and peanut residue from other farmers for feeding the cattle. It cost me nearly VND1.2 million each year. Additionally, I had to buy rice grain for cooking soup for feeding cattle as well, because my elephant grass was not enough for cattle. Since I have a new forage garden, I no longer buy rice straw or peanut residue. The amount spent on buying concentrates has also reduced.

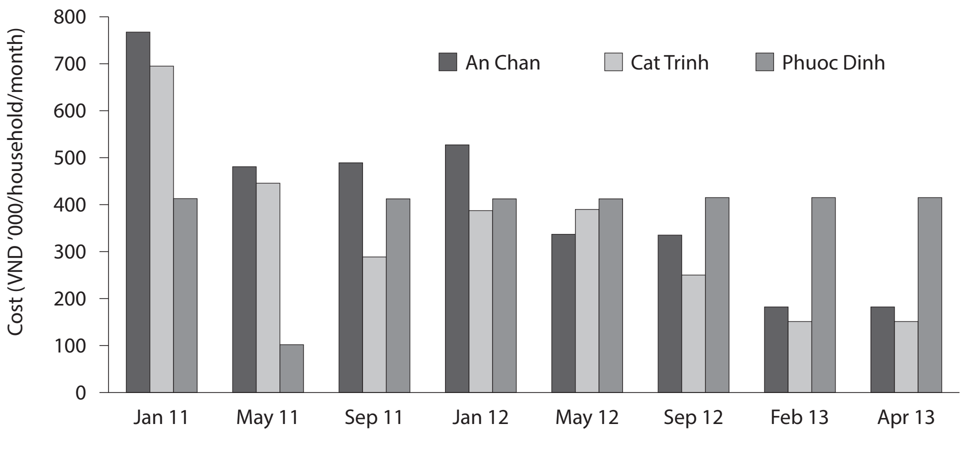

Figure 2. Changes in cost of cattle production across the study communes. Source: household interviews

Mr Hai's story illustrates a significant cost saving for cattle production, leading to an increase in potential net profit from this activity due to the reduction of concentrate purchases for cattle production.

During household interviews, 40% of best-bet farmers indicated that their net income from cattle production increased due to the lower production costs associated with reduced reliance on purchased concentrates since the development of fresh forage banks, while some farmers had completely replaced concentrates with new fresh forages in cattle diets. Although there has not been a specific empirical study during this project on the effect of improved fresh forage supply and quality on cattle performance, farmers typically reported noticeable improvement in cattle condition which many consider has contributed directly to improved cattle prices.

Through participation in the best-bet program, farmers also reported an increased awareness of the need to improve cattle housing, water supply, growing and feeding of more tree legumes, and conserving more crop residues to improve cattle productivity. According to An Chan commune best-bet farmers, Mr Phuc and Mr Diem, middlemen normally base assessments of cattle on appearance when negotiating sale prices. They also report that since applying suggested forage and cattle-related best-bet options, their cattle now attract better sale prices than before from these traders. Other best-bet farmers in An Chan, Cat Trinh and Phuoc Dinh reported similar experiences.

Table 1 indicates farmer perceptions of the main reasons for increased cattle prices during their engagement in the best-bet program. More than half of the best-bet farmers surveyed responded that the increase in income from cattle sales was primarily due to improved condition of their cattle through forage supply, improved cattle housing and use of crop residues. Interestingly, over half of the best-bet farmers also said that attendance at the farmer training workshops had allowed them to exchange experiences with other farmers, thereby enhancing their awareness of market information. They felt that this in turn contributed to the improved prices received for their cattle.

Reduced labour time for cattle production

In all three communes, the total labour time for cattle production fell by around 55% compared with the beginning of project (Figure 3), mainly due to the significant reduction in time spent gathering native grass for cut-and-carry feeding and for supervising grazing. This saving coincides with the establishment and expansion of new and existing fresh forage resources in areas close to where cattle are kept. Ease of access to a good supply of high-quality fresh forage has also greatly reduced the reliance on traditional grazing/herding and native grass cut-and-carry in all three study communes. In Phuoc Dinh commune (Ninh Thuan province), the drier climate and lack of available forage forced farmers (including those involved in the best-bet program) to lead their cattle far away from home to look for feed every dry season. In addition, many farmers had to rely on purchasing truckloads of rice straw from far away to meet dry-season cattle feed requirements. However, those best-bet farmers who successfully established and expanded new areas of fresh forage reported significant time and labour savings on those activities compared to pre-project times.

Mr Thai, a farmer at Son Hai village in Phuoc Dinh, said that:

> Previously, I had to take my cattle to the forest's edge for grazing. In the dry season, I also had to go far from home for cutting grass which took me 5 or 6 hours per day. But now, I have forage in my backyard, so I do not need to spend a lot of time for grazing and cutting grass. It just takes me one hour for cutting forage and feeding the cattle now.

Table 1. Reasons for increased income from cattle production in the study communes (% of farmers)

Reason	Cat Trinh (n = 15)	An Chan (n = 15)	Phuoc Dinh (n = 15)
Reduced production cost	40	53	40
Better access to information on market prices	53	67	73
Improved cattle condition	73	60	47
Increase in market price	80	93	100

Source: household interviews

Mr Thai's story is quite similar to that of other farmers in An Chan and Cat Trinh. Mr Khanh from An Chan commune stated that:

> I used to take cattle 6 km far from home for grazing because the elephant grass in the backyard was not enough for five cattle. In the afternoon, my wife also had to cut native grass along the dam and rice field which took 3 or 4 hours per day. Now, I have 500 m^2 of forage in my backyard; next year I will plant a further 400 m^2 of forage near my maize farm. My wife can save 2 hours from cut-and-carry and I can save 3 hours from managing the animals while grazing.

Saving labour time has affected other daily activities of best-bet farmers. The household interviews indicated that saved time has been reallocated to miscellaneous crop management tasks, more housework, looking after their children and older parents, and doing more off-farm work. Some of these activities have in turn increased household income (directly, or indirectly via generating cost savings) while improving household wellbeing by providing more free time for leisure and family or community activities. Mr Thai, a farmer from Phuoc Dinh commune, stated that:

> Since there has been greater availability of forage in my backyard, I no longer have to spend time cutting native grass. I used my saved time for expanding 700 m^2 of green bean and chilli of which 30% of crop product will be for home consumption, and the rest will be sold for nearly [VND]1 million per crop.

In practice, most of the best-bet farmers in Phuoc Dinh commune live at their farms during the week, which are approximately 5 km away from their homes in the village, and so used their freed up time and labour for crop production activities rather than off-farm or family activities.

In contrast, best-bet farmers in An Chan and Cat Trinh communes spent their saved labour time on doing more off-farm work because this livelihood activity can help them earn more money. Mr Xin, a farmer from Cat Trinh, said that:

> Normally my wife is responsible for managing the crop production. Sometimes I also help her; however, I am quite busy with my work as a carpenter. Previously, I was not able to earn a lot of money from this activity because I looked after my cattle. But now I can save time from cattle production activities because I have my own forage area in my garden. For this reason, I will try to spend time making more furniture to earn money.

The above-mentioned stories were among various ones related to the use of saved labour time for improving household income. The saved labour time also affected other social activities of households. For instance, the daughter of Mr Thi, a farmer from An Chan commune, said that:

> When my mother had to take cattle grazing, I had to cook the lunch. For this reason, I sometimes went to school late and spent a part of my learning time cooking meals. But now, my mother can cook meals for my family because she no longer takes cattle grazing, and I can spend my time learning.

Table 2 illustrates how time and labour saved from reduced time spent cutting and carrying forage

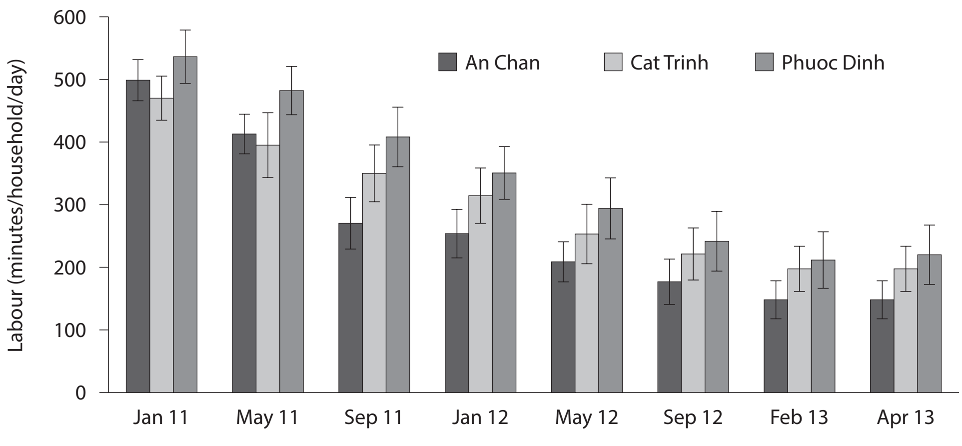

Figure 3. Labour time required for cattle production in the study communes. Source: household interviews

and managing grazing activities was reallocated by households to other on-farm, off-farm and non-farm activities, some of which had direct and indirect impacts on household income and wellbeing.

Enhancing the social capital among the farmers

For the purposes of this study, social capital was defined as the network between social entities through which the benefits of participation can be derived. To assess the change in social capital among the farmers, the indicators of meetings among farmers, mutual support among farmers and network transactions were explored. Regarding farmer meetings, besides the meetings organised by the project, the farmers in the three communes more frequently arranged meetings by themselves to discuss forage and cattle production.

Mr Binh, a farmer from Phuoc Dinh commune, mentioned that:

> We were not only involved in project meetings but also arranged meetings by ourselves, especially when we had commenced harvesting forages and were expanding the planted area. Because this process was quite new to us, we needed discussion on how to best implement changes so we could raise the productivity of our forage gardens. At those meetings, we not only learned about new techniques in cattle production, we but also mutually shared experiences in cattle management and selling; thereby, I learned from other farmers and conversely they learned from me.

This story illustrates the increase in meetings among the farmers, which can enhance relationships and networks (Narayan and Pritchett 1997; Harper and Kelly 2003). This outcome was also reflected in responses by other farmers at An Chan and Cat Trinh when more than 60% of them responded that their involvement in project activities helped them to meet each other more frequently, thereby increasing their understanding, reciprocal learning and exchange of experience about improving cattle production.

The indicator of mutual support among farmers refers to the measurement of social capital argued by Spellerberg (2001) and Harper and Kelly (2003). These authors identified the mutual support among social actors as the basis of social support and behaviours of social entities to strengthen the social capital. In the three communes, the strengthening of social capital was not only among the best-bet farmers but also included the ‘scale-out’ farmers who subsequently applied techniques and options learned from best-bet farmers in their own farming systems. Many farmers in Cat Trinh, An Chan and Phuoc Dinh who were not directly involved in the project have acquired planting material, particularly *Brachiaria* hybrid cv. Mulato II, from best-bet farmers, to establish their own forage gardens. At the same time, they appear to have acquired the necessary knowledge and skills to grow, manage and feed these new forages from the best-bet farmers. This fulfils a prime objective of the best-bet research for development (R4D) delivery model of Lisson et al. (2010) to have best-bet farmers act as key agents of technology and knowledge dispersion. As a result, the capacity for sustainable uptake of improved cattle production has scaled out to the broader village community alongside the new forages which have underpinned the initial success of the best-bet program. Figure 4 indicates the trend in number of scale-out farmers generated from contact with best-bet farmers in all three study communes between the project start and September 2012.

Table 2. Reallocation of saved labour time to other activities in the study communes (% of farmers)

Activity	Cat Trinh (n = 15)	An Chan (n = 15)	Phuoc Dinh (n = 15)
Look after crop production	40	27	47
Clean the cattle house	27	47	20
Look after pigs and poultry	47	40	33
Off-farm work	33	27	27
Monitor the children’s studies	20	33	13
Do housework	53	60	53
Look after the grandparents	20	40	27
Cut-and-carry forage	40	27	47

Source: household interviews

The last aspect of social capital focused on in this study is the transaction of network benefits to its actors. According to Stone (2001), social capital can be assessed by two groups of indicators including 'proximal' and 'distal', the latter of which refers to the benefit that social actors can obtain. For the three communes, most of the best-bet farmers responded that they had acquired greater capacity to access and understand market information due to their involvement in such networks with other farmers. Mr Lam, a farmer from Cat Trinh, stated that:

> When we met together at the workshops, we also talked about the market price of cattle and the availability of middlemen. The selling price of cattle fluctuates very often, which some farmers were not aware of. For this reason, they sold their cattle at a lower price than they expected. Since I changed from a cow–calf system to a finishing system, I have had dealings with a lot of traders, so I have good access to cattle prices. When I meet with other farmers I always let them know about the current price and the expected fluctuation of price in the coming month so that the farmers can get more profit from selling cattle.

Mr Lam's story suggests that because of the involvement in workshops and informal meetings, the best-bet farmers could obtain the benefit of learning how to access market information, which can in turn lead to better prices for their cattle.

The social capital aspect was also expressed through vertical linkages between the farmers and researchers within the PAR learning framework of the best-bet research for development approach, which fostered mutual respect and trust (Ganesan 1994; Dyer and Singh 1998). As the best-bet program progressed, farmers worked more closely with project field staff because of the trust and confidence accumulated via the stepwise 'working and learning together' strategy employed. More than 70% of farmers responded that they grew more confident about meeting project staff over time, once they realised they could discuss and learn about new techniques in cattle and forage management from these people. Trust in this case was assessed by the following questions:

1. Do you believe what the project staff told you regarding the effectiveness of best-bet activities?
2. Are you willing to implement what project staff suggested to you?
3. Are you willing to share with the project staff about any problems you encounter in cattle and forage management, so that they can give you a recommendation?

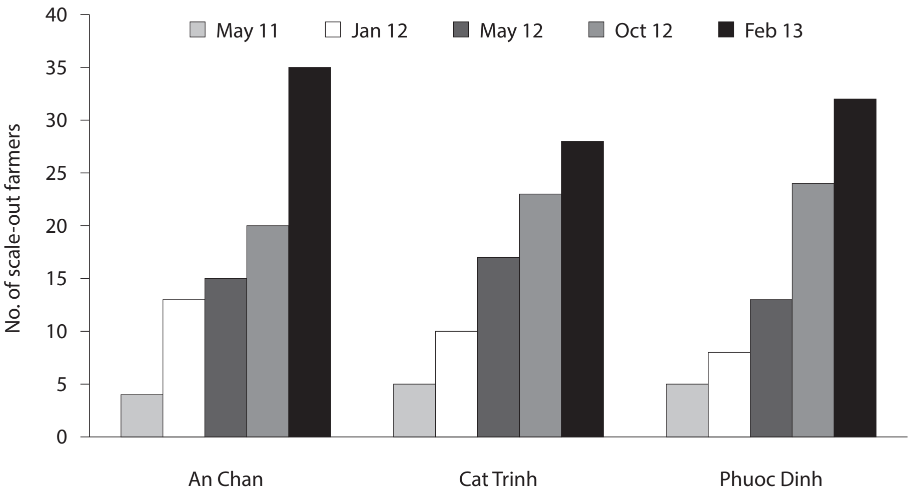

Figure 4. Trend in the number of scale-out farmers adopting new forage cultivation generated from contact with best-bet farmers in the study communes between May 2011 and September 2012. Source: household interviews

Farmer responses illustrate the trust between farmers and researchers. For instance, Mr Kiet, a farmer from Cat Trinh, stated that:

> When the project staff were here in early 2010, I often dodged them, because I was busy and they took a lot of my time. Also, they needed a small piece of my garden for a trial forage cultivation, but I was not sure about the usefulness of this so I was not happy about it. After the project staff went to my home several times to guide me in how to manage the forage and feed the cattle, I recognised the improvement of my cattle production. My cattle looked better in appearance, and I saved both labour time and input costs. Now I can tell them my problems in cattle production and get their suggestions for a solution.

Due to the frequent contact between the project staff and farmers, trust was accumulated, which in turn encouraged farmers to apply and adapt the best-bet activities, benefiting the households. At An Chan and Phuoc Dinh communes, because of the long distance project field staff had to travel, farmers were not visited as often, so trust between farmers and field staff at these communes took longer to develop. In this situation, the farmer workshops initiated by the project team played a much stronger role in cementing trust and confidence via interactive practical demonstrations of new techniques and options. At these workshops, the project staff also invited some of the 'early adopter' best-bet farmers to talk directly to other farmers about their experiences with new grass and Taramba plantings and cattle management activities. This farmer-to-farmer interaction led to much greater communication between best-bet farmers and thus greater 'ownership' of the best-bet program among these farmers.

Conclusion

This study gives an account of the application of a 'best-bet' participatory research approach, similar to that developed by Lisson et al. (2010), aimed at building sustainable and profitable livestock systems for mixed crop–livestock farming communities in the SCC region of Vietnam. The participants involved in this project included researchers, the staff of provincial and district Departments of Agriculture and Rural Development, commune extension staff and farmers at four stages: (1) benchmarking the current farming system; (2) identifying and on-farm testing of best-bet activities; (3) household planning for practising best-bet activities; and (4) monitoring and evaluation. The impact assessment results revealed that the project achieved positive outcomes for the livelihoods and wellbeing of participating smallholder farmers, in terms of increasing income, saving labour time on cattle production and improving social capital. The project supported an increase in the level of local participation in the research process through collaborating closely with local institutions, providing training and experience related to best-bet adoption. This created the opportunity for investment in local capacity building, both for smallholders and supporting agencies.

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Section 5: Risks of groundwater pollution from agriculture

The common practices of using higher amounts of fertilisers for vegetable production and raising cattle around households and mismanagement of manure and urine, together with lack of a proper sewerage system, are common features around the sandy plains of south-central coastal Vietnam. Hence, the risk of nutrient leaching and contamination of the groundwater is high. This section presents a survey of nutrient contamination of water collected from various surface and groundwater sources.

A survey of surface and groundwater quality contamination in south-central coastal Vietnam

Do Thi Thanh Truc[1], Surender Mann[2], Nguyen Quang Chon[1] and Richard W. Bell[2]

Abstract

Contamination of groundwater is posing a threat as a result of intensification of agriculture in south-central coastal (SCC) Vietnam. Increased use of chemical fertilisers on rice and vegetable crops and increased density of cattle around settlements are the main reasons for groundwater contamination. Villagers are dependent on groundwater and stream water as a supply for daily use and for crop irrigation. The risk of surface and groundwater contamination from nutrient run-off and leaching is likely to be high in coastal areas as the majority of the soils represent sands. However, few data exist to confirm this. The objective of this study was to collect and test water samples from various sources (bore wells, open wells, streams and irrigation canals) at different times of the year—mainly from An Chan commune, Tuy An district, Phu Yen province, where intensification of crops and livestock has taken place in recent years. Sampling was carried out from April 2011 to April 2012.

The results indicated that dissolved phosphate (PO_4^{3-}) and nitrate (NO_3^-) levels mainly met the criteria that are regulated for drinking water, at least to the minimum standard. However, in some samples of surface water for phosphate and surface and groundwater for nitrate, the levels were too high—up to 10.9 mg NO_3^-/L was found in stream/canal water, and up to 14 mg PO_4^{3-}/L and 50 mg NO_3^-/L in groundwater. These results confirm that contamination of surface and groundwater is a problem affecting An Chan commune and highlights the need to implement strategies to improve nutrient management on coastal sands in the SCC region. The outcomes from this study confirm that future detailed research is required to determine the sources of water contamination. Key sources are likely to include fertilisers applied to rice and vegetables, wastes from cattle and fisheries, and also human waste, due to lack of proper drainage systems in this region

Introduction

Population growth, along with rural and urban development, puts pressure on water resources through increasing demand and accelerates the rate of water pollution in affected areas. Such pressures are threatening the sustainability of water resources in south-central coastal (SCC) Vietnam but to date there has been limited study on the impacts of rural and urban development on groundwater quality in this region.

The sandy terrain with shallow unconfined groundwater that occurs along the coastal zone of SCC Vietnam is one such area where groundwater quality can be affected as a result of intensification of crops and livestock. Phu Yen province is a typical example. It lies on the coast and has a sandy terrain with an average annual rainfall of 1,800–2,100 mm. It has a short wet and long dry season and droughts are a regular feature of this region during summer.

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Similar rainfall patterns also occur in Khanh Hoa and Quang Nam provinces, while Binh Thuan and Ninh Thuan provinces, located at the southern end of SCC Vietnam, have an annual average rainfall of 700 mm.

An Chan is one of 15 communes belonging to Tuy An district, Phu Yen province. An Chan has a population of 9,243 spread over 13.53 km^2, with crops, livestock and fisheries as the main sources of income for the rural people. With an area of 682.4 hectares (ha), 50% of agricultural land in the commune is used for annual crops such as vegetables and rice (unpublished An Chan commune final report, December 2011). Farmers have small landholdings and are used to traditional farming practices. Apart from having poor fertility sandy coastal terrain, water resources have contributed to an agroecological zone characterised by shallow groundwater, wells, bores and run-off water. Such groundwater resources are unconfined and shallow, making them vulnerable to seawater intrusion and pollution from nutrient and agricultural chemical leaching.

Nutrient leaching occurs when accumulation of nutrients such as nitrate (NO_3^-) and phosphate (PO_4^{3-}) in the soil profile coincides with, or is followed by, a period of high irrigation or rainfall (Di and Cameron 2002). Thus, poor management of nitrogen (N) and phosphorus (P) fertilisers, manures and irrigation are likely to be primary sources of nutrient contamination in groundwater associated with the sands of SCC Vietnam. Increasing nitrate concentrations in groundwater were recorded in Ninh Thuan province within the regions where agricultural production had intensified (Keen et al. 2011). High nitrate levels in groundwater and surface water used for human consumption are of particular concern due to the serious health risk they pose (WHO 2011).

According to Australian guidelines (ARMCANZ and ANZECC 2000), the permissible nitrate concentrations in water should be less than 10 mg NO_3^-/L for drinking water. While phosphate is of less concern for drinking water, it does pose an environmental pollution risk, contributing to blue-algae blooms and growth of pathogens that pose a risk to human health. As is common in SCC Vietnam, groundwater is the main source of drinking water in An Chan commune, but the quality of this water is not known. With agriculture intensifying in An Chan and surrounding areas, it is likely that water quality is poor or at least in decline. In this chapter, we report on a water quality survey undertaken in An Chan between April 2011 and April 2012.

Materials and methods

The investigation was carried out for different water bodies, including surface water (in streams and agricultural irrigation canals) and groundwater (bore wells and open wells) in An Chan commune, Tuy An district, Phu Yen province, with particular reference to three villages in which the income of villagers is based mainly on agriculture and fisheries—namely, Phu Thanh, Phu Phong and Phu Quy villages.

The surface water collection points were chosen by elevation from upstream of the irrigation canal, and then by tracking the flow of the water downstream (Figure 1). Groundwater samples were collected from households with bore wells and open wells along a transect from west to east (Figure 1).

Samples of water were collected five times over 1 year from April 2011 to April 2012 . In the first year, timing of sampling was based on application of nutrients to crops to test their presence in different water bodies at crop harvesting periods, in April, May and November. In 2012, February and April were chosen for sampling water at the beginning and end of a crop season.

Samples were tested for electrical conductivity (EC), pH, phosphate and nitrate. The samples were filtered on site through a 0.45 mm cellulose acetate membrane filter, and kept in plastic vials in a cold container during transport to the laboratory for analysis. The level of phosphate was analysed using the ammonium molybdate spectrophotometer method (International Organization for Standardization (ISO) 6878:2004) and nitrate using the spectrometric method using sulfosalicylic acid at 415 nm wavelength (ISO 7890-3:1998 E).

The quality of water was assessed based on the parameters used for selection of the surface and groundwater resources in the water supply system (Table 1).

Results and discussion

Climate

The average temperature in this region remained between 25 and 29 °C throughout the study period. The main rainy season was between October and December and the rest of the period had low rainfall (Table 2). Evaporation was highest in May when the temperatures were highest.

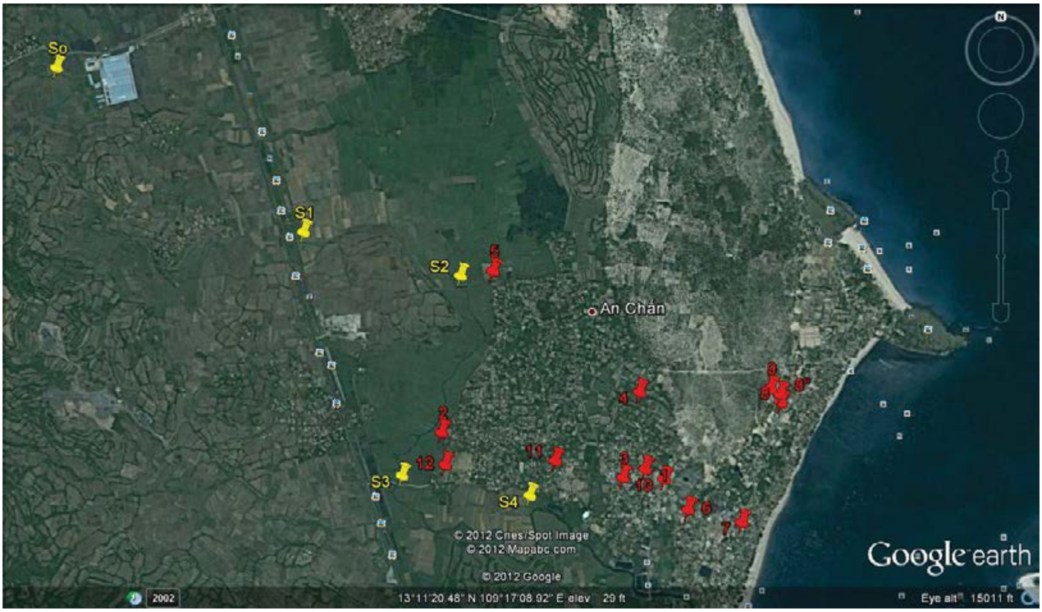

Figure 1. Sites for water samplings in An Chan commune, Phu Yen province, Vietnam. Note: yellow points indicate surface water sites and the red points refer to bore well and open well sites.

Table 1. Criteria for surface and groundwater quality

Level[a]	Parameters		
	pH	Nitrate (NO_3^-) (mg/L)	Phosphate (PO_4^{3-}) (mg/L)
A	6.5–8.5	0	0.0
B	6.0–9.0	<6	<1.5
C	>9.0 and <6.0	<10	<2.0

[a] A = good; B = medium; C = poor
Source: Vietnamese standard for water quality TCXD 233: 1999

Table 2. Average monthly temperatures, total monthly rainfall and evaporation in An Chan commune, Tuy An district, Phu Yen province, 2011–12

Date	Temperature (°C)	Rainfall (mm)	Evaporation (mm/day)
April 2011	26.0	128	90
May 2011	28.8	115	130
November 2011	26.0	308	69
February 2012	24.5	31	75
April 2012	27.9	152	89

Table 3. Values of pH and electrical conductivity (EC) for surface water and groundwater in An Chan commune, 2011–12

Water source	pH					EC (dS/m)				
	April 2011	May 2011	November 2011	February 2012	April 2012	April 2011	May 2011	November 2011	February 2012	April 2012
Streams/canals	7.6	8.0	7.6	7.8	7.4	0.863	1.207	0.292	0.338	0.331
Open wells	7.1	7.0	7.2	7.6	7.3	0.516	0.509	0.345	0.394	0.400
Bore wells	7.3	–	7.3	7.6	7.2	0.750	–	0.631	0.289	0.601

pH and electrical conductivity

The pH of water was neutral at all times of sampling (Table 3) and was within the range specified for drinking water (Table 1). The EC was a bit higher during April–May 2011 compared with other times of sampling; however, the values were still in the acceptable range. Higher concentrations of salts in the water as a result of the dry period may have been the cause of elevated EC levels. Lower EC levels during November–February—the main rainy season, when the watertable is almost at the surface—were the result of dilution.

Nitrate

Surface water quality

Samples were taken from upstream to downstream following the gradient of water flow of the irrigation canal. The sampling points are shown in Figure 1. The lowest values of nitrate were recorded in February 2012, while the highest values were recorded in November 2011 (Figure 2). Almost all samples were within the acceptable range (level A or B in Table 1). There was no clear pattern in nitrate concentrations along the gradient of the water flow of the canal. A rapid change from 2.7 mg NO_3^-/L to an unacceptably high 10.9 mg NO_3^-/L was recorded in November 2011 between the first and second sampling points. 2011 was a year of relatively low rainfall and this may have been the cause of high nitrate levels. In addition, nitrogen fertiliser applied to crops adjacent to the canal may have been the cause of high nitrate levels as intensification of crops requires regular application of fertilisers.

Groundwater quality

Values of nitrate in open wells and bore wells varied significantly in the study area. Both types of wells are used for irrigation and to meet water requirements for daily household activities. Open wells had

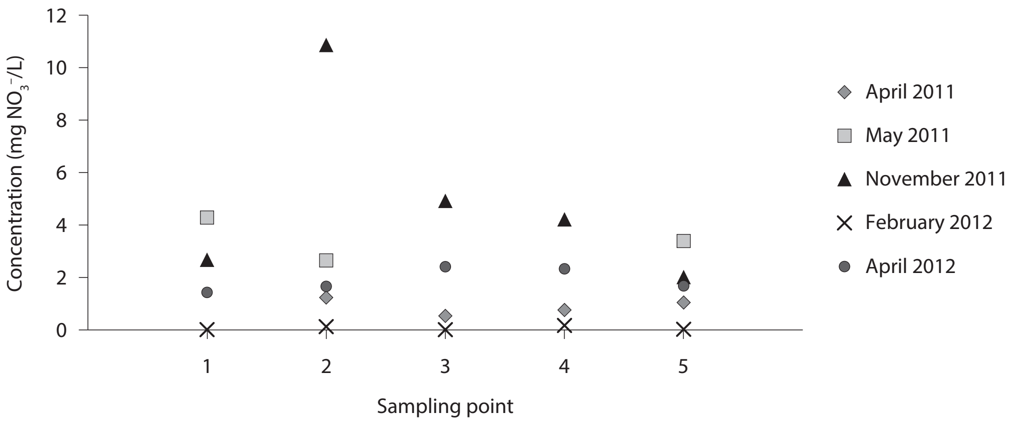

Figure 2. Nitrate-nitrogen level in surface water in An Chan commune, 2011–12. Note: there was no water in sampling points 3 and 4 in May 2011 (hence, no data).

acceptable as well as high nitrate levels (classed as level C, Table 1) in quality (Figure 3). Bore wells had the same pattern as open wells but some of their values reached as high as 50 mg NO_3^-/L (Figure 4). Higher rainfall in some months may have diluted nitrate concentrations in open wells more than in bore wells, and/or the greater depth of open wells (5 m) compared with bore wells (4 m) may contribute to variability in nitrate levels.

Phosphate

Concentrations of phosphate in both surface water and wells are shown in Figures 5 and 6. Streams and canals (surface water) had acceptable levels of phosphate (<2 mg PO_4^{3-}/L). However, both open wells and bore wells had higher levels of phosphate (8–14 mg PO_4^{3-}/L) during April 2012, which reflects the impact of the dry season.

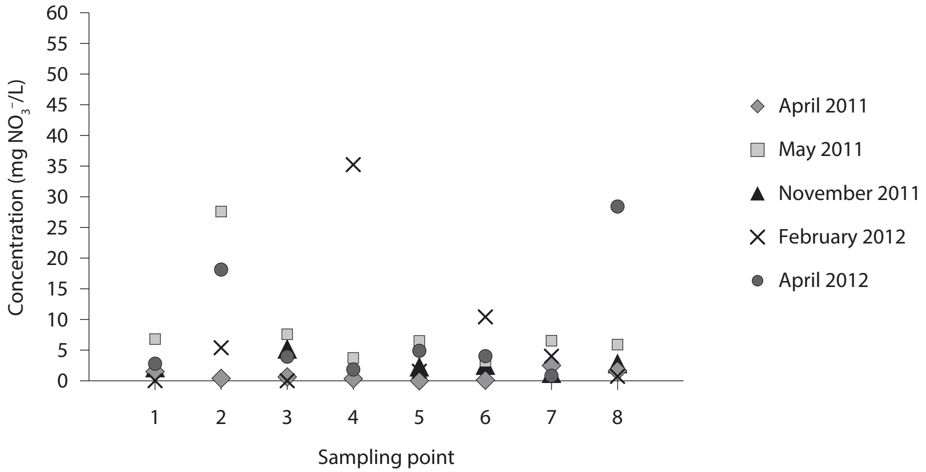

Figure 3. Open well water nitrate concentrations, 2011–12

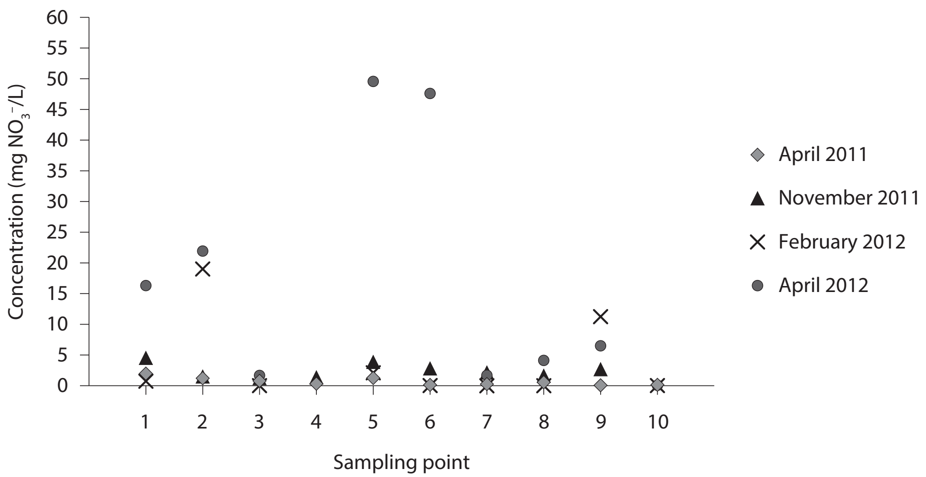

Figure 4. Bore well water nitrate concentrations, 2011–12

Water in open wells had higher levels of phosphate than in bore wells throughout the sampling period and were often much higher than the recommended limits for drinking water of 2 mg PO_4^{3-}/L (Figure 6). Most open wells have clear water while bore wells are sometimes muddy; hence, people prefer to use open wells rather than bore wells. However, based on these results, bore wells have a better water quality than open wells in terms of phosphate content.

The survey period was too short to draw long-term conclusions. In addition, one would have assumed that the trend for phosphate and nitrate levels would

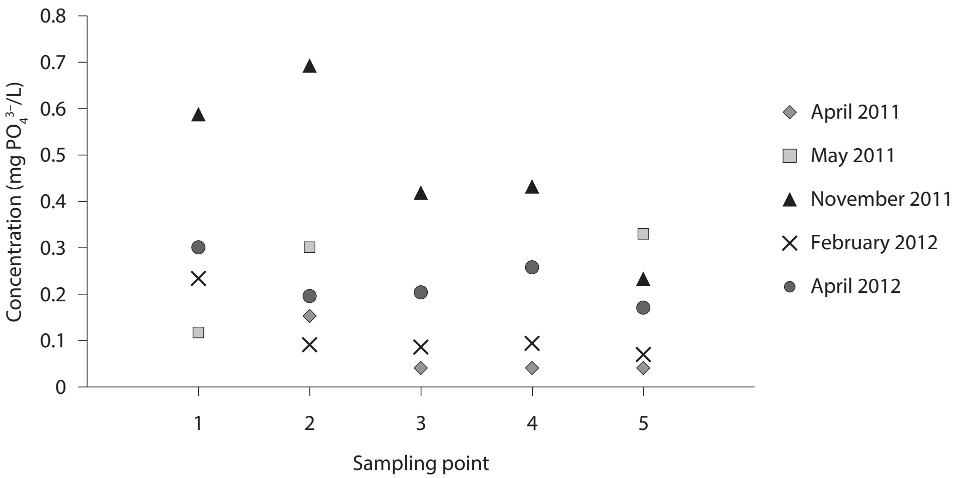

Figure 5. Phosphate concentration in surface water, 2011–12

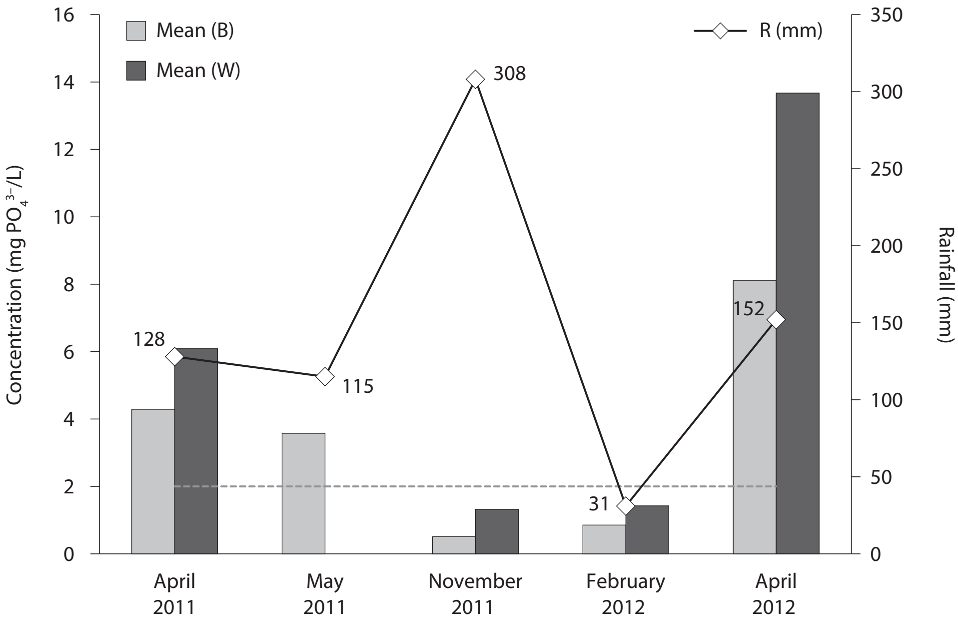

Figure 6. Concentration of phosphate in open (O) wells and bore (B) wells, 2011–12. Note: open wells were not sampled in May 2011

have been similar. This poses the question of whether the analytical techniques used for measuring phosphate and nitrate were appropriate, as quality control has been an issue with most of the laboratories in Vietnam. Nonetheless, in-depth study needs to be carried out in the coastal regions where sandy soils dominate the landscape and intensification of crops and livestock is increasing rapidly. As a result of intensification of crops, higher doses of fertilisers are applied regularly, particularly for vegetable crops.

Increasing numbers of livestock housed adjacent to the houses over sandy soil pose a further risk of contamination of groundwater as a result of faecal and urine disposal. Nitrate and phosphate leaching in sandy soils is a common feature due to low cation and anion exchange capacity (Bell et al. 2015).

Previous studies carried out in Ninh Thuan, another of the provinces of SCC Vietnam, also found higher levels of nitrates in water (Keen et al. 2011), suggesting that all areas within the SCC region need to be surveyed and monitored for water quality.

Conclusion

The concentrations of nitrate and phosphate indicated some water contamination in shallow groundwater sampled from open and bore wells in An Chan commune. The values of up to 50 mg NO_3^-/L and 14 mg PO_4^{3-}/L were found in some of the samples raising concern about the quality of water consumed by the community in An Chan in particular, Phu Yen province in general, and in other coastal regions. Further research is required to pinpoint the source of nutrient pollution, especially in the SCC region.

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Section 6: Key learning from the various studies and integration of findings

This section summarises key findings of all the chapters in the proceedings and briefly describes the components of the multi-disciplinary work carried out since 2007 with investments by the Australian Centre for International Agricultural Research (ACIAR) and the Vietnamese Government. The chapter is an outcome of the reflections of the authors and the lessons learnt. It also describes the opportunities that can enhance crop and livestock productivity in the region and sets priorities for investments to make systems more sustainable.

Opportunities and priorities for further investment in improving the productivity and sustainability of crop and livestock systems on sands in south-central coastal Vietnam

Richard W. Bell[1], Hoang Minh Tam[2], Robert Summers[3], David Parsons[4] and Allan McKay[3]

Abstract

The South-central coastal (SCC) region of Vietnam has challenging constraints to productive and sustainable intensification of agriculture: low fertility sandy soils, long dry seasons and shallow groundwater. The present proceedings describe studies in three provinces (Binh Dinh, Phu Yen and Ninh Thuan) representing a range of climates, farming systems and sandy landscapes of SCC Vietnam. The chapters in these proceedings analysed the value chains for key agricultural commodities, characterised the constraints on the sands, demonstrated the productivity gains from balanced nutrient inputs, soil amendments and better irrigation scheduling and showed improved profitability of beef-cattle management through better quality forages and programs to improve on-farm practices. Many interventions for improved market access and profitability of cropping and beef-cattle enterprises have been identified and partially tested. More details of these findings are outlined below and in the preceding chapters. Identification and alleviation of soil constraints are highlighted as a key priority for productive cropping in this region. Integration of cropping with profitable livestock production is a notable opportunity for the intensification of farming systems. Sustainability of groundwater resources is a significant issue for the future of agriculture in the SCC region of Vietnam.

Introduction

Development of profitable and sustainable crop and livestock production systems in challenging environments (poor, sandy soils under water-limiting conditions) of south-central coastal (SCC) Vietnam has progressed from Australia–Vietnam research collaboration. The baseline conditions of farming systems studied in Binh Dinh, Phu Yen and Ninh Thuan provinces indicate both similarities and significant differences across SCC Vietnam (Hoang Thi Thai Hoa et al. 2015a, c). The research described in these proceedings was designed as a multidisciplinary venture linked with national research institutes, including provincially based research and extension departments (Mann et al. 2015). Its aim was to identify and facilitate adoption of promising resource management practices for sustainable and profitable crop and livestock production systems best suited to local conditions that enabled improved market engagement. The papers in these proceedings analysed the value chains for key agricultural commodities, characterised the constraints on the sands

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of SCC Vietnam, demonstrated the productivity gains from balanced nutrient inputs, soil amendments and better irrigation scheduling, and showed improved profitability of beef-cattle management through better quality forages and programs to improve on-farm practices. Many interventions for improved market access and profitability of cropping and beef-cattle enterprises have been identified and partially tested. Key findings are outlined below. Opportunities and priorites identified are discussed and then the relevance of the findings to the wide coastal zone of central Vietnam is analysed. The identification and alleviation of soil constraints is highlighted as a key priority for productive cropping. The intensification of farming systems by integration of cropping with profitable livestock production is a notable opportunity. Sustainability of groundwater resources was identified as a significant challenge for the future of agriculture in the SCC region of Vietnam.

Value-chain analysis of the major commodities

Value-chain analysis of key agricultural products (peanut, cashew, mango, beef cattle, cassava, sesame and garlic) reveals a wide range of potential chain improvements that would benefit farmers in the SCC region. There are clear opportunities to boost productivity and profitability within the prevalent low-input farming systems. Simple and cost-effective interventions in areas such as postharvest technology and marketplace improvements can have an immediate effect. Many of these interventions are the subject of soil fertility, crop and animal nutrition and irrigation research reported within these proceedings. Progress has been made on understanding and facilitating improvements in a range of product quality related issues.

Peanut

Farming systems incorporating peanuts are well suited to intensive cultivation on poor sands, particularly in Binh Dinh province. These farming systems help poverty reduction and soil improvement (Phan Thi Giac Tam and McKay 2015). However, the development of these farming systems has resulted in the depletion of groundwater in the dry season, due to overexploitation and possibly exacerbated by climate variability. Recognising the severity of water depletion, farmers have begun to apply water-saving measures, such as sprinklers, while biochar made from rice straw is another input with potential for increased water use efficiency. While these interventions are gaining popularity, there is a growing need for extension support to maximise the benefit of groundwater use while reducing impacts of its overuse.

To overcome the increasing effects of storms due to climate variability, Binh Dinh authorities have supported autumn–winter peanut cropping to replace cassava in the rainy season. This peanut crop, despite low productivity due to postharvest damage, is still economically viable for farmers because of high prices. The postharvest and seed storage problems for the autumn–winter peanut crop are potentially solved by the introduction of grain dryers (Phan Thi Giac Tam and McKay 2015).

Cashew

Cashew trees are adapted to soil and climatic conditions in other areas of Vietnam and cashews generate high export revenue so that it is important that a clear cashew industry development strategy is pursued. While cashew yields and profitability can be improved, especially in Binh Dinh province, it is concluded that cashew in Phu Yen and Ninh Thuan provinces is not capable of improving the livelihood of farm households. There are many unproductive orchards where yields are low due to a low-input production approach. Constraints in cashew production include lack of improved varieties, poor site selection and lack of good grafted trees for planting. Yields can be increased by adoption of more intensive production methods in plantations of suitable grafted varieties. Balanced crop nutrition including micronutrients in conjunction with incorporation of biochar has been shown to boost yields. Domestic cashew nut supply is inadequate to fulfil the requirements of processors. The cashew-processing industry is potentially a major source of jobs for the population of the SCC region. Phu Yen and Ninh Thuan cannot supply enough raw cashews to meet processor demand and processors are dependent on importing raw cashews. Cashew plantations are significant in agricultural production in SCC Vietnam although many policies and technical problems need to be solved for higher productivity (Nguyen Duy Duc and Pham Nhat Hanh 2015).

Mango

A significant market opportunity currently exists for mango producers in SCC Vietnam because their main harvest season is later than the main season in the Mekong River Delta region. However, it is important to note that increasing 'off-season' production of mangoes from the Mekong River Delta is occurring via the use of growth regulators to manipulate flowering time and this has the potential to compete with SCC production. To capture mango market opportunities, SCC mango quality, varieties and postharvest handling will need to be improved. Opportunities also exist to boost yield and profitability of mango by improved crop nutrition and water use efficiency (Hoang Vinh et al. 2015a, b; Hoang Minh Tam et al. 2015). Mango production in the three focus communes (Cat Trinh in Binh Dinh province, An Chan in Phu Yen province and Phuoc Dinh in Ninh Thuan province) was on a small scale with low investment and productivity. The number of fruit traders was low and linkages among mango growers, collectors, wholesalers and retailers was limited. Growers receive a high proportion of the profit in the mango value chain; however, lack of capital investment often limits inputs such as fertilisers. Mango production in SCC Vietnam is a fledgling industry and requires coordination and collaboration to reach its potential (Luong Ngoc Trung Lap and Nguyen Minh Chau 2015).

Beef cattle

Cattle husbandry makes an important contribution to income, cash flow and financial stability of farm households in the SCC region of Vietnam (Ho Cao Viet et al. 2015a). Prices of live cattle and beef meat have tended to move upwards over time, and demand for beef is strong in the south and city markets. Farmers' attitudes to cattle production are changing rapidly, with more focus on intensive management and breed improvement. Government policies and private enterprises can improve both quality and quantity of cattle herds in the three provinces by supporting the establishment of slaughter facilities, veterinary services, programs of artificial insemination, and expanded pasture and forage production. Cattle manure is an important source of nutrients for cropping land (Hoang Vinh et al. 2015a; Hoang Thi Thai Hoa 2015b).

Benchmarking studies of beef-cattle production suggest that practices vary greatly. Substantial improvements can be achieved through improved management, particularly better feed management. Participatory research has been very successful in livestock and fodder species work, resulting in substantial uptake of practices as a direct result of trials and workshops (Ho Le Phi Khanh et al. 2015). Improved management practices, including more intensive cultivation of forages, can lead to substantial labour savings. Demonstration and pilot studies are an important and necessary requirement for widespread adoption of practices by regional authorities and extension staff. Inclusion of exchange staff into the program has had very positive impacts on research understanding and communications (Ho Le Phi Khanh et al. 2015).

Cassava

In recent years, high variation in the cassava price influenced farmer incomes and willingness to continue growing cassava. Reduced selling prices (by 20% at the farm gate) combined with increasing input costs decreased cassava profits in 2011 by about 30% compared with 2010. However, several promising options were identified to improve the profit from cassava and decrease price volatility. Firstly, small-scale cassava-processing units (sticky and dried starch processing) generate more stable income and help mitigate risks of falling prices. The storage of cassava roots by traditional methods and use as a feed for fattening the cattle or as a source of modified feed in the dry season is a high-efficiency option for farmer households in the context of falling fresh root prices. Income from cattle fed on cassava by-products is a source of capital for cassava cultivation and vice versa in the farming system. Cassava products and by-products are important feed sources for cattle, especially during the dry season. Cattle production enables greater flexibility in cassava production where the farmer has the option of selling to processors or retaining for animal feed depending upon the returns. Production of cassava chips is also highly efficient and profitable but requires good weather, can be on only a small scale and needs high labour input. Starch-processing factories still play an important role in the cassava value chain, but dependence on the Chinese market is risky (Ho Cao Viet et al. 2015b).

Sesame

Sesame is a drought-tolerant short-season high-value crop suited to SCC Vietnam, although yields are generally low under rainfed conditions on sands. Sesame is a good fit in rotation with peanuts in this region. For sesame production, farmers often lack access to capital to increase scale and adopt improved production technology. New varieties of sesame with higher yield and quality are a high priority for industry development. The biggest issue for sesame collectors is lack of access to capital. Traders also lack capital and bank loans are difficult to source, so private loans with high interest rates are common. Equipment to measure moisture content of sesame seeds and suitable transportation are needed by sesame collectors. Assessment of market demand is difficult because there are few close links between sellers and consumers. Although the collectors play an important role, there is no policy or system supporting the delivery to farmers of market price information. For sesame, the long value chain and loose linkages do not encourage a focus on quality control along the chain. Without support, farmers are expected to continue to prefer crops such as cassava rather than face the risks with sesame (Nguyen Thanh Phuong and Nguyen Van Duong 2015).

Garlic

The small-size garlic produced in Ninh Thuan province has a reputation for superior flavour in Vietnam. It is a relatively minor crop but important in that it is one of only a few crops that can be profitably produced on sands in Ninh Thuan. Together with onions, garlic has contributed significantly to household income but the sector in the province appears to be declining in area and production. Yield has been unstable in recent years because of a combination of unfavourable weather and poor farming practices. Demand from both domestic and foreign markets remains strong with unmet demand. However, the relatively small production scale causes some disadvantages in terms of price forecasting and setting.

Garlic production has high levels of inputs and associated high production costs. These are associated with overuse of pesticides and incomplete fertiliser application. While growers in Ninh Thuan have long had experience with growing garlic they appear to lack technical knowledge and skills to cope with emerging conditions such as climate extremes and disease incursion, resulting in low yields, poor quality and reducing growers' profits.

Due to its long association with garlic, Ninh Thuan province had a strong and experienced collector force, traders and a network that links from local production to market. The fact that there are presently individuals and traders who are pioneering and promoting safe production and safe products to market is considered to be a strength as their interest lies in exporting good-quality, residue-free products to other countries to get higher value. The value distribution within the chain seemed fair except for the deduction ratio (arbitrary quality classification of garlic bulbs assessed by the collectors, averaging 5%) that has long been applied to growers, lowering the profit margin of the farmers from 32.5% to 27.5%. Wholesalers normally apply only a 1% deduction ratio to collectors, shifting 4% profit margin in their favour that could have gone to the producers (Nguyen Van Bang and McKay 2015).

Soil properties: nutrient and soil water constraints

Sands occupy over 0.5 million hectares (ha) in Vietnam, with over two-thirds of that area in SCC Vietnam (Bell et al. 2015). There is a range of constraints that limit agricultural productivity on the SCC sands. The present studies determined the range of sand profile types in the SCC region, their origin and distribution, and key limiting properties (Bell et al. 2015). Study areas were located in Phu Cat district of Binh Dinh province, Tuy An district of Phu Yen province and Thuan Nam district of Ninh Thuan province to capture the main variation in types of sands and climatic influence on land use.

Soil properties and constraints

The sands were diverse in clay content, soil colour, pH and texture, which varied with depth. Most of these differences can be attributed to parent material which comprised aeolian sands (from white and red dunes), alluvial terraces, marine sediments, colluvial sediments (mostly from granite) and in situ weathered granite, with or without surface reworking of sands by aeolian, fluvial or slope processes. Most of the sands were acid, but even when strongly acid contained little extractable aluminium. Alkaline sands in restricted areas were also identified in Ninh Thuan and Phu Yen provinces. Organic carbon, cation exchange capacity (CEC) and water retention at –0.1 bars were generally very low but clearly increased with clay content that varied from zero to almost 20%. Management influences on sand properties were also evident. On acid sand that have been used for crop and vegetable production, there was evidence of phosphorus leaching down profiles. Peanut fields in Binh Dinh often had elevated, even moderately alkaline, near-surface pH attributed to repeated lime applications. In Binh Dinh, there was some evidence of compaction of sands in the rooting zone for crops.

In addition to the constraints identified in the Soil Constraints and Management Package (SCAMP) assessment of 56 profiles, a diverse range of nutrient disorders were diagnosed in sands in Phu Cat district (Binh Dinh province) and Ninh Phuoc and Thuan Nam districts (Ninh Thuan province) (Hoang Minh Tam et al. 2015). On most of the sands, multiple deficiencies were identified. While potassium and sulfur were deficient on all sands tested, the suite of deficient micronutrient deficiencies varied among types of sands. Hence, it is concluded that nutrient deficiencies need to be systematically diagnosed in SCC Vietnam in order to develop productive and profitable cropping systems after correction of these deficiencies.

Irrigation is essential for crop production in the dry season in SCC Vietnam. Use of a mini evaporation pan to guide irrigation frequency and the amount of water applied increased peanut yield in Phu Cat district on sands compared with the farmers' irrigation practice. The yield increase varied from 0.23 to 0.50 t/ha in 3 years, 2010–12. Importantly, the number of irrigation events required decreased by 50% with substantial labour savings from the use of the mini pan to schedule irrigation (Hoang Vinh et al. 2015b). The results suggest that substantial improvements in water use efficiency can be gained by better irrigation techniques (mini pan) for peanut. However, further experiments to validate these findings across a wider range of sites on farmers' fields are needed, together with a program to demonstrate profitability on a larger field scale. In addition, more efficient water delivery and labour savings are likely with alternatives to the current practice of watering by hand-held hoses.

Water resources

Water resources have been identified as being under threat through a combination of over-utilisation (Keen and Chu Thai Hoanh 2015; Phan Thi Giac Tam and McKay 2015), drought or climate change, and contamination (Do Thi Thanh Truc et al. 2015) in the study area. The present findings suggest that irrigation efficiency can be greatly improved in some crops at least, but that more systematic evaluation of the best technologies for farmers in SCC Vietnam is urgently needed.

In summary, there appear to be multiple nutrient deficiencies in many of the crops studied, and opportunities for considerable savings in water through improved irrigation practices on sands of SCC Vietnam. Hence, significant productivity, profitability and sustainability gains are possible through integrated nutrient, soil and water management in this region. However, systematic programs of research are needed to design packages of practices suitable for farmers in SCC Vietnam. These need to be supplemented by programs to test recommendations and investigate further options for adoption by farmers. Better management of organic by-products in the farm system (e.g. manure, biochar, crop residues) and inclusion of livestock in the on-farm studies should be integral to such investigations (Hoang Vinh et al. 2015a). The application of biochar to sands in Vietnam soils would appear to have potential given: its stability in soils relative to organic matter; the nutrient value of biochar; and comparative simplicity of its manufacture. However, there are competing uses of crop residues for livestock feedstock as opposed to biochar manufacture. To improve nutrient retention in sands of SCC Vietnam, biochars may need to be applied regularly over many years. To meet this demand, further development is required for home-based production technology of biochar from rice husk, a readily available feedstock, which has the added benefit of being able to produce gas for domestic cooking.

Opportunities and priorities

A key output of the studies reported here was to identify promising interventions for value chains that would increase profitability and market access for producers in SCC Vietnam. Interventions in peanut, cashew, mango and beef-cattle value chains appear to have most promise of delivering widespread benefits to smallholder farmers in SCC Vietnam. We suggest that further support from the Government of Vietnam could be directed to help local authorities implement strategies recommended in these proceedings (Section 3). Continued monitoring of the impacts of these technical interventions is also required.

Peanut

To increase the competitiveness of the peanut value chain in SCC Vietnam, better market facilities and upgraded mechanisation for harvesting, threshing, grading and drying are needed. Traders play a very important role in the peanut value chain and policy support is needed in terms of access to credit and capacity building (i.e. training in postharvest technology, food safety, business management) and provision of world market information. Greater input to the technology transfer process is needed to lift farmer awareness and aid adoption. Significant profitability increases can be achieved through balanced nutrient supply, including potassium, sulfur and micronutrients, but fertiliser application packages that are profitable for farmers need to be designed and demonstrated in the region for farmer adoption. Opportunities and directions for development of nutrient management packages are discussed elsewhere (Bell et al. 2015; Hoang Minh Tam et al. 2015; Hoang Thi Thai Hoa et al. 2015b; Hoang Vinh et al. 2015a; Hall and Hoang Vinh 2015) and summarised below.

Cashew

For cashew, careful consideration of the suitability and viability of this tree crop on sands in SCC Vietnam is needed. For areas identified as most promising for cashew, a selection program to identify large kernel, disease-tolerant varieties that are suited to local conditions was proposed in the value-chain study (Nguyen Duy Duc and Pham Nhat Hanh 2015). A strategy for the cashew nut industry (varieties, technology requirements, investment etc.) should be developed through collective decision-making processes that will take into account risks faced by each participant in the value chain. Improved crop management practices for nutrition, irrigation and disease control need to be widely extended to improve yields of existing plantations. These improvements in tree management for productivity need to be coupled to a strategy for the staged replacement of old trees in plantations by improved grafted varieties or replacement of cashew entirely with other farm enterprises in order to raise farmers' incomes in the SCC region.

Mango

Mango from the SCC Vietnam arrive in the markets in major cites later than those from the Mekong River Delta, giving the SCC region a comparative advantage if the value chain and branding for mango fruit from SCC Vietnam can be developed (Luong Ngoc Trung Lap and Nguyen Minh Chau 2015). For mango in the SCC region, a comprehensive assessment of the market opportunities and potential market size needs to be undertaken so that rapid industry expansion does not result in oversupply. Training and extension of improved cultural practices for farmers is required. Consideration should be given to establishing a mango cooperative, particularly if an improved, differentiated mango variety becomes available. Opportunities were identified for boosting yield of mango with application of potassium, sulfur and micronutrients at adequate rates (Hoang Minh Tam et al. 2015; Hoang Vinh et al. 2015a).

Beef cattle

For cattle, it is recommended that support programs be strengthened, focusing on remote areas, where farmers face difficulties in accessing veterinary services and animal husbandry training (Ho Cao Viet et al. 2015a). Forage areas could be increased by introducing new grass varieties that are highly productive and drought tolerant to meet the feed demand of increasing numbers of cattle. A successful scale-out activity involving farmer-to-farmer learning of the technology for growing and utilising improved pastures is described in Ho Le Phi Khanh et al. (2015). Efforts should be made to commence a pilot program for cattle-raising households, and including the local middlemen, to organise a vertically coordinated chain for supplying higher quality beef to markets. Planning is needed to increase slaughter and processing capacity in the SCC region in order to supply beef meat and other processed products to large city markets. Training for farmers and extension staff on marketing is also needed.

Cassava

For cassava, it is recommended that a plan be developed for processing factories in the region, focusing on cassava chip production (Ho Cao Viet et al. 2015b). Cassava-processing factories would diversify the market and avoid dependence on the Chinese starch market. There is a need to select and release high-starch (>30%) short-season cassava varieties that are well adapted to lowland conditions. Scaling up and establishment of small-scale cassava-processing units by groups of farmers could be considered for improving market options and returns from cassava. However, such a strategy would require a change in goverment policy after assessing the risks of environmental pollution from the disposal of processing waste and the best means of coordination of small processing units and whether they can maintain product quality. Wider adoption of the method of traditional storage of roots in the rainy season, combined with its use as a modified feed source for fattening cattle in the dry season, would further buffer cassava production against price fluctuations.

Sesame

For sesame, a better understanding of the yield potential of improved genotypes that meet high-value end uses is needed under both rainfed and irrigated production systems on sands in SCC Vietnam. This could be conducted in conjunction with rotation studies with other annual crops, such as peanuts and cassava, and should include crop nutrition and soil amendment studies. There is a need to provide improved and timely market and price information to sesame growers (Nguyen Thanh Phuong and Nguyen Van Duong 2015). Publication and extension of research findings for sesame in the SCC region would act as an aid to industry development.

Garlic

For garlic in Ninh Thuan province, further investigation into the constraints of crop productivity on sands is required. There appears to be deterioration in garlic yield and quality in Ninh Thuan (Nguyen Van Bang and McKay 2015). Investigation of the causes and remedies is suggested, including assessing the quality and virus status of planting material. Some government-sponsored programs are already underway to assist farmers to improve productivity. Assessment of the impact of this work should precede any future research on these crops. There is strong need for coordination of information sharing in the garlic value chain. Future work should occur under the framework of collective action, including a grower association and consideration of cooperative marketing, a good agricultural practices (GAP) system, quality management and regional branding.

Labour saving

Innovations that can release farm labour for other work should be a high priority for SCC Vietnam. Considerable labour savings have been seen in mini-pan irrigation and fodder management. Aside from the obvious economic considerations, there are possible social impacts since household labour can be better directed to other income-earning opportunities. In addition, the younger generations are not keen in taking up agricultural or processing-related jobs, which may create a labour shortage that hampers agricultural industry in SCC Vietnam (e.g. Nguyen Duy Duc and Pham Nhat Hanh 2015).

Soil constraints and their alleviation

The occurrence of potassium (K) and sulfur (S) deficiencies on all the sands tested in SCC Vietnam (Bell et al. 2015; Hoang Minh Tam et al. 2015) suggests that these elements need greater emphasis in crop nutrient management. However, research on rates, forms, method of placement and timing of application should underpin the development of fertiliser recommendations for these elements. This needs to be supplemented by on-farm demonstration of the efficacy of the packages designed. The supply chain also needs to be analysed to ensure that suitable fertiliser products are available and are marketed in the area of sands where K and S are essential for productive crop production.

The discovery of micronutrient deficiencies (especially boron (B) and copper (Cu)) on the sands investigated in SCC Vietnam opens new opportunities for increased crop productivity (Bell et al. 2015; Hoang Minh Tam et al. 2015; Hoang Vinh et al. 2015a). However, accurate diagnosis is needed to determine which micronutrients will be deficient, since the suite of deficient micronutrients varies among sand types (Hoang Minh Tam et al. 2015). As with K and S, research on optimal rates, forms, methods of placement and timing of application should underpin the development of recommendations. Crop differences in sensitivity to micronutrients will also need to be determined. Fertiliser companies should be involved in designing and marketing of appropriate micronutrient fertiliser products for crops grown on sands. This needs to be supplemented by on-farm demonstrations of the efficacy and profitability of the crop nutrition packages designed.

The positive responses of peanut on sands in Phu Cat district, Binh Dinh province, to a range of nutrients (K, S, Cu, B, molybdenum), to biochar and to manure suggest that optimising nutrient supply needs an integrated nutrient management (INM) approach (Hoang Vinh et al. 2015a). Given the range of variables that affect nutrient supply, and their interaction with irrigation management, a systematic research program is required over the next several years to optimise nutrient and water supply for annual and perennial crops on sands of SCC Vietnam. The implications of this research for other provinces in the SCC region (Binh Thuan, Ninh Thuan, Kanh Hoa, Phu Yen, Quang Nam, Quang Ngai) need to be considered. It is clear that improvements in yield and profit can be achieved by better managing nutrients and water for crop production but further work is needed on designing and demonstrating profitable packages of practices for farmers. There is potential to use variable inputs across orchards to maximise the profitability of fertiliser and irrigation inputs (Hall and Hoang Vinh 2015). A widespread program to identify nutrient deficiencies and make nutrient management recommendations would greatly improve farmer incomes.

In both Australia and Vietnam, promising results from biochar application suggest it could be a profitable soil amendment material that boosts crop productivity on sands (Hall and Bell, in press; Hoang Vinh et al. 2015a). Positive effects of biochar on nutrient supply need to be balanced against the risk of increased phosphorus leaching from some forms of biochar (data not shown). The underlying mechanism behind crop responses to biochar on sands needs further study. In the study of Hall and Bell (in press) on sands of the southern coastal region of Western Australia, the main benefit of biochar was nutrient supply, but this boosted crop production for only 3 years before the supply was exhausted. Promising results with biochar application on sands in Phu Cat district suggest that a value-chain analysis of this product would be worthwhile to understand how research can intervene to commercialise this technology so that products are available to farmers. Rice husks, which are available in large quantities, dispersed across the region, are a prospective stock for biochar production. However, a business case for producing and marketing the biochar needs to be developed. Even where biochar is not a feasible option, there is a range of organic resources available and used on farms in SCC Vietnam and positive effects on crop yield and nutrient balance are evident from studies (Hoang Thi Thai Hoa et al. 2015a, b; Hoang Minh Tam et al. 2015).

The mini-pan technique is a valuable tool for simple scheduling of irrigation water. It must be calibrated for each crop but there is considerable potential for reduction in water use and labour if further work is directed at this. Already, substantial reduction in water use to grow peanut has been demonstrated when scheduling applications of water according to the mini-pan technique (Hoang Vinh et al. 2015b). A strategy to take this finding forward for adoption by farmers is needed. Labour-saving and more efficient water delivery methods also need to be explored as alternatives to the present reliance on hand-held hoses to irrigate crops. On-farm evaluation of a range of technologies such as sprinklers, sprayers and drippers is needed to identify the methods most suitable for farmers in SCC Vietnam as is training in the design and management of irrigation systems.

The addition of clay to sands in Western Australia has consistently increased crop yields by 20–80% (Hall et al. 2010). These increases have been attributed to more even wetting of the soil resulting in improved crop emergence, to nutrient addition (in particular, K) and to nutrient retention due to the higher CEC of clay compared with sand. The addition of 100 tonnes (t) of clay/ha increased soil CEC by 1.7 cmol/kg while also increasing soil carbon by 0.2% (Hall et al. 2010). The addition of clays to soils is currently practised in a limited way in SCC Vietnam and the benefits of clay addition have been demonstrated on sands in Phu Yen (Do Thi ThaiTruc, personal communication). Vegetable yields increased by 40–70% in sands amended with local clay from nearby paddy fields in An Chan commune. The attraction of clay amendment of sands is that it results in a permanent increase in water and nutrient retention. However, sourcing sufficient quantities of suitable clay from on-farm or off-farm sources and demonstrating their efficacy and profitable use in the SCC region requires more thorough investigation.

Integration of cropping and livestock systems

Mixed crop–livestock farms are common in SCC Vietnam and enable farmers to diversify income and access potential complementarities between livestock and cropping. Levels of integration range from very little (where crops and livestock are present on the same farm but managed separately) to highly integrated systems (where outputs from one activity are inputs for another activity). A range of pathways for interaction does exist, including manure for crop production, livestock for traction and grazing, residues in crop production, and use of crop stovers for animal production. Forage crops for livestock can also be used as part of a cropping rotation.

Manure is a valuable output of livestock systems, and the amount collected increases as cattle are managed under more intensive stall-feeding systems rather than extensive grazing systems. Farmers typically apply manure to the first rice crop early in the year. Following this, the majority of farmers sell manure to collectors and traders, who arrange transfer to farmers in the highlands. Manure can provide an important source of supplementary income; however, the implications for management of on-farm nutrient balances are unclear.

There are potential economic benefits of mixed crop–livestock systems. Livestock production can offer an alternative means of income generation, potentially with better income than solely from cropping. Alternatively, cattle can provide a less seasonal source of income than crop production alone. Having a readily saleable asset (like cattle or other livestock) could help smooth income and allow households to respond to various shocks for which they need income, as has been observed in other systems. Not all farmers choose to invest in livestock in addition to cropping. Building a breeding herd can take producers a significant amount of time, even if all breeding animals are kept rather than sold. Producers either require access to capital to be able to make a sizeable initial investment, or have another source of income to provide for household needs while stock numbers are increasing without generating income from sales.

A greater level of crop–livestock integration does not necessarily result in increased income. Traditionally, farmers use rice straw, a poor-quality animal feed, because other feeding options are limited. Farmers with access to higher quality stovers, such as peanut tops, are likely to offer these to cattle. Farmers who have access to common grazing lands will often take advantage of this opportunity, because it is 'free' and requires little or no economic investment (if time is not taken into account, e.g Ninh Thuan). Crop–livestock systems generally become more integrated as population pressure increases and land becomes less available, possibly also due to grazing restrictions on common land. Under these circumstances, farmers are forced to consider other methods of feeding their cattle, providing an opportunity for introducing improved forage systems.

Spreading the impact of key findings

Significant progress was reported in these proceedings on realising opportunities for improved productivity and sustainability of crop and livestock production on sands in selected cropping systems in SCC Vietnam. However, the studies were designed to examine representative locations within the region without being a comprehensive or exhaustive coverage of the issues. Moreover, the focus was on sands in each study area. Hence, there is a need to place these results in context in the SCC region to determine the domains where they are relevant and the likely gaps that should form the basis for ongoing studies.

Geographical scope

A geographically restricted selection of soils has been investigated in detail in SCC Vietnam (Bell et al. 2015). The detailed studies were restricted to one district in each of three provinces, and generally most of the work was done in a single commune covering 5,000–10,000 ha in that district. Even though study sites were selected to be representative of a broader region, there is a need to broaden the geographical scope of further studies on sands of SCC VN and possibly to north-central coastal (NCC) Vietnam. There is likely to be a greater diversity of sands encountered in a systematic region-wide soil survey of the coastal sandy terrain. Moreover, the range of other soils that occurs interspersed with the sands, particularly the heavier textured soils on the lowlands (where rice production is concentrated), need to be incorporated into a landscape-scale understanding of land and water management and agricultural systems.

The climate in the northern provinces of SCC Vietnam (Quang Ngai to Binh Thuan) and of NCC Vietnam (Thua Thien Hue to Ha Tinh) differs from that encountered in the present study and hence this influence needs to be factored into the conclusions drawn. Thua Thien Hue and Quang Nam have much higher total rainfall and more intense rainfall during September–November. Unlike other locations, these provinces also have an extended rainy season with nearly 200 mm of rainfall in January. The range of temperatures is also greater in these two provinces than around the city of Vinh to the north or Ninh Thuan to the south. The minimum temperature, especially during winter, increases with the progression southwards. These differences may affect water and nutrient use efficiency and crop productivity.

Soils

The sands examined already show considerable diversity in properties. Parent materials and geomorphic origin of the parent material appear to explain most of the variation (Bell et al. 2015), although there was evidence of changes in soil properties due to management practices. More detailed studies are needed to define the full range of sands in central Vietnam and develop techniques for efficient use of water and nutrient management systems on these sands. Based on research to date (Bell et al. 2015; Hoang Minh Tam et al. 2015; Hoang Vinh et al. 2015a; Hoang Thi Thai Hoa et al. 2015a, b), the best management practices are likely to involve complete nutrient supply (including K, S and micronutrients), addition of soil amendments and more efficient irrigation techniques.

Low rainfall zone

The low rainfall zone in Ninh Thuan and Binh Thuan provinces remains a challenge for research and for agricultural productivity. The unpredictable rainfall regime suggests that long-term research programs are needed to thoroughly explore new options for productivity, resilience and sustainability. A more opportunistic and flexible approach to rainfed cropping should be pursued in the coastal zone of these provinces based on patterns of in-season rainfall (some opportunities may only be worth pursuing when heavy rain falls), supplemented by animal production, agroforestry and small-scale irrigation, where water resources permit. Consideration also needs to be given to institutional capability to mount and maintain a long-term research and development program in these provinces.

Livestock and forages

The present project has examined only forages and cattle production (Nguyen Huu Van et al. 2015; Nguyen Xuan Ba et al. 2015). However, small ruminants (sheep and goats) also have great potential for SCC Vietnam, due to their smaller body size and greater affordability for smallholders. For livestock and smaller ruminants, supplemental feeding options could be further explored for improved animal nutrition and health through a combination of feeding experiments and modelling. There would be value in the development of a decision-support tool to help extension agents give tailored advice to individual farmers given the range of available feeding options and prices. As the issues with feeding limitations become less widespread due to improved livestock nutrition, there will be a need to focus on other constraints for cattle production, including breeds and meat quality.

The project focused on encouraging farmers to move from extensive grazing of cattle to semi-intensive stall-feeding, in order to reduce labour, increase production and relieve pressure on common lands (Nguyen Huu Van et al. 2015; Nguyen Xuan Ba et al. 2015). However, in some areas, particularly in Ninh Thuan province, there is opportunity to develop land management strategies for extensive areas of privately owned dryland areas, but long-term research and development would be needed to design grazing management systems that are both productive and sustainable on these easily degraded sands. Mineral deficiencies, particularly in sheep, remain a largely unexplored area of research for animals reliant on feed produced on infertile sands, and could be reducing production and quality. For example, in Hoang Minh Tam et al. (2015), we have identified deficiencies of copper on most sands plus deficiencies of zinc and molybdenum on some sands. The low levels of these micronutrients, and of sulfur, may be impairing animal nutrition and hence animal productivity and on the supplementation of these nutrients for humans through the food value chain.

While major production gains were demonstrated with the production and feeding of forage grasses, leucaena is proving to be highly adapted to SCC climate and soils, and could play a major role in providing protein for ruminant production. However, it is essential that the issues which may threaten its success, such as variety selection, pests and toxicity, are monitored for future adoption.

Groundwater resources

There are significant knowledge gaps in the agriculture sector about the groundwater resources of the study area (Keen and Chu Thai Hoanh 2015). Widespread dependence on groundwater for irrigation in SCC Vietnam suggests that greater understanding of this resource is required by farmers and agricultural officers at commune and provincial levels to sustainably manage it. Critical information requirements for agriculture in the SCC region include: the size of the groundwater resource; annual recharge rates; the underlying hydrogeological structure of the aquifers; competing uses for groundwater; and current rates of abstraction by all users. Further study should examine the sustainability of this resource given current and projected future rates of exploitation. The risk from pollution of groundwater and surface water by fertiliser, animal waste, human settlements and agricultural chemicals (Do Thi Thai Truc et al. 2015) and from saline intrusion due to over pumping on the coastal zone also needs more thorough investigation.

Improving the analysis of economic drivers of productivity improvement

During the value-chain studies, it became evident that there are only limited tools for farmers to assist with decision-making for crop and farming systems to respond more rapidly to market signals within the constraints of available land, labour and credit. The Farm Economic Model (FEM) was developed and evaluated by potential users as a tool for assessing the profitability of farming systems involving annual and perennial cropping as well livestock enterprises (Summers et al. 2013). The model has received good support from regional Department of Agricultural and Rural Development (DARD) staff. Further training of SCC DARD staff in both basic economic enterprise analysis and use of the model would support more informed crop and farming system decision-making by farmers. There is scope for the use of this tool in the generation and development of regional or provincial models to estimate or project the financial and logistical impact of proposed interventions or changes to cropping enterprises or infrastructure. The keys to achieving such a goal are skills in Excel modelling and understanding of farm management techniques and approaches. Further investment in training would be required to achieve this. Incrementally, the collection and collation of enterprise data placed into such a framework would make this a very powerful decision-making tool for investors in agricultural farming systems and in development of SCC Vietnam.

Building capacity

The above analysis reveals a diverse range of challenges and opportunities for the development of profitable and sustainable agriculture in SCC Vietnam. Realising the benefits of these opportunities and tackling the challenges requires a strengthening of skills and capacity in the region in public research and extension institutions and in the private sector, particularly in the food supply and market chains. The key priorities for capacity building are in: identification of bottlenecks in the value chains of agricultural produce and then in the design and implementation of effective interventions; irrigation design and technology; nutrient management for upland crops on sands; integration of productive livestock enterprises with crop production on smallholdings; planning for sustainable and productive groundwater use; and nutrient management strategies to minimise pollution of shallow groundwater.

Conclusions

While agriculture in SCC Vietnam is hampered by distance from major markets, low fertility sands and the long dry season, the present studies point to promising interventions to improve profitability and sustainability. Labour saving was identified as a priority for cattle producers and farmers practising irrigation with hand-held hoses. Expansion of beef-cattle production was a promising option for the SCC region, especially when integrated with cropping. Productivity increases of mango, cashew and peanut are feasible with improved varieties, soil nutrient and water management. Promising technologies were identified for increased water use efficiency. These technologies may help to reverse excessive exploitation of groundwater, especially in peanut production areas of Binh Dinh province. Reduced nutrient pollution of groundwater also warrants more attention. For mango, off-season production is a great opportunity for expansion of production and increased value, especially in Binh Dinh. For cassava, environmentally sustainable cultivation techniques should be improved and extended to farmers; technologies that increase price and decrease price volatility are a high priority. By contrast, realistic assessments are needed to determine the areas where continued production of cashew should be promoted. The present findings have relevance for the whole of the coastal central region of Vietnam where sands are prevalent.

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