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Sustainable Management of Soil in Oil Palm Plantings

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Sustainable Management of Soil in Oil Palm Plantings

Proceedings of a workshop held in Medan, Indonesia, 7–8 November 2013

Editors: Michael J. Webb, Paul N. Nelson, Cécile Bessou, Jean-Pierre Caliman, Edy S. Sutarta

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Cover: Technical advisors and a smallholder oil palm grower examining a recent volcanic ash soil on his oil palm block in West New Britain, Papua New Guinea (Photo: Paul Nelson).

Foreword

Oil palm is a globally important source of vegetable oil, being used in a wide variety of foods and other products. For many tropical countries it is an economically important crop, fulfilling local demand for vegetable oil and generating large export incomes. It is grown by plantation companies and smallholder families; often in a nucleus or plasma system where the smallholders supply oil palm fruit to a centralised mill. As demand for vegetable oil increases, due to growing and increasingly wealthy populations, the industry is expanding rapidly onto new land and there is an increasing need for ecological intensification of production.

To ensure continuous production into the future and to safeguard the condition of the broader environment it is crucial that the condition of the soil in oil palm plantations be maintained or improved. In our rapidly changing environment, new management approaches will be needed to optimise production and sustainability. Such advances will rely heavily on science- and system-based understanding of oil palm agroecosystems. This workshop brought together 41 scientists from 10 countries to discuss and advance sustainability of soil management in oil palm production systems.

The workshop and subsequent proceedings covered a broad range of topics: soil types and properties; water and nutrient cycling; effects of organic residues; biogeochemical processes; biological processes; monitoring, modelling and assessment, and; synthesis and discussion. The papers produced during the workshop will be useful to scientists and managers throughout the tropics. I hope that the information and approaches discussed in this volume will be used widely, stimulating better understanding and care of vital soil resources.

Nick Austin
Chief Executive Officer
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Contents

Introduction

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The workshop on 'Sustainable management of soil in oil palm plantings', held in Medan, Indonesia, on 7–8 November 2013, brought together 41 scientists from 10 countries, under the auspices of PalmINet (www.palminet.com) and the International Conference on Oil Palm and the Environment (ICOPE, www.icope-series.com).

The overall objective of the workshop was to improve the management of soil in oil palm agro-ecosystems through generation of better (more holistic and site-specific) information and advice to growers. The workshop focused on synthesis of knowledge and identification of research gaps by scientists working in oil palm systems, with particular emphasis on indicators of sustainability to help growers underpin certification of the Roundtable on Sustainable Palm Oil (RSPO).

The aims of the workshop were to:

1. Create and strengthen links and facilitate exchange of ideas between scientists working on sustainable soil management in oil palm.
2. Synthesise the challenges and approaches for improving sustainability of soil management under oil palm and chart a way forward for collaborative research and production of decision-support materials for managers.

It is appropriate that the workshop was held in Medan, where the oldest commercial oil palm plantations, established around 1911, are still producing, now into their fifth generation of palms. Medan is also the place of initial discussions that led to the formation of the RSPO. The RSPO held its 11th annual meeting and 10th General Assembly in Medan in the week following the workshop.

In these proceedings, we present the papers (mostly as abstracts only) given at the workshop and summaries of discussions that were held. Copies of slide presentations given during the workshop are accessible at the PalmINet website (community.plantnet-project.org/pg/groups/2879/palminet/).

We gratefully acknowledge the workshop sponsors—the International Conference on Oil Palm and the Environment (ICOPE, www.icope-series.com), the Australian Centre for International Agricultural Research (ACIAR, www.aciar.gov.au), the Crawford Fund (www.crawfordfund.org), the International Plant Nutrition Institute – Southeast Asia Program (IPNI-SEAP, www.ipni.net), PalmINet (www.palminet.com) and the organisations employing the participants.

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Soil types and properties

Soil properties and their influence on oil palm management and yield

S. Paramananthan[1]

Abstract

Most tropical soils are considered to be infertile due to intensive weathering and leaching caused by the high temperatures and heavy rainfall that prevail in these areas. The key to their management is to understand their characteristics so that a package of management practices can be used to overcome their limitations. The parent materials from which tropical soils are formed mainly determine their physical, chemical and mineralogical properties. The physical and chemical properties determine the type of management and the yield of oil palm on these soils. Physical characteristics, such as colour, determine the iron content, structure, porosity and phosphate management in these soils. Texture and structure control their internal drainage. The effective soil depth as influenced by the presence of gravel, stone or underlying rock controls rooting depth, moisture availability and susceptibility to wind damage. The chemical characteristics such as carbon/nitrogen ratio, total and available phosphorus and exchangeable cations are often low as is the cation exchange capacity and base saturation. A table to evaluate their chemical characteristics for oil palm is given in the paper. In order to manage these soils, they can be grouped into soil management groups using their particle size class, fertility status and the presence of gravels or other adverse soil conditions. The management implications of these factors determine their yield.

Introduction

The sustainable production of oil palm involves many considerations of land selection, planting materials, technical and administrative management, labour availability, harvesting efficiency and environmental conditions. The cost of producing economically sustainable yields will depend largely on the nature of the land and soils on which the palms are grown. The nature of the land and soil will, to a large extent, determine the appropriate management practices to be employed and the yield potential.

The oil palm has a relatively shallow, coarse and inefficient root system, with most of the active roots found in the upper 30 cm of the soil (Gray 1969; Tinker 1976). Therefore, to maintain an adequate nutrient supply to the palm, the nutrient concentration in the soil must be higher than that required for most crops.

Since each soil has its own peculiar characteristics, it is important to select the best soil for oil palm cultivation. It is important to identify the limitation a soil has and apply a parcel of soil management practices specifically tailored to the site and soil. Paramananthan (1987) has proposed the criteria and class limits to assess and evaluate the land and soil characteristics for oil palm cultivation (Table 1).

Objective of this paper

The objective of this paper is to review the soil properties and their effect on oil palm management and yield. Other characteristics of the land, such as the climate, topography, elevation and drainage, also play an important role in determining the management and yield of oil palm. It is, however, important to remember that interactions between the various characteristics are common.

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Table 1. Evaluation of land characteristics for oil palm (estate-level management)

CHARACTERISTIC	Degree of limitation				
	Not limiting S1	Minor S2	Moderate S3	Serious N1	Very serious N2
CLIMATE					
Annual rainfall (mm)	>2,000	1,700–2,000	1,450–1,700	1,250–1,450	<1,250
Dry season (months)	–	1	1–2	2–3	>3
Mean annual max. temp. (°C)	>29	27–29	24–27	22–24	<22
Mean annual min. temp. (°C)	>20	18–20	16–18	14–16	<14
Mean annual temp. (°C)	>25	22–25	20–22	18–20	<18
TOPOGRAPHY					
Slope (%)	0–12	12–24	24–38	38–50	>50
WETNESS					
Drainage class	Moderate to imperfect	Well and somewhat excessive	Poor (aeric) (easily drained)	Poor (typic) (difficult to drain)	Very poor
Flooding	Not flooded	Not flooded	Minor	Moderate	Severe
PHYSICAL SOIL CONDITIONS					
Texture/structure	Cs, SC,CL, SiCs, SiCl	Co, L, SCo	SCL, Cm	SL, LSf	LSco, S
Depth (cm)	>100	75–100	50–75	25–50	<25
Depth to top of sulfuric horizon (cm)	>100	75–100	50–75	25–50	<25
Thickness of peat (cm)	<50	50–150	150–300	>300	–
SOIL FERTILITY CONDITIONS					
Weathering stage (effective CEC)	≥16	<16	–	–	–
Base saturation (%) A horizon	>35	20–35	<20	–	–
Organic carbon (%) A horizon	≥1.5	<1.5	–	–	–
Salinity (dS/m) (50 cm)	0–1,000	1,000–2,000	2,000–3,000	3,000–4,000	>4,000

Note: C = clay; S = sand; L = loam; Si = silt; s = structured; m = massive; o = oxic horizon; f = fine; co = coarse; CEC = cation exchange capacity
Source: Paramananthan (1987)

Physical soil characteristics

Physical soil characteristics are those which a soil surveyor uses to differentiate the different soils in the field. These include:

- parent material
- colour
- texture/structure
- depth
- presence of gravels/stones
- drainage class.

Parent materials of the soils

Compared to temperate soils, most tropical soils are highly weathered and infertile. This is mainly due to the differences in weathering between the temperate and tropical regions as a result of differences in climate. Temperate soils are mainly formed under seasonal low temperature and rainfall and are more subject to physical weathering, resulting in shallow to moderately deep soils rich in nutrients (Alfisols, Mollisols). Tropical soils, on the other hand, are subject to intensive weathering under high continuous temperatures and high rainfall. Thus, these soils are deep, infertile soils formed mainly by chemical weathering and leaching (Oxisols/Ultisols). Parent materials determine, to a large extent, the physical, chemical and mineralogical characteristics of tropical soils. It is therefore not surprising that parent materials are used to distinguish the various soil types in the tropics. In Malaysia, for example, parent materials are used at a high level to separate soil groupings.

Soil colour

One of the easily distinguishable characteristics of a soil is its colour. This is recognised using a Munsell Soil Colour Chart. The colour is described using its hue and value/chroma. The hue of a soil can change from 10R → 10YR → 2.5Y → BG and often reflects the iron content in the soil. Soils with red or brown hues indicate high iron content and therefore have higher potential to fix phosphorus (P). Soils having a high value/low chroma (chromas <2), e.g. 8/1, 7/1, indicate wetness or low iron content. Such soils tend to have poorer structures and can hinder root development. Colour can also be used to differentiate drainage classes, e.g. well drained, imperfectly drained, poorly drained or very poorly drained. On the other hand, soils with low value/low chroma, e.g. 2/1, 2/2, 3/1, 3/2, indicate black colours and soils often rich in organic carbon, e.g. peats or organic clays. Such soils can have a high carbon:nitrogen (C:N) ratio and result in problems with nitrogen availability.

Texture and structure

Texture refers to the relative amounts of clay, silt and sand in the fine earth (<2 mm) fraction of a soil. The soil structure refers to how these components are held together to form soil aggregates. Iron and organic matter greatly assist in aggregating these particles. In iron-rich soils with clay contents of over 70%, these fine particles can be bonded together to form pseudosands/silts. Such soils (often Oxisols) have high porosity and can result in good rooting but the plant may suffer from moisture stress, especially during low rainfall periods and when the palms are young. Thus, yield fluctuations are common. Where the iron content is low in a soil with similar clay contents, the soil can be massive and it will have low porosity and result in poor rooting. Temporary flooding can be common.

The clay fraction of a soil is the most active and important fraction. Clay helps retain moisture and nutrients. The clay fraction, through it mineralogy, determines the fertility potential of the soil via its cation exchange capacity (CEC). Sandy soils have low moisture and nutrient retention capacity. Thus, we need to ameliorate this by the use of organic manures or empty fruit bunches (EFB).

Skeletal soils

The presence of ironstone or lateritic fragments or gravels, stones etc. reduces the effective volume of the fine earth fraction. If present in large quantities, these skeletal grains can also reduce the effective soil depth and reduce root penetration, especially if a dense gravel layer is more than 25 cm thick.

Soil depth

Most oil palm roots occur in the upper 30 cm of the soil profile. If the soil is shallow, this will reduce the effective soil depth. This can be ameliorated by the application of EFB. If iron-rich gravels occur, additional P fertilisers will also be required.

Chemical impediment

Chemical impediments such as acid sulfate layers (pH <3.5 and jarosite mottles) or toxic elements such as ions of aluminium, hydrogen, manganese and nickel, or even boron can be an impediment, which will lead to poor root growth, resulting in poor crop anchorage and susceptibility to wind damage. This will also result in poor nutrient and moisture uptake.

Chemical soil characteristics

Soil chemical characteristics can be more easily corrected compared with physical properties. Most tropical soils have a low inherent fertility status and require fertilisers to obtain and maintain good yields. The most important chemical characteristics are:

- organic matter and N content in the topsoil
- soil P
- CEC
- concentration of soil potassium (K), calcium and magnesium (Mg)
- base saturation (%) in the topsoil
- soil pH
- salinity (dS/m) to 50 cm depth
- micronutrients.

Soil chemical analyses are carried out periodically (once every 3–5 years) in order to:

- estimate the soil nutrient supply
- estimate the capacity of a soil to store and immobilise nutrients
- measure the differences in soil fertility between soil horizons
- measure spatial and temporal differences in soil chemical properties.

It must be remembered that the application of mineral fertilisers over the weeded circles and on the frond heap placed in alternate inter-rows affects fertiliser uptake and soil chemical properties. Soil sampling should therefore be taken from both of these two zones. Large changes in soil chemical properties during the palm's 25-year cycle are to be expected. The soil's nutrient-supplying power is difficult to predict using soil chemical analyses as this is affected by other factors, such as soil physical properties and soil moisture supply. Consequently, foliar or plant analyses are often preferred to soil chemical analysis, especially to estimate the requirements of trace elements (copper, boron and zinc). The results of the soil analyses are often interpreted for mineral soils using Goh and Chew (1997) (Table 2).

Soil management groups

Once a piece of land has been planted with a crop such as rubber or oil palm, we need to look at how the estate is to be managed. Thus, the mapped soils need to be placed into management groups. Each management group will consist of soils for which a set of management practices can be applied.

Twelve soil management groups for mineral soils and nine groups for organic soils have been developed for use in Malaysia (Paramananthan 2010). The mineral soil groups are mainly based on the subsoil (25–75 cm) textures, drainage class and presence of special diagnostic horizons, such as acid sulfate and spodic horizons. For the organic soils, the groups are based on the nature of the soil organic matter in the subsurface tier (50–100 cm) and the presence, absence and nature of wood within the upper 100 cm depth.

Currently, these mineral and organic management groups are being subdivided into subgroups using other characteristics such as high iron content, low CEC and aluminium saturation depth of organic layers.

Conclusion

It is apparent that tropical soils are quite distinct from temperate soils. This is due to high temperature and rainfall and the consequent leaching that these tropical soils undergo. An understanding of the soil properties will assist greatly in determining how these soils should be managed for oil palm cultivation.

Table 2. Soil fertility evaluation for oil palm

Property	Units	Very low	Low	Moderate	High	Very high
pH	–	<3.5	4.0	4.2	5.5	>5.5
Organic C	%	<0.8	1.2	1.5	2.5	>2.5
Total N	%	0.08	0.12	0.15	0.25	>0.25
Total P	mg/kg	<120	200	250	400	>400
Available P	mg/kg	<8	15	20	25	>25
Exchangeable K	$cmol^+/kg$	<0.08	0.2	0.25	0.3	>0.3
Exchangeable Mg	$cmol^+/kg$	<0.08	0.2	0.25	0.3	>0.3
Effective CEC	$cmol^+/kg$	<6	12	15	18	>18
Deficiency	–	Likely	Possible	–	–	Induced
Hidden hunger	–	–	–	Likely	–	Possible
Response to fertilisers	–	Definite	Likely	Possible	–	Possible

Note: C = carbon; N = nitrogen; P = phosphorus; K = potassium; Mg = magnesium; CEC = cation exchange capacity
Source: Goh and Chew (1997)

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Soil management issues affecting oil palm development in Indonesia

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Abstract

Oil palm plantations have developed rapidly in Indonesia in the last 20 years. Now, they cover more than 9 million hectares and are distributed through 22 provinces, from Sumatra, Kalimantan and Sulawesi, to Papua. Development of oil palm in Indonesia faces several issues related to soil limiting factors for oil palm growth, including drought, peatland and swampy areas, and sandy soil. In addition, improving soil quality, especially soil fertility, is an issue that needs to be addressed in order to support oil palm productivity and sustainability. Soil-borne pathogens, such as *Ganoderma* spp., are becoming important in causing disease in oil palm plantations, especially in second and third generation oil palms. In general, best management practices have been developed to deal with those issues so that planters can manage their plantations properly. However, more research is still required to increase the efficiency and effectiveness of the existing practices, and to tackle new soil management challenges in oil palm plantations.

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Peat soil properties and management implications

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Abstract

Tropical peat is formed from semi-decomposed woody materials under anaerobic, waterlogged conditions. Peat has very low macro- and micronutrient contents by weight. Coupled with a very low bulk density of 0.1–0.3 g/cm^3, volumetric nutrient content becomes very low. Peat contains a minimum of 30% organic matter and a maximum approaching 100% (weight/weight; w/w) and this translates to a very high organic carbon (C) content (12–60% w/w). Peat soil with thickness ranging from 0.5 m to >10 m has C in the range of 500–700 t/(ha.m). It has hydrophilic properties so that, even at the top of the dome, natural peat forest is water saturated most of the year, with the water content reaching 13 times its dry mass. Oil palm has a very wide range of adaptability and with a 'moderate' management level, it becomes very productive on peatland. Drainage is essential to facilitate root growth, but along with drainage, peat loses some of its water storage function. It also subsides and emits carbon dioxide (CO_2) due to increased aerobic microbial activity. It seems that controlling the water table at 50–70 cm is ideal for root growth and oil palm production. Deeper drainage is not only unnecessary, but it reduces production and potentially increases CO_2 emissions. Fertilisation for both macro- and micronutrients (phosphorus, potassium, calcium, magnesium, zinc, copper, boron), and amelioration by one kind or a combination of (dolomitic) lime, manure and mineral soil materials, are necessary for satisfactory palm oil production.

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Land management for oil palm development at high altitude

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Abstract

About 4.8% (9.15 million hectares) of the 190 million hectare total land area in Indonesia comprises oil palm plantations. As the limited suitable land for oil palm plantation is reduced, oil palm plantations expand into marginal land, e.g. high altitude land—for example, Bah Birung Ulu (BBU) plantation, PTPN IV (Persero). Based on previous land suitability evaluation, BBU plantation was considered unsuitable for oil palm cultivation because of its high altitude (>600 m above sea level), resulting in low minimum air temperatures (<18 °C). However, since 1990, global warming in North Sumatra has contributed to increases in air temperature of as much as 1 °C and, as a result, it is rare to find minimum air temperatures below 18 °C. This will result in oil palm plantations becoming suitable at higher altitudes. Several approaches will be needed to improve soil characteristics (low pH and andic character), and to take into consideration climatic conditions, suitable planting material, precision agricultural practices, organic matter application, and soil and water conservation. Through these approaches, optimum oil palm productivity can be achieved. Currently, oil palm productivity in the BBU plantation is almost equal to the S3 oil palm productivity standard released by the Indonesian Oil Palm Research Institute.

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Water and nutrient cycling

Water management in and around sustainability of soil fertility

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Abstract

Besides preventing deficit or surplus of water that affects development and yield of oil palm and managing surface run-off to minimise erosion and nutrient leaching, water management has a major influence on soil fertility evolution. The soil water regime is closely interrelated with organic matter evolution, soil fauna development and soil physical property changes, especially in peat soil. Under the general heading of 'water management', there are indeed two different but interrelated issues: (i) the water management device design; and (ii) its operation. Design issues have been the focus of much research and are very well documented. System operation requires accumulation of experience and sound knowledge of current field conditions to prevent or reduce the effects of natural hazards. It is often the weak point that research may substantially improve by developing a 'systemic' operational approach to link drainage system characteristics, soil water regime and climatic and hydrological conditions. In the light of the expected adverse effects of climate change (more pronounced dry and wet periods), the issue is of particular importance to avoid risks of flooding and insufficient drainage. The approach could be used to deal with constraints that are often facing extensions of oil palm plantation in flooded plains where it is necessary to consider at the same time external conditions affecting 'drainability' and natural drainage flow, as well as the predictable changes with time in soil physical characteristics.

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Sustainable nutrient management in the oil palm ecosystem

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Abstract

Good production practice that is agriculturally sustainable has been developed by the oil palm plantation management. This requires environmental responsibility towards conservation of natural resources, waste reduction, recycling and disposal in an environmentally cost-effective and socially responsible manner. The yields of oil palm are dependent on using good planting material and optimising fertilisation rates, together with agro-management practices and climatic influences. Sound agronomic practices through efficient nutrient management include optimum application of balanced fertilisers, maintaining good groundcover, recycling of residue, and soil and water conservation. All of these measures can contribute to high yield. Manuring of palms supplies sufficient nutrients to promote healthy vegetative growth, produce maximum economic oil palm yield, and build resistance to pests and diseases. For balanced nutrient applications, fertiliser requirement is calculated and based on nutrients removed, immobilised and lost from the system. One needs to integrate the use of mineral fertilisers, palm residues and palm oil mill wastes for sustainable nutrient management. Management of residue during replanting of oil palm by adoption of zero burning is very important in retaining the availability of biomass, which contains a significant pool of nutrients. By adopting the innovative replanting technique in which the young palms are planted into the residue rows, a significant saving in the use of chemical fertilisers can be realised—of at least 50% of the standard fertiliser rate over 5 years. This paper reviews the oil palm nutrient management and recycling of nutrients in oil palm plantations for sustainable production.

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Some keys points on palm nutrition diagnosis

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Abstract

The reaction of two genotypes to the same nitrogen–phosphorus–potassium (NPK) fertilisation policy with different magnesium (Mg) fertilisation regimes was studied in two adjacent factorial-design experiments on a mineral soil in Indonesia. The different Mg-fertilisation regimes were chosen after observing contrasted foliar Mg contents in the two different trials. The first experiment (ALCP61—planted with (DA5D×DA3D) × LM2T material with a low foliar Mg signature) received dolomite at a higher rate than in the second experiment (ALCP62—planted with a high foliar Mg signature with (DA5DxDA3D) × LM311P material). After 10 years of this different fertilisation regime, yield was evaluated as well as nutrition of oil palm through foliar and rachis analysis, complemented with soil analysis. The high Mg foliar content in the ALCP62 trial misled us to thinking that Mg fertilisation was not needed. Indeed, the limited supply of dolomite in ALCP62 induced changes in the cation equilibrium which was prejudicial to the nutrient balance in the leaf, as well as in the soil, especially when large amounts of potassium chloride were applied. It acidified the soil, decreased the exchangeable calcium and consequently the available P and total P, leading to an imbalanced palm nutrition which affected production. It allows us to conclude that the differences in foliar contents (Mg in this study) are specific to certain genotypes and need to be considered as such. Therefore, it is important to improve our knowledge in the nutrition × genotype interactions to obtain reliable indicators for responsible fertiliser management.

Introduction

Leaf analysis and fertiliser trials are widely used in oil palm estates to assess nutrient status and fertiliser requirements of the crop (Caliman et al. 1994). Optimal yields correspond to specific leaf nutrient contents and leaf analysis indicates the most limiting nutrients (Foster 2003). Yield response surfaces obtained from factorial fertiliser trials and leaf nutrient concentration response surfaces to fertiliser application compared with commercial leaf data allow determination of corrective fertiliser requirements (Webb 2009). Among those specific leaf nutrient contents, the nitrogen/phosphorus (N/P) balance governs P nutrition, and optimum P values are calculated from optimum leaf N values (Tampubolon et al. 1990). However, contrasted foliar levels according to the genetic origin of the planting material have been observed (Jacquemard et al. 2010) and it is assumed that target nutrient levels may differ according to genetic origins (Ollivier et al. 2013). This is the case in the experiment presented here, preliminary results of which were described by Jacquemard et al. (2010). The present results, which correspond to the latest round of observations, are compared with the chemical characteristics of the soil collected at the end of experimentation.

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Material and methods

Two factorial trials were set up side by side at the Aek Loba plantation (North Sumatra) with planting material of two contrasted foliar Mg content types

(ALCP61 and ALCP62) to study the effect of four fertilisers on mineral nutrition and production.

Aek Loba soils are rhyolitic soils of volcanic origin derived from Lake Toba–erupted material commonly called Toba acid tuffs. The soils at Aek Loba are very sandy and acidic, with a low cation exchange capacity (CEC) as measured by the cobaltihexamine method (Ciesielski et al. 1997) (Table 1).

Table 1. Soil (0–20 cm depth) and rainfall characteristics of trial locations

Characteristic	ALCP61	ALCP62
Organic matter (%)	2.23	2.12
pH	5.37	5.08
Cation exchange capacity ($cmol^{+}kg^{-1}$)	2.86	2.53
Clay (%)	16.5	17.4
Silt (%)	10.9	8.3
Sand (%)	72.6	74.3
Mean annual rainfall (mm) 1998–2008	2,396	2,396

The first trial (ALCP61) was planted with (DA5D×DA3D) × LM2T self material. The second (ALCP62) was planted with (DA5D×DA3D) × LM311P. LM311P is a pisifera form of LM6. The two trials were set up and planted in 1989.

The design comprises three factors—N, P and potassium (K)—studied at three levels. Fertiliser treatments were first applied in 1992; the N and K rates were applied as two split applications per year. From the beginning of the experiment, foliar magnesium (Mg) contents were found to be significantly different, with 0.251% and 0.338% for ALCP61 and ALCP62, respectively, observed in 1993. This discrepancy continued and the different Mg nutrition regimes were started in 1997. The ALCP61 experiment, showing a low foliar Mg signature, received dolomite at a higher rate (average application of 0.75 kg/palm/year) than the ALCP62 experiment which expressed a high foliar Mg signature (average application of 0.25 kg/palm/year) and in which foliage never shows Mg deficiency symptoms. A change in the potassium chloride (KCl) rate was made in 1999 (Table 2).

These experiments ran until 2007. Crude palm oil (CPO) yield was evaluated in 2006 and 2007 as well as nutrition of oil palm through foliar and rachis analysis. Soil sampling and analyses were implemented at the end of experiment in the contrasted treatments plots (N0P0K0, N0P2K2, N2P0K2, N2P2K0 and N2P2K2 in both trials, completed with N2P2K1 in ALCP61and with N1P0K1, N1P1K1 and N1P2K1 in ALCP62).

Table 2. Fertiliser treatments (kg/palm/year)

	Level 0	Level 1	Level 2
Urea	0.0	1.0	3.0
Rock phosphate (RP)	0.0	0.5	1.5
Potassium chloride (KCl)			
before 1999	0.0	1.0	3.0
since 1999	1.0	2.0	4.0
Dolomite ALCP61		0.5	1.0
Dolomite ALCP62	0.0	0.5	

Results and discussion

After 15 years of testing combinations of fertilisers and nearly 10 years of different Mg nutrition regimes, yield results obtained in the last 2 years of trial observation are shown in Table 3.

Table 3. Crude palm oil (CPO) yields (2006–2007) predicted for different nitrogen–phosphorus–potassium–magnesium (NPKMg) fertiliser combinations from fitted response functions

(a) ALCP61

Treatment (kg/palm)				Predicted CPO (t/ha/year)
Urea	RP	KCl	Dolomite	
0	0	1	0.5	7.34
0	0	1	1	7.50
3	1.5	1	1	7.86
3	1.5	4	1	7.96

(b) ALCP62

Treatment (kg/palm)				Predicted CPO (t/ha/year)
Urea	RP	KCl	Dolomite	
0	0	1	0	6.23
0	0	2	0	6.56
0	0	2	0.5	6.83
0	0.5	2	0	6.93
0	0.5	2	0.5	7.21
1	0.5	2	0.5	7.57
1	1.5	2	0.5	7.68
1	1.5	4	0.5	6.61
3	1.5	4	0.5	6.12

Note: RP = rock phosphate; dolomite = calcium magnesium carbonate

Very high CPO yields were obtained in ALCP61, with an optimum crop yield (nearly 8 t/ha/year) reached with the maximum rates of fertiliser application, and 7.3 t/ha/year with only 1 kg KCl and 0.5 kg dolomite applied per year and per palm.

The results appeared more contrasted with ALCP62. The CPO yield was lower with the lowest rate (1 kg KCl/palm/year), but yield response to P application was vigorous (with an increase of 1.4 t/ha/year). The highest rate of P fertilisation gave optimum yield (7.68 t/ha/year), but increasing the N (urea) and/or the K uptake strongly depressed the yield by more than 1 t/ha.

The main effects of the K-fertiliser treatments on leaflet nutrient levels in frond 17 in the last 3 years of experiments are shown in Table 4. Potassium fertiliser at 2 kg/palm/year and 4 kg/palm/year significantly raised the concentration of K in the leaflets in ALCP61, but the levels are lower in ALCP62 and the significant threshold is reached with 4 kg/palm/year. As expected, exchangeable K observed in the soil increased with increasing KCl (Figure 1).

Considering the calcium (Ca) status in the leaflet, the levels were lower in ALCP62 than in ALCP61 as Ca brought in via the dolomite fertiliser was lower in ALCP62 than in ALCP61. We also observed a drop in calcium with the increasing rate of KCl (Table 4). The drop in foliar Ca contents with the increasing rate of KCl is consistent with what is observed in the exchangeable Ca in the soil (Figure 1). At highest rates of KCl, Cl combines with Ca to form calcium chloride which is leached. It is a decalcifying effect of K fertilisers.

In regards to Mg, the depressing effect of K fertiliser was very strong in ALCP61. The supply of 1 kg of dolomite maintained the Mg content at 0.182% in ALCP61 while a level of 0.221% was achieved in ALCP62 with nil application of dolomite. At equivalent supply of dolomite (0.5 kg/palm/year), foliar Mg content was 0.225% for ALCP62 versus 0.142% for ALCP61. For Mg, if the foliar analysis is consistent with the exchangeable Mg observed in the soil in ALCP61, it is not the case for ALCP62. Because of the little supply of dolomite in ALCP62, the exchangeable Mg in the soil was lower, but despite this low level, the contents in the leaflet remained at a high level (Table 4).

The imbalance in leaflet N and P contents (Figure 2) and the exchangeable P and total P in the soil (Figure 3) could explain the drop in yield observed for ALCP62, especially when the high rate of K fertilisers was applied.

The low P content in leaflets observed at high levels of K was also consistent with what we observed in the exchangeable P measured with the Olsen Dabin method (Dabin 1967) and total P in the soil, which decreased dramatically.

The drop in leaflet P content was much less accentuated in ALCP61, the available P was maintained and the total P remained at a satisfactory level (Figure 3).

We observed previously that the decrease in the exchangeable Ca content in the soil was more pronounced in ALCP62, increasing the acidification of the soil. We assume that the different forms of phosphoric acid not fixed to the calcium ions disappeared

Table 4. Main effects of potassium and magnesium fertilisers (kg/palm/year) on leaflet nutrient levels (2006–2008)

Treatment	Nutrient	Nutrient level (%) by fertiliser regime				
		KCl 1	KCl 2	KCl 4	Dol. 0.5	Dol. 1
ALCP61	Potassium	0.859c	0.938b	1.061a	0.972a	0.934b
	Calcium	0.891a	0.890a	0.844b	0.885	0.865
	Magnesium	0.189a	0.162b	0.135c	0.142b	0.182a
					Dol. 0	**Dol. 0.5**
ALCP62	Potassium	0.843b	0.838b	0.886a	0.858	0.845
	Calcium	0.849ab	0.873a	0.815b	0.818	0.821
	Magnesium	0.239a	0.220b	0.210b	0.221	0.225

Note: KCl = potassium chloride; Dol. = dolomite; within the same row and within each nutrient addition, numbers followed by the same letter are not significantly different ($p < 0.05$)

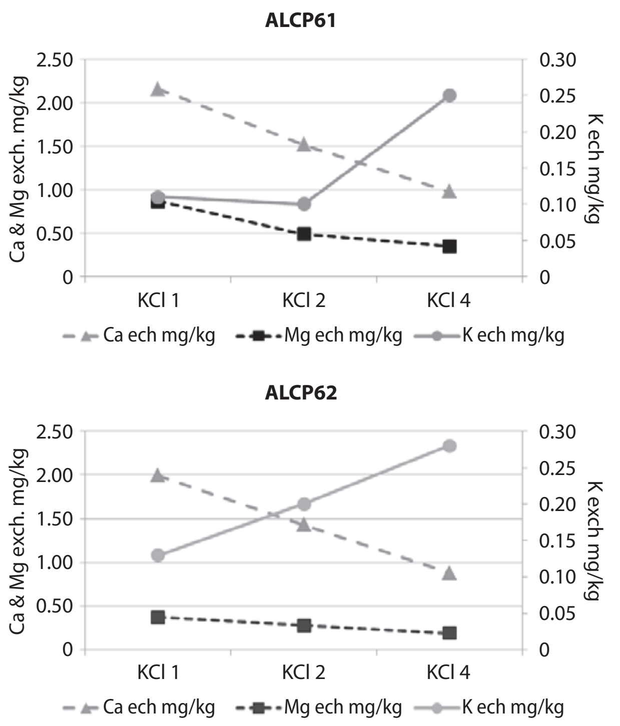

Figure 1. Effects of potassium fertilisers on soil exchangeable cations K, Ca, Mg (0–20 cm) in the two treatments (2008)

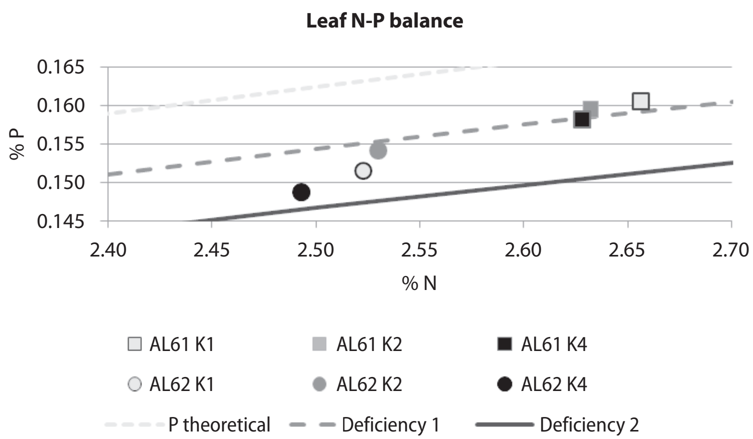

Figure 2. Leaflet nitrogen (N) and phosphorus (P) content equilibrium (2006–2008) (P theoretical value using Tampubolon equation)

because they were combined with aluminium or iron and were no longer available.

The Mg and related Ca brought in with the dolomite and the P status were the key issues of the experiment. Since the beginning of the trial, the very significant differences in the leaf Mg content between the two types of planting material led to a subdivision for each experiment with the consequences related previously. The high leaflet Mg content observed in ALCP62 was not compensated by sufficient magnesium-calcic fertilisers and led to a depletion of Ca and Mg in the soil accentuated with high KCl and urea applications. The decrease of exchangeable Ca and consequently the available P and total P led to an imbalanced palm nutrition which affected production.

These observations allow us to highlight that foliar diagnosis need to be taken with caution to assess nutrient status and fertiliser requirements of the crop. In this example, the LM311P material showed very high foliar Mg levels even when Mg inputs were nil and are most probably limiting sustained production. The method of determining Mg fertilisation through foliar analysis is therefore inappropriate for this material which behaves very differently from LM2T material. Another diagnostic tool has then to be used to predict deficiencies for crosses of this kind. This confirms that differences in foliar contents are often specific to certain genotypes and need to be considered as such. Therefore, it is important to improve our knowledge in the nutrition × genotype interactions to obtain reliable indicators for a responsible fertiliser management.

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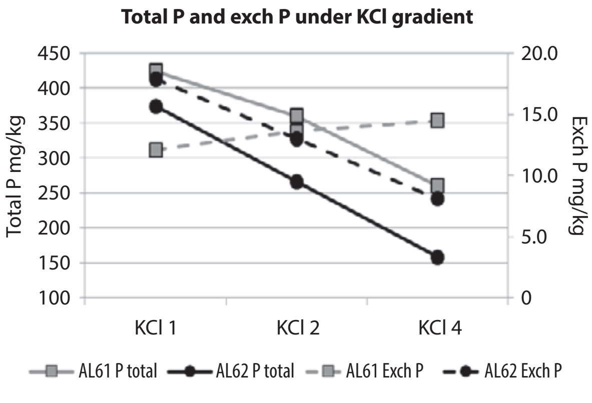

Figure 3. Exchangeable phosphorus (P) and total P in soil (0–20 cm depth)

Potassium and magnesium retention and losses, as affected by soil and other site factors

Noto E. Prabowo[1], Paul N. Nelson[2]

Abstract

Seven long-term nitrogen–phosphorus–potassium–magnesium (NPKMg) fertiliser trials in different Sumatran sites showed different responses of oil palm (*Elaeis guiineensis* Jacq.) to fertilisers. Identification of important site factors and quantification of their contribution to the response variation was studied. The information is essential to improve the current fertiliser recommendation system used for commercial fields with similar characteristics. Soil type, mineralogy, topography and rainfall were possible factors responsible for the variation. Retention of applied K and Mg in the soil in the fertiliser trials was measured. Losses in run-off and leaching were studied in additional trials at sites with different rainfall and slopes, and a pot trial. In the long-term fertiliser trials, the soils retained 9–41% of the applied K and 73–102% of the applied Mg. Nutrient loss was more affected by rainfall than soil type. The site at P. Rambong, with twice the rainfall of Bah Lias, had six and eight times greater loads of leaching and run-off, respectively. At the flat sites, losses of K and Mg in surface run-off were 1% and 2% of that applied, respectively, at Bah Lias, and 18% and 10%, respectively, at P. Rambong. Losses of K and Mg in deep drainage were 2% and 5%, respectively, at Bah Lias, and 15% and 23%, respectively, at P. Rambong. At the higher rainfall site, losses of K and Mg in surface run-off were 28% and 13%, respectively. It may be possible to reduce losses by changing fertiliser application practices and by implementing soil and water conservation measures.

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Potassium fixation and release: effects of management under oil palm in alluvial clay soils, Milne Bay Province, Papua New Guinea

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Abstract

Potassium (K) deficiency is common in oil palm on alluvial clay soils in Milne Bay Province, Papua New Guinea. These soils have high exchangeable calcium and magnesium and low exchangeable K contents and clay mineralogy dominated by smectite and vermiculite, which fix K. Potassium fertiliser is applied in oil palm plantations to alleviate K deficiency. To improve profitability and soil fertility, it is important to understand the fate of applied K. This study was undertaken to determine the effects of K-fertiliser history and surface management on K fixation and release in these soils. Soils were sampled from three management zones in plots with and without a history of K-fertiliser application in two long-term (13 years) fertiliser trials. In the laboratory, potassium chloride was added to the soil and ammonium acetate used to extract exchangeable K. Fixed K was determined as the difference between added K and exchangeable K.

Fixation was significantly ($p < 0.001$) affected by the K fertiliser history and management zones. In soils and zones that had received no K fertiliser, 27% of added K was fixed in both trials, while in the plots with a history of K fertiliser, there was little net fixation in the weeded circle zone and a considerable release in the frond pile and 'between zones' zones. This study showed that fixation and release was a function of management, suggesting that K-fertiliser placement might have a considerable effect on uptake efficiency in these K-fixing soils.

Introduction

Fixation and release of potassium (K) are important processes influencing the availability of K to plants in soils dominated by the expanding 2:1 clay minerals smectite and vermiculite. These minerals can hold large amounts of K in their interlayers and release it when there is low concentration of K in soil solution.

Potassium deficiency is common in oil palm and other crops grown on alluvial clay soils (Fluvaquents) of coastal Papua New Guinea (Best 1977). Alluvial clay soils of Milne Bay Province, apart from having high exchangeable calcium (Ca) and magnesium (Mg) and low exchangeable K contents, also contain smectite and vermiculite, which can fix K (Bleeker 1988). Regular K-fertiliser application has been recommended to oil palm plantations in Milne Bay Province since the 1980s. In oil palm production systems, fertiliser application and soil management are highly spatially variable and this could be expected to influence the fate of K. To our knowledge, there have been no studies of the fate of K applied to K-fixing soils under oil palm. The fate of applied K is likely to influence the efficiency of uptake, profitability and soil fertility. Hence, the aim of the study was to determine the effects of K-fertiliser history and surface management on K fixation and release in oil palm plantations on alluvial clay soils in Milne Bay Province.

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Materials and methods

Soils were sampled in 2007 from Papua New Guinea Oil Palm Research Association Trials 502 and 504, which are long-term fertiliser trials established in1994, to determine the fertiliser requirements for nitrogen (N) and K. Soil samples (0–0.3 m depth) were taken from five management zones; harvest path (HP), weeded circle (WC), frond tips (FT), frond piles (FP) and between zones (BZ) in two plots to which no K fertiliser had been applied and two plots that had received K fertiliser at an annual rate of 3.8 kg K/palm/year. Soil samples were passed through a 2 mm sieve, air dried, packed into sealed plastic bags and sent to James Cook University, Australia, for analysis. In this paper, results from three zones only (WC, BZ and FP) are presented. Clay mineralogy is dominated by smectite in Trial 502 and vermiculite in Trial 504.

In the laboratory, the soils were analysed for selected chemical properties and K-fixation behaviour. For the K-fixation study, nine different concentrations of potassium chloride (KCl) (equivalent to 0, 3.2, 6.4, 9.6, 12.8, 16.0, 19.2, 22.4 and 25.6 mmol K/kg soil) were added to the soil. Exchangeable K was then extracted using 1 M ammonium acetate. The decanted equilibrium solutions and ammonium acetate extracts were analysed for K. Fixed K was calculated by subtracting decanted equilibrium solution K and ammonium acetate extractable K from added K.

Soil characteristics

Without K fertiliser, the exchangeable K content was below the commonly quoted critical level (20 $mmol^+/kg$) at both sites. Exchangeable Ca and Mg contents were high at both sites. These high Mg:K and Ca:K ratios are typical of clay soils in this region. Exchangeable Mg:K and Ca:K ratios greater than 10 and 20, respectively, are unfavourable and can reduce K uptake (Bleeker 1988). Contents of exchangeable K and non-exchangeable K were significantly higher in plots with a history of K fertiliser than those without K fertiliser. Organic carbon (C) content, electrical conductivity (EC) and cation exchange capacity (CEC) were higher and pH lower in Trial 504 than in Trial 502 (Table 1).

Table 1. Some chemical properties of soils in Trials 502 and 504 (mean of two plots)

Trial	K fert.	Zone	OC	pH 1:5 (water)	EC 1:5	Exchangeable cations ($mmol^+/kg$)					ECEC	K_{nex}
						K	Na	Ca	Mg	Acidity		
502	–K	WC	21.4	6.1	59	2.1	7.1	297	145	3.2	454	2.2
	–K	BZ	19.9	5.8	76	1.4	7.3	289	128	4.5	430	1.9
	–K	FP	27.6	6.1	96	1.5	6.8	319	154	2.0	483	1.8
502	+K	WC	20.2	6.5	73	15.3	7.4	357	160	2.0	542	11.3
	+K	BZ	20.3	6.2	79	31.3	6.7	342	132	2.6	515	19.0
	+K	FP	30.2	6.2	99	66.7	4.7	343	136	1.9	552	35.6
502 mean			*23.3*	*6.2*	*80*	*19.7*	*6.7*	*325*	*143*	*2.7*	*496*	*12.0*
504	–K	WC	20.6	5.9	119	2.5	2.7	261	109	2.9	378	7.1
	–K	BZ	24.0	5.0	131	2.0	2.6	242	82	10.6	339	6.1
	–K	FP	27.7	5.8	129	2.2	2.9	270	99	2.6	377	6.6
504	+K	WC	24.5	6.0	145	12.0	2.6	265	120	2.0	402	18.5
	+K	BZ	25.4	5.1	194	21.5	2.4	231	92	9.2	356	21.6
	+K	FP	31.4	5.4	140	26.6	1.9	226	80	5.7	340	26.9
504 mean			*25.6*	*5.5*	*143*	*11.1*	*2.5*	*249*	*97*	*5.5*	*365*	*14.5*

Note: OC = organic carbon (g/kg); EC = electrical conductivity (µS/cm); K = potassium; Na = sodium; Ca = calcium; Mg = magnesium; ECEC = effective cation exchange capacity ($mmol^+/kg$); K_{nex} = non-exchangeable K ($mmol^+/kg$); WC = weeded circle; BZ = between zones; FP = frond piles

Results and discussion

Both fixation and release of K occurred, depending on the K-fertiliser history, surface management and amount of K added (Table 2). In the plots with a history of no K fertiliser, K fixation increased with the level of added K. In K-fertilised plots, there was considerable release (as indicated by the negative values) of non-exchangeable K in the BZ and FP zones, whereas less net fixation or release occurred in the WC zone. The amount of K released from the BZ and FP zones in the K-fertilised plots also increased with levels of added K. More K was released from the non-exchangeable pool in Trial 502 than in Trial 504.

In plots with no K fertiliser, the proportion of added K that was fixed decreased with increasing rates of added K and there were little or no differences between the two sites and zones (Figure 1). This is in contrast to the amount of K fixed, which increased with increasing rates of added K. Apart from the lowest K addition rate, about 10–30% of the added K was fixed at both sites in the plots with no K fertiliser, with no significant effect of addition rate or management zone.

In K-fertilised plots, fixation and release both occurred, as indicated by positive and negative 'fixation' values in Table 2. Net release of fixed K was greater in Trial 502 than Trial 504, and greater in the BZ and FP zones than in the WC zone (Figure 1).

Fixation and release of K were highly influenced by K-fertiliser history and less so by management zones and sites. The fixation capacity of K in the native soil did not differ significantly between the two trials, despite differences in clay mineralogy, organic matter content and pH. There was no release of K from the soils with no K-fertiliser history. This is because exchangeable and non-exchangeable K pools in these plots were very small due to continuous uptake by the oil palm without replenishment by K-fertiliser inputs. In plots with a history of K fertiliser, there were significant ($p < 0.005$) differences in both amount and proportion of K fixed and released between the two trial sites and the three management zones. Addition of K also enhanced release of K from the BZ and FP zones. Most of the fertiliser applied in the plantations is normally applied in these two zones. Fertiliser application increased exchangeable and

Table 2. Amounts of potassium (K) fixed with the different treatments and at various levels of added K

Treatments			K added to soil (mmol/kg soil)							
Trial	K fert.	Zone	0.0	3.2	9.6	12.8	16.0	19.2	22.4	25.6
			Amounts of fixed K (mmol/kg soil)							
502	–K	WC	–0.2	1.8	2.3	1.3	5.3	3.8	3.6	5.2
502	–K	BZ	–0.2	1.9	2.5	3.2	5.1	4.1	4.4	3.6
502	–K	FP	–0.2	1.9	2.7	2.5	4.7	3.6	4.3	5.3
502	+K	WC	–2.0	0.3	–4.5	–5.5	–0.6	–2.4	–2.4	–1.3
502	+K	BZ	–5.2	–2.7	–9.9	–12.0	–9.5	–10.5	–11.2	–9.5
502	+K	FP	–6.3	–3.7	–14.8	–14.4	–13.8	–16.5	–15.5	–5.1
502 –K mean			*–0.2*	*1.9*	*2.5*	*2.3*	*5.0*	*3.8*	*4.1*	*4.7*
502 +K mean			*–4.5*	*–2.0*	*–9.7*	*–10.6*	*–8.0*	*–9.8*	*–9.7*	*–8.6*
502 mean			*–0.3*	*1.5*	*2.1*	*3.0*	*4.5*	*3.5*	*5.7*	*6.7*
504	–K	WC	–0.3	1.6	2.4	3.2	5.0	4.3	7.0	7.9
504	–K	BZ	–0.3	1.4	1.8	3.6	3.2	2.5	4.8	5.4
504	–K	FP	–0.4	1.6	2.1	2.3	5.2	3.8	5.4	6.8
504	+K	WC	–1.6	0.4	0.8	2.6	2.2	1.4	3.5	5.3
504	+K	BZ	–3.7	–2.2	–7.9	–5.6	–4.4	–7.4	–4.7	–5.0
504	+K	FP	–4.8	–3.3	–10.3	–7.5	–6.6	–9.6	–7.8	–7.7
504 –K mean			*–0.3*	*1.5*	*2.1*	*3.0*	*4.5*	*3.5*	*5.7*	*6.7*
504 +K mean			*–3.4*	*–1.7*	*–5.8*	*–3.5*	*–2.9*	*–5.2*	*–3.0*	*–2.5*
504 mean			*–1.9*	*–0.1*	*–1.9*	*–0.2*	*0.8*	*–0.8*	*1.4*	*2.1*

non-exchangeable K contents of the soil by 23- and 8-fold, respectively, in trial 502, and by 6- and 3-fold, respectively, in trial 504. Soil analysis also confirmed higher exchangeable and non-exchangeable K contents in these two zones compared to the WC zone. In the WC zone of the K-fertilised plots, some proportion of the applied K was fixed but not as much as the WC zone in the plots with no history of K-fertiliser application. About 14.1% and 25.7% of the added K in the K-fertilised plots was fixed from the WC zone of Trials 502 and 504, respectively.

Although both trials have the same fixation capacity (results from –K plots), more K was released in Trial 502 than Trial 504 (+K plots) due to higher contents of exchangeable and non-exchangeable K, and possibly also due to the difference in clay mineralogy between sites. In smectite, the inner peripheral space is not held together by hydrogen bonds, hence it is able to swell with adequate hydration, allowing for rapid passage of K ions out of the interlayer. Vermiculite, on the other hand, has peripheral spaces that impede ion exchange reactions and reduce the rate at which K is released from its interlayer (Sparks and Huang 1985). The difference in release between the soils at the two trial sites could also be related to differences in response to K fertiliser between the sites. The response of yield and leaf K content to fertiliser was larger for Trial 502 than for Trial 504.

The results of this study have implications for management of K fertiliser to oil palms grown on alluvial clay soils with 2:1 clay mineralogy. When K fertiliser is applied in zones or soils low in K reserves, a considerable portion of that K will be fixed by the soil and may not eventually become available for the oil palm uptake. Whereas if K fertiliser is applied to areas with high K concentration from a prolonged history of K-fertiliser application, then there will be no net K fixation, and the added K will be immediately available. Therefore, judicious placement of K fertiliser might be used to improve the agronomic efficiency and benefit:cost ratio of current additions. From this study, the BZ and FP zones have higher K reserves than the WC zone, so continued placement of K fertiliser on those zones will minimise the proportion that is fixed, thus improving K uptake by the oil palm. Given the high cost of fertiliser, it may even be economic to continue placing fertiliser in the same zones after the palms in the current crop have been felled and replanted.

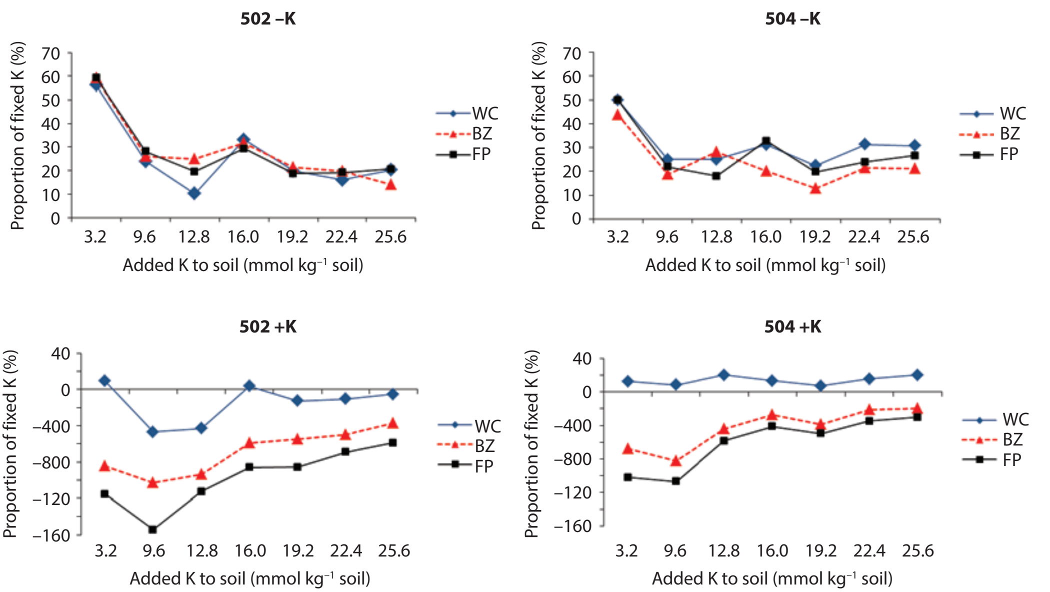

Figure 1. Proportion of added potassium (K) that was fixed in weeded circle (WC), between zones (BZ) and frond pile (FP) zones in Trials 502 and 504

Conclusion

This study showed that the fixation and release of K in alluvial soils of Milne Bay Province, Papua New Guinea under oil palm cultivation were influenced by management. Fixation and release of K were related more to the K-fertiliser history than the other two factors (trial site and management zones). Approximately 10–30% of the K added to the soil in laboratory trials was fixed in the plots and zones with a history of no K fertiliser in both trials. Release of K from the non-exchangeable pool was mainly influenced by the amount of non-exchangeable K and the trial site. In K-fertilised plots, release of K was greater in Trial 502 than in Trial 504.

When K fertiliser is applied in zones or soils low in K reserves, a considerable portion of that K will be fixed by the soil and becomes temporarily unavailable for uptake by the palms. Whereas if K fertiliser is applied to zones or plots with a prolonged history of K-fertiliser application, there will be no net K fixation, instead added K will be immediately available. From this study, the BZ and FP zones have higher K reserves, so continued placement of K fertiliser on these zones will minimise the proportion that is fixed, thus improving K uptake by the oil palm.

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Effects of organic residues

Soil properties are affected by management of pruned fronds in palm plantations of smallholders in western Africa

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Abstract

Carbon stock, some chemical parameters and microbial activities of soil were studied in smallholder oil palm plantations located in south-eastern Benin (2°30' – 2°45' E, 6°35' – 7°45' N). Two age groups (7–11 and 16–19 years old) of 12 palm plantations were chosen on a slightly desaturated and depleted Oxisol. They were characterised by two practices of pruned frond management on the soil: total recycling (TR) and no recycling (NR) of fronds. Three palm trees of each frond management practice were chosen per age group. The soil was sampled at 0–5, 5–10, 10–20, 20–30 and 30–50 cm for determination of carbon (C), nitrogen, calcium, magnesium and potassium content, pH, microbial biomass and carbon dioxide release. Bulk density was determined for calculation of C stock (650 kg/m^2; ~0–50 cm) of soil. Frond recycling impacted soil properties in the mature plantations, corresponding to 10 years of recycling. TR increased soil C stock under frond piles by 70% compared with NR practices. Surprisingly, soil C stock did not decrease over time under NR. The significant increase of C stock after 10 years of TR (frond recycling) improved several soil parameters in the first 20 cm soil depth. The soil was enriched in organic matter (20 g C/kg) and nitrogen (1.5 g N/kg). The cationic exchange capacity reached average values (7 cmol$^+$/kg); two times higher than in the case of NR practices. Microbial biomass was also increased under TR practices in the first 20 cm soil depth, whereas soil respiration was significantly increased at 0–5 cm.

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Effects of empty fruit bunch (EFB) application on soil fauna feeding activity in oil palm plantations

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Abstract

Sustainable soil management is seen as one of the important strategies for increasing and maintaining ecosystem services in oil palm plantations. It is a method that is proposed to enhance palm oil production, improve soil health and mitigate soil erosion. Application of recycled oil palm residue, such as empty fruit bunches (EFB), is therefore a widely used soil management practice in commercial oil palm plantations. Previous studies showed that applying EFB in the field enhanced soil fertility and production. However, the effects of EFB application on the soil biota are still poorly understood. We used bait lamina sticks to examine soil fauna feeding activity in the EFB-applied and the chemical-fertilised oil palm area, and also in an adjoining secondary forest as baseline, in Sumatra, Indonesia. We examined three different management zones in both the EFB-applied and the chemical-fertilised oil palm area: fertiliser circles, frond heaps and harvesting paths. Soil under EFB placement was also examined in the EFB-applied area. The results showed that the soil fauna feeding activity was higher in the soils under EFB placement than the soils in other management zones in both the EFB-applied and the chemical-fertilised oil palm area. In addition, feeding activity in the secondary forest was lower than all the management zones in both the EFB-applied and the chemical-fertilised oil palm area. Results also indicated that feeding activity was higher near the soil surface and decreased with depth in both oil palm and forest. We therefore suggest EFB application as an effective way to enhance soil fauna feeding activity in oil palm plantations.

Introduction

The increasing global demand for palm oil has caused the expansion of oil palm plantations, especially in South-East Asia. In 2010, the global land cover of oil palm plantations had reached 15 million hectares, with more than half of the plantations located in Malaysia and Indonesia (Gilbert 2012). Demand for palm oil is expected to double by 2030 in Indonesia, which serves as the world's largest oil palm grower (Gilbert 2012). Sustainable soil management is seen as one of the most important strategies for increasing and maintaining ecosystem services within oil palm plantations. It is a method that is suggested to enhance palm oil production, improve soil health, and mitigate soil erosion (Foster et al. 2011; Sayer et al. 2012). Application of recycled oil palm residue, such as empty fruit bunches (EFB) from palm oil mills, is therefore one

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of the most widely used soil management practices in commercial oil palm plantations.

Previous studies have shown that EFB application enhanced soil chemical properties, vegetative growth and palm oil production (Loong et al. 1987; Abu Bakar et al. 2010; Comte et al. 2013). However, the effects of EFB application on the soil biota, which contributes to the initial decomposition of organic matter and nutrient cycling, remains largely unknown. In this study, we used bait lamina sticks (Römbke et al. 2006; Birkhofer et al. 2011) to understand the effects of applying EFB on soil fauna feeding activity in oil palm plantations. We also examined soil feeding activity in an adjoining secondary forest as a baseline for comparing with the agricultural oil palm agroecosystem.

Material and methods

Site description

The research was undertaken in an oil palm plantation and a nearby secondary forest patch in Kampar District, Riau Province, Sumatra (0° 32'26.50" N 101° 04'19.80" E). The 20-year-old oil palm plantation (Rama Rama Estate) was developed in 1992 and is managed by PT SMART, Indonesia. The adjoining secondary forest has been co-managed by the Indonesian Department of Forestry, PT SMART and the local communities.

The climate of this region is tropical humid with an average rainfall of 2,400 mm year^{-1} (230 mm/month in the wet season, 140 mm/month in the dry season), and the average monthly temperature ranges from 26 to 32 °C (Comte et al. 2013). The soils are Ferralsols with loamy lowland soil class in the oil palm area and loamy-sand upland soil class in the forest area (Comte et al. 2013).

In the oil palm plantation, palm trees are planted in a triangular spacing (9 m apart), with harvesting paths and frond heaps at alternate rows. Every palm tree trunk is surrounded by a 1.5 m radius weed-free fertiliser circle, which is the major place for applying chemical fertilisers. The 1.5 m wide harvesting paths are used for agriculture-related traffic. The 1.5 m wide frond heaps are used for placing pruned fronds; this area is the only place where understorey grass and ferns grow freely in abundance.

There are two main fertilisation types of commercial plots in the oil palm plantation: EFB-applied plots and chemical-fertilised plots. The average size of a commercial plot is 0.3 km^2. In EFB-applied plots, EFB is applied at one side of harvesting paths, and chemical fertilisers are also applied but with a lower dosage and frequency, in order to compensate for the nutrients released from EFB. Only chemical fertilisers are applied in chemical-fertilised plots.

Experimental design

Sampling areas within the plantation were established using the following criteria: (i) the soil types were the same, namely Typic Dystrudepts; (ii) the EFB-applied plots had been applied with EFB yearly or every 2 years for at least 8 years, and the last application was in 2012 (i.e. within 6–18 months of the field study); (iii) the chemical-fertilised plots had been manually fertilised since the beginning of the planting. The resulting sampling area was 1.2 km^2 for the EFB-applied area, which constituted four continuous commercial plots, and 0.3 km^2 for the chemical-fertilised area, which constituted one commercial plot. The distance between the EFB-applied and the chemical-fertilised area was 300 m.

A nested design was applied for measuring soil fauna feeding activity. In both the EFB-applied area and the chemical-fertilised area, three 0.01 km^2 subareas were randomly assigned and six oil palm trees within each subarea were randomly selected. The distance between each tree was at least 9 m. For each sampling tree in the EFB-applied area, the soil fauna feeding activity was measured at four management zones: beneath the EFB, inside the fertiliser circles, under the frond heaps, and at the side of the harvesting paths. For each sampling tree in the chemical-fertilised area, the activity was measured at three management zones: inside the fertiliser circles, under the frond heaps, and at the side of the harvesting paths. This design led to a total of 72 sampling points in the EFB-applied area and 54 sampling points in the chemical-fertilised area.

The secondary forest area (2.7 km^2 patch) was the closest forest (6 km) to the oil palm sampling area. Within the forest area, three 0.0036 km^2 subareas were chosen, covering of an area of 1 km^2 forest. Each of the subareas was at least 300 m from the other subareas, 50 m from the forest edge and 100 m from the nearest stream. In each of these subareas, two 20 m parallel transects were designed covering the centre of the subarea. In each transect, three sampling points were chosen, 10 m apart from the adjacent point. This design led to a total of six sampling points per subarea and 18 sampling points in the forest area.

Bait lamina sticks (Terra Protecta GmbH, Berlin, Germany) are polyvinyl chloride (PVC) strips (1 × 6 × 120 mm) with 16 apertures of 1.5 mm diameter and 5 mm apart (Kratz 1998). The bait used in the apertures was made of cellulose powder, bran flakes and active carbon (70:27:3). At each measuring point, a matrix of six bait lamina sticks were placed in a 12 cm × 24 cm grid, in which the sticks were 12 cm apart. The sticks were inserted vertically until the top aperture reached just below the soil surface, and the bottom aperture was at a depth of 8 cm below the soil surface. A total of 864 sticks across all 144 sampling points were inserted on 16 July 2013. All the sticks were collected after 6 days of exposure, and each aperture was recorded as 0 (without perforation) or 1 (partial or complete perforation) for binomial analysis.

Statistical analysis

The overall proportion of perforated holes of the six bait lamina sticks within each sampling point was used to represent the soil fauna feeding activity at each sampling point. A general additive model was used for analysing the binary variable of perforations. The soil fauna feeding activity of a total from seven management zones in oil palms were compared: four zones in the EFB-applied area (EFB zone, fertiliser circles, harvesting paths and frond heaps) and three zones in the chemical-fertilised area (fertiliser circles, frond heaps and harvesting paths). The activity in the forests was also compared as a baseline control. The subarea, sampling points and individual bait lamina sticks were analysed as nested random effects. Depth of feeding was included in the model with a cubic regression spline smoother. Models with one general smoother for depth and smoothers by groups of oil palm management zones were compared using Akaike information criterion (AIC) scores to examine whether the feeding depth patterns differed among management zones. The optimal model with four groups of smoothers for depth (EFB; fertiliser circles in EFB-applied area; forest; the rest of the management zones) was selected as the best fitting model. Analyses were carried out using gamm4 package for R software version 3.0.2 (R Core Team 2013).

Results

The overall mean feeding activity was 41% for all the treatments. In EFB-applied area, the soil fauna feeding activity was significantly higher in soils underneath EFB than all other management zones ($Z_{7,16} = 4.71$, $p < 0.0001$) (Figure 1a). Soil fauna feeding activity in fertiliser circles was significantly lower than all other management zones ($Z_{7,16} = 4.71$, $p < 0.0001$). There was no significant difference between frond heaps and harvest paths. In the chemical-fertilised area, the feeding activity in all the three zones was similar (Figure 1b). Feeding activity in the secondary forest was lower than all the management zones of both the EFB-applied and the chemical-fertilised areas ($p < 0.0005$). Feeding activity was the highest near the soil surface, and the activity decreased with depth (Figure 1b, p-values of the smoother < 0.0001).

Discussion

Our results show that soil fauna feeding activity is significantly higher in soils underneath EFB than all the other management zones in both the EFB-applied area and chemical-fertilised area. EFB is a source of fresh organic matter and food for soil fauna and microbial communities. Thus, soil fauna abundance may increase following EFB application and hence may contribute to higher fauna feeding activity observed under the EFB application (Filzek et al. 2004; Förster et al. 2004; Römbke et al. 2006). This has important implications as through decomposition and humification by soil decomposers, soil carbon and nutrient content are increased after applying EFB (Caliman et al. 2001; Abu Bakar et al. 2010; Comte et al. 2013).

EFB application on the surface of the soil prevents direct sun exposure, thus reducing soil temperature and increasing soil moisture (Chiew and Rahman 2002; Abu Bakar et al. 2010). As climatic factors serve as a determining factor for feeding activity (Gongalsky et al. 2004, 2008; Simpson et al. 2012), the mulching effect of EFB may also trigger greater soil fauna feeding activity.

Previous studies have also shown that addition of EFB enhances soil structure and physical properties by improving the water-holding capacity and soil permeability (Caliman et al. 2001; Chiew and Rahman 2002). The improved soil structure may be due to accelerated decomposition processes, resulting in the production of humic substances which loosen the soil, provide macropores and change the soil profile (Weil and Brady 2002). Gongalsky et al. (2004) found that soil profile structure is one of the main factors affecting feeding activity. As soils in oil palm plantations are usually compacted due to initial land-use change and regular traffic, addition of EFB may enhance the soil profile structure and thus improve feeding activity.

EFB application in oil palm plantations enhances soil chemistry, including soil pH, cation exchange capacity and base saturation (Caliman et al. 2001; Abu Bakar et al. 2010; Comte et al. 2013). Geissen and Brümmer (1999) showed that feeding activity of soil fauna is related to soil chemical parameters following fertilisation and liming in deciduous forest soil. This may explain the higher performance of feeding activity at soil under EFB and fertiliser circles of the EFB-applied area.

Our study showed that soil fauna feeding activity in the secondary forest was lower than in all the management zones in oil palm plantations (both the EFB-applied and chemical-fertilised areas). This result is similar to a previous study by Römbke et al. (2006) in the Amazon region, where the feeding activity in primary and secondary forest was lower than in mixed-species tree plantations. The authors suggested that the higher feeding activity may be due to the correlation of higher abundance of soil mesofauna in the plantations (Römbke et al. 2006).

Since this study was conducted in an oil palm plantation and a nearby forest in central Sumatra, the interpretation of results is restricted to this area of the same climatic conditions and soil type. Replications of the experiments at different oil palm sites in Sumatra are to be conducted. In addition, further analyses are underway to investigate whether these possible factors as discussed above contribute to variable performances in soil fauna feeding activity under different soil management regimes in oil palm plantations.

Acknowledgments

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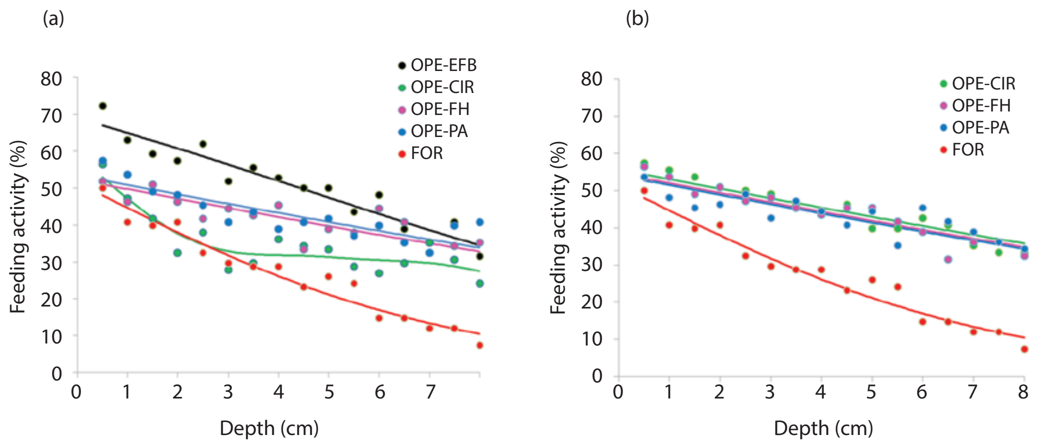

Figure 1. Variation (mean ± SE) of soil fauna feeding activity as a function of depth in EFB-applied area (a) and chemical-fertilised area (b). Note: OPE = EFB-applied oil palm area; OPC = chemical-fertilised oil palm area; FOR = forest; PA = harvesting path; CIR = fertiliser circle; FH = frond heaps

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Biogeochemical processes

Soil carbon and soil carbon dioxide respiration dynamics in oil palm

Iain Goodrick[1]

Abstract

Little is currently known about soil organic carbon (SOC) dynamics following conversion to oil palm and virtually nothing for conversion of grassland. We measured changes in SOC stocks following conversion of tropical grassland to oil palm plantations in Papua New Guinea using a chronosequence of plantations planted over a 25-year period and stable carbon isotope ratios of SOC. The grassland and oil palm soils had average SOC stocks of 10.7 and 12.0 kg/m^2, respectively, across all the study sites, to a depth of 1.5 m. In the 0–0.05 m depth interval, 0.79 kg/m^2 of SOC was gained from oil palm inputs over 25 years and approximately the same amount of the original grass-derived SOC was lost. For the whole soil profile (0–1.5 m), 3.4 kg/m^2 of SOC was gained from oil palm inputs with no significant losses of grass-derived SOC. The grass-derived SOC stocks were more resistant to decrease than SOC reported in other studies. Oil palm-derived SOC accumulated more slowly where soil nitrogen contents were high. Taking into account above- and below-ground carbon stocks, conversion of grassland to oil palm plantations in this region resulted in net sequestration of carbon. Soil-respired carbon dioxide (CO_2) was also investigated. Respiration was measured for a 25-year-old oil palm plantation on volcanic ash soil in Papua New Guinea using a method that accounted for spatial variability throughout the plantation. Seasonal and diurnal variation was investigated and the daytime soil respiration rate was calculated at 6.86 µmol CO_2/m^2/s.

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Soil acidification processes and indicators

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Abstract

Acidification of soil occurs in most environments, including unmodified natural environments. However, under agricultural conditions, the acidification rate is often increased because of nitrogen (N) fertiliser use and export of the agricultural product. This acidification can be mitigated with the use of liming materials but these are not often used under oil palm. Acidification due to N-fertiliser use is a result of one or both of two processes: conversion of ammonium to nitrate; and incomplete uptake (leaching) of the resultant nitrate. Some fertilisers (e.g. ammonium sulfate) are acidifying even if all resultant nitrate is taken up. Acidification due to product export is a result of the imbalance between the export of cations and anions. This cannot be avoided unless all the by-products of milling are returned to the oil palm blocks—which is impractical. Acidification of soil affects many processes that can be detrimental to growth of the current crop and may limit options for future crops. It also may cause irreversible damage to the soil. Acidification rates depend on the amount of acid being added (net acid addition rate; NAAR) and the ability of the soil to resist pH change (pH buffering capacity; pHBC). Some researchers have used the concept of 'time to critical pH' as an indicator of sustainability. However, such an approach assumes that pHBC is linear across the pH range of interest—which is mostly not true. We have chosen to use just the NAAR as an indicator as this reflects the effect of current practice and it is clear from the calculations what remedial actions can be taken depending on the soil condition.

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Influence of soil nitrogen fertilisers on soil acidification in Papua New Guinea

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Abstract

Soil acidification is a worldwide concern with many cropping systems where nitrogen (N) fertilisers are used. Inorganic N fertilisers are generally used to improve and maintain high yields, especially with oil palm; however, little is known about their effects on soil acidification in tree crops, especially oil palm cropping systems. This study looked at the effects of different N fertilisers on soil pH, and suggests strategies to sustainably grow oil palm in Papua New Guinea. Soil samples were collected in a grid design from a N-fertiliser trial that has been receiving five different N-fertiliser types for more than 8 years. The palms were receiving N at 0, 420, 840 and 1,680 g N/palm/year. Soil pH was measured for composite samples from all the plots and individual grid points for two of the plots that received the highest ammonium chloride rates. Soil pH was significantly ($p < 0.001$) influenced by N-fertiliser type and rate but the effects reduced with depth. Soil pH was reduced to the greatest extent by ammonium chloride at the highest rate, to depths greater than 90 cm, while urea had the least effect. At normal N rates, pH was reduced by 0.2–0.4 units. Soil pH was highly variable ($p < 0.001$) between points within the same plot, ranging from 3.86 to 6.87. Soil acidification at different grid points was a function of N-fertiliser placement. Alternating use of different N sources and application of empty fruit bunches are recommended to minimise acidification rates.

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Biological processes

Does the oil palm root system uniformly distribute in standard plantation?

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Abstract

Despite their importance for plant production, estimations of below-ground biomass and its distribution in the soil of an oil palm plantation are still difficult and time-consuming to make, and no single reliable methodology is available for different root types. Moreover, soil organic matter distribution may vary within a plantation depending on the management of pruned fronds and the distribution pattern of frond piles. In order to characterise root distribution within oil palm plantations, two sampling methods based on different soil sampling volumes were tested in Indonesia (Libo, Sumatra) and West Africa (Pobè, Benin): auger (8 cm in diameter), simplified Voronoi trench (2.7 m^3) and a full Voronoi trench (5.8 m^3), chosen as the reference method. Results indicated that the auger method underestimated root biomass estimation by 4% and 53% compared with the Voronoi method in 2- and 17-year-old plantations, respectively. The simplified Voronoi method is proposed to estimate root biomass in field conditions. Results also showed a significant ($p < 0.001$) positive correlation of root biomass and root length density to nutrient and soil organic matter content when we compared frond pile areas and frond-free pile inter-row. The impacts were significant for coarse and fine roots in Indonesia and for fine roots only in Benin. Moreover, these effects were observed mainly in the first 20 cm of soil and decreased thereafter with increasing soil depth and distance to frond piles. Recycling pruned leaves in the oil palm plantation promoted a significant development of roots and provided benefits to the oil palm for water and nutrient supply.

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Role of microbial communities in fertility of soil of perennial tropical plantations: potentialities for oil palm plantations

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Abstract

The perennial plantations of rubber trees (*Hevea brasilensis* Muell. Arg.), oil palm trees (*Elaeis guineensis*) and coffee trees (*Coffea* L.) are economically important in South-East Asia. Despite some initiatives promoting organic farming, mineral fertilisers are predominately used for growing these crops, with huge economic and environmental consequences. It is well known that for many agricultural and horticultural systems, a healthy soil microbial community leads to healthier plants and increased yields. That can be explained by the extensive interactions between plant roots and soil micro-organisms that further affect plant nutrition either directly by influencing mineral nutrient availability, or indirectly through root-growth promotion enhancing uptake efficiency. The increased understanding of the roles of root- or rhizosphere-associated microbes in plant nutrition and/or crop yields has resulted in their promotion for use in agricultural production as alternatives or supplements to mineral and/or organic fertilisers. However, little information is available concerning perennial plantations. Moreover, there is an obvious lack of promotion of beneficial soil micro-organisms to farmers, associated with a lack of market penetration of microbial inoculants for limiting the use of mineral fertilisers. Our presentation describes how the soil micro-organisms could efficiently be used for improving and sustaining the production of perennial plantations in South-East Asia. Several examples will be given to illustrate the way forward and an example of oil palm plantations will be emphasised.

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Impact of practices on the comprehensive fertility of soil under oil palm

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Abstract

The project had objectives to assess the integration of soil organic matter and soil biota (micro- and macrofauna) in comprehensive fertility of oil palm agroecosystems and to develop knowledge toward a comprehensive fertility diagnosis to manage organic and inorganic fertiliser applications in a synergistic way.

Spatial variability around the palm was studied in five locations: Path, Path-Circle, Circle, Circle-Windrow and Windrow. In each location, samples of litter and soil were taken at two depths (15 and 30 cm). Analyses were done on the physical and chemical traits, on macrofauna, nematodes and micro-organisms. In litter, results showed that total macrofauna were abundant in all zones. In soil, the application of empty fruit bunches (EFB) on the Path zone induced significant changes in the Path and Path-Circle zones, but also in the Circle and even in the Windrow. Macrofauna had a significantly higher density in the Circle and Windrow zones than other areas. Analyses of nematodes, bacteria and fungi confirmed these trends. The 15–30 cm horizon had very low soil biota densities.

Temporal variability after EFB application was studied under the Path at 1, 3, 6, 12, 18, 24 months after EFB application. The results clearly indicated three periods—during the first period of 6 months, soil chemical and faunal traits were strongly changed. The second period (12 to 18 months) looked like a period of relative stability. After 24 months, most of the comprehensive fertility traits increased.

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Effect of soil properties and nutrition on oil palm bud rot disease—a Colombian experience

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Abstract

Oil palm bud rot (OPBR) is the main disease that the oil palm industry has faced in tropical America. In Colombia during the last 10 years, there has been almost 70,000 hectares eradicated in the four regions that have been affected by the disease. The disease severity and recovery depend on the location conditions. Research conducted at Colombian plantations and research stations concentrated on the relationship between climate and soil conditions with the degree of susceptibility of the oil palm progenies to disease and their recovery process. Rainfall distribution and relative humidity were associated with disease incidence and severity. Poor drainage was the main factor related to the occurrence of OPBR. Generally, high clay content, soil compaction, low infiltration and low hydraulic conductivity rates were correlated with high incidence of the disease. Leaf manganese concentration (>250 to 1,200 mg/kg) is a good indicator of poor drainage conditions and high values were associated with high incidence of the disease. Soil acidity, as well as an imbalance of soil and leaf cations, was correlated with high progress of the disease. Among the agronomical practices in the eastern Colombian region that proved to be effective in reducing the incidence and increasing the recovery process of affected palms were drainage improvement, soil acidity alleviation, integrated nutrient management, reduction of soil compaction and mounding the planting row. In some regions (Tumaco and Puerto Wilches) where OPBR has become lethal, planting interspecific (O×G) hybrid is the most effective strategy to mitigate the impact of the disease.

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Modelling, monitoring and assessment

Understanding soil processes in oil palm plantations using an agricultural systems model

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Abstract

Many soil processes are related to cycles of water, carbon and nitrogen. Agricultural systems models are regularly employed to study such processes because of their ability to integrate and explore a range of environmental and crop management factors. However, no such model is currently available for oil palm production systems. We developed one within the Agricultural Production Systems Simulator (APSIM) framework and tested it using data from nitrogen (N) fertiliser trials across a range of environments within Papua New Guinea. The model captured key trends in canopy development, biomass production and yield of fresh fruit bunches due to plantation age, climate and N management. The model was used to estimate the effects of plantation age and N-fertiliser management on soil carbon and N-cycling processes at one site. Soil carbon increased during the immature phase and then remained constant (with high fertiliser rate) or declined (zero fertiliser) during the mature phase. During the immature phase, there were substantial leaching losses of nitrate, and gaseous emissions of nitrous oxide and N_2 from the soil, driven by the inputs of N from the previous oil palm crop residues and from N fixation by the leguminous cover crop. During the mature phase, N losses increased with increasing N-fertiliser rate. The model was shown to be a useful tool for exploring possible effects of environmental and management factors on soil processes. Simulations suggested that the immature phase is an important and understudied period for N losses and soil organic matter accumulation.

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Soil fertility, evolving concepts and assessments

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Abstract

Many authors have discussed the concept of soil fertility. Despite some disagreement on the exact terminology, soil fertility retrospectively appeared to focus generally on the use of soil for agriculture. It was defined some 150 years ago, while agricultural sciences mostly focused on soil physical and chemical properties. More recently, with the increasing awareness of environmental issues related to agricultural land use and the development of new knowledge on ecosystems, more comprehensive approaches to soil quality were developed. Since the 1980s, growing knowledge on the roles of soil organic matter and living organisms has emphasised the importance of understanding and assessing the biological components of the soil and their functions alongside the physical and chemical components. Soil is described as a living system that fulfils several functions, such as primary production, environmental filter and climate regulation. Following the metaphor of a complex living 'organism', the term 'soil health' is thus used by some authors instead of soil quality. Soil quality is hence defined as the soil fitness for use, which cannot be measured directly. It must be assessed in a sensitive and holistic way that accounts for both inherent properties and dynamic responses to management and resistance to environmental stress. Several sets of indicators and more integrated methods have been developed. However, further research is still needed to consolidate assessment guidelines that would help to model better the impact of agricultural practices on soil quality and to define strategies for a sustainable management of soil quality.

History of soil fertility and soil quality concepts

The scientific notion of soil fertility originated, around the 1850s, from the focus in agronomy on the use of soil to support production (Patzel et al. 2000) (*ferre* means 'to carry', 'to support' in Latin). It coincided with the beginning of the 'mineralist period' (1840s–1940s) that started with the first scientific demonstration of the origin of plant dry matter from mineral compounds, leading to the conclusion that carbon comes from carbon dioxide, hydrogen from water and other nutrients from solubilised salts in soil and water (Manlay et al. 2007). In this early stage of soil fertility conception, agricultural sciences hence mostly emphasised the role of physical and chemical properties of soil to support plant growth. From there on, soil fertility became a matter for both disciplines of agronomy and soil sciences. The mainstream approach considered soil fertility as dependent on some inherent qualities resulting from the expression of soil-forming factors. This approach led to work on soil classification and survey tables, where a land capability concept overlapped with a soil fertility one.

The concept of soil fertility has been chronically debated as background knowledge and social and political contexts evolved. Its circumscription varies widely, from literature where actual yield or productivity is identical with or fully representative of soil fertility, to literature introducing more or less complex definitions based on the combinations of several factors including soil properties, climate, work and

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social or cultural parameters (Patzel et al. 2000). Until the 1980s, there was no clear chronological evolution of the concept. The various interpretations co-existed. For instance, one of the earliest definitions stated that 'soil fertility is a product of soil and manpower' (von Wulffen 1847). This focus on work or cultivation can be found again in later definitions (e.g. Blohm 1964). Further definitions have run through the times concomitantly. In their analytical review, the authors concluded that the concept of soil fertility cannot be grasped in one single technical definition. First, it refers to a disposition which is never present at hand. Second, it cannot escape the trade-off relationship between distinctness and completeness due to the plurality of significant aspects transgressing the realm of natural sciences (Patzel et al. 2000).

At the end of the 'mineralist period', concomitant increasing scientific knowledge of soils and rising concern about the environmental impact of inadequate agricultural practices, notably erosion impact, led to a renewed interest in the study of soil organic matter (SOM) (Lewandowski et al. 1999; Manlay et al. 2007). This period marked a turning point in the analysis of soil with a widening of the perception beyond the plant nutrition theories to further ecosystem functions. But it was not until the concerns about the economic and ecological costs of the intensive use of synthetic fertilisers had become more severe following the green revolution, that the soil fertility focus on nutrient storage and productivity was abandoned for a wider vision of soil as a complex living organo-mineral system (Manlay et al. 2007). A political change towards sustainable agriculture was called for (WCED 1987).

In the 1980s, North American authors started to discuss and define a new concept—soil quality—accounting for the multiple dimensions (physical, chemical and biological) and functions of soil (Warkentin and Fletcher 1977 (the authors who introduced the term 'soil quality'); Doran and Parkin 1994; Patzel et al. 2000; Karlen et al. 2003). The first definitions of soil quality were close to those of sustainable agriculture. In essence, preserving or improving soil quality is about maintaining the long-term functions of soils, i.e. it is about sustainability (Doran et al. 1996). The current most common definition is: 'Soil quality is the fitness of a specific kind of soil to function within its surroundings, support plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation' (Karlen et al. 1997). Emphasis is put on both inherent properties of soil ('a specific kind of soil') and dynamic interactive processes (Larson and Pierce 1991). Nowadays, some authors still argue that soil fertility and soil quality may be interchangeable, and the terminology remains relative to the discipline or the application sector. Soil health may be also used instead of soil quality by some authors who want to insist on the metaphoric holistic approach of soil as a living organism (Idowu et al. 2007). Setting aside some ideological considerations linked to the terminology, authors tend to agree that '(1) soils have both inherent and dynamic properties and processes, and that (2) soil quality assessment must reflect biological, chemical, and physical properties, processes and their interactions' (Karlen et al. 2003).

The comprehensive approach

Soil conditions are defined by physical, chemical and biological properties. All these proprieties depend on land-use practices but also inherent soil properties (texture, type of clay, cation exchange capacity). These properties are not independent but linked with complex interactions, and affect soil processes and functions (Larson and Pierce 1991). Physical properties are an important aspect of soil quality; for example, soil storage capacity of plant-available water, bulk density and water infiltration (Grimaldi et al. 2002; Moebius et al. 2007). Chemical properties, such as content of phosphorus and nitrogen and ions of calcium, magnesium and potassium, are essential for plant nutrition and thus contribute to productivity. Soil organic matter is also essential and linked to several soil properties and functions. For example, its composition affects soil structure and porosity, water infiltration, moisture, plant nutrient availability and soil organisms (Bot and Benites 2005). In summary, soil organic matter influences almost all important properties that contribute to soil quality (Bot and Benites 2005).

Another important aspect is living organisms (a component of soil organic matter). Soil organisms can be divided into four metric categories: microorganisms (<100 µm), mesofauna (100 µm – 2 mm), macrofauna (2 mm – 20 mm) and megafauna (>20 mm) (Swift et al. 1979). These organisms contribute to several soil functions: decomposition, nutrient cycling etc. (Lavelle 1997; Lavelle et al. 1994, 2006). Soil organisms can also be divided into functional categories: detritivores, predators/grazers, decomposers, pathogens, herbivores and ecosystem engineers (*sensu* Jones et al. 1994), i.e. organisms that create or significantly modify habitats).

Interactions between chemical, physical and biological properties are strong and complex. Soil organism communities are influenced by soil properties acting like an environmental filter but soil fauna can also impact soil properties—physical or chemical. For example, bioturbation of ecosystem engineers in soil can impact macroporosity and, as a consequence, water infiltration. By the fragmentation and decomposition of litter, soil organisms also affect chemical properties, such as plant-available nitrogen. Earthworms can also help to reduce plant diseases. For example, it has been shown than earthworms improve resistance of rice against pathogen nematodes (Blouin et al. 2005), although the mechanisms remain unclear. For all these reasons, soil organisms are often considered as good indicators of soil quality/fertility, as part of an integrative and holistic approach. Some approaches consider empirically that higher values are better considering biomass, abundance or diversity of soil organisms. Other approaches try to identify organisms or traits responsible for precise functions and try to quantify them.

The different approaches developed to assess soil quality using soil organisms are thus based on quantity, structure or function (Table 1): total biomass of soil micro-organisms (bacteria and fungi) can be evaluated with the classical method of fumigation-extraction (Wu et al. 1990) or, more recently, quantitative polymerase chain reaction (qPCR) (El Azhari et al. 2008). Soil enzymes, produced by micro-organisms, are also good indicators to assess soil quality through soil biochemical functioning (Dick et al. 1997; Alkorta et al. 2003). This approach allows evaluating functions of interest. Molecular methods, like PCR denaturing gradient gel electrophoresis (PCR-DGGE) or phospholipid fatty acid (PLFA) profiling (Bloem et al. 2006) assess soil micro-organism diversity. Nematodes are also used as bio-indicators for soil quality (Neher 2001; Yeates 2003) and indicators using micro-arthropods (e.g. Collembola, Acari) have also been developed (Parisi et al. 2005). Earthworms (biomass, abundance, diversity and proportion of ecological categories—epigeics, anecics, endogeics) are also classically used to assess soil quality (Paoletti 1999; Peres et al. 2008).

Assessment of soil quality

Since it is a broad, integrative and context-dependent concept, soil quality cannot be measured directly. Instead several proxy measurements, called soil quality indicators, may together provide clues about how the soil is functioning as viewed from one or more soil-use perspectives. There exist various methods based on more or less numerous and integrated indicators (Figure 1), and not much international agreement on a proper harmonised framework (Nortcliff 2002). Nowadays, the most prevalent research theme on soil quality focuses on indicator selection and evaluation (Karlen et al. 2003).

The lack of success in quantifying soil quality through minimum data sets and indexes has highlighted the local and long-term nature of trends in soil quality (Lewandowski et al. 1999). Given some inherent specific properties of each soil and the multiple functions that may be investigated, there cannot be a unique turnkey assessment, or a rating system against which all soils can be compared (Karlen et al. 2003). The selection of appropriate indicators must aim to account for (i) site specificities in terms of both soil type and land-use objectives, and (ii) the dynamic nature of processes and temporal

Table 1. Biological indicators of soil quality: fauna classification and information level

Information level	Micro-flora/fauna	Meso-fauna	Macro/mega-fauna
Quantity (biomass/abundance)	Extraction Fumigation-extraction qPCR	Extraction	TSBF, formalin extraction, mustard extraction
Structure/diversity	PCR-DGGE, PLFA profiling	Richness Biodiversity index	Richness Biodiversity index
Activity/function	Enzyme activities Microrespiration	Functional traits Ecological categories	Functional traits Ecological categories

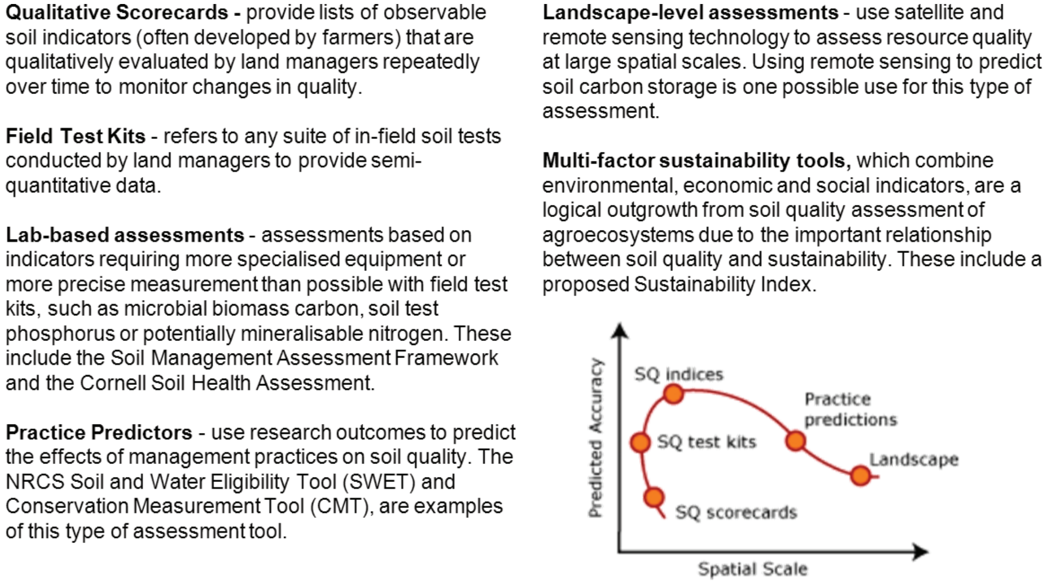

Figure 1. Types of soil quality (SQ) assessment tools and their predicted accuracy. Resource webpage: http://soilquality.org (accessed 30 January 2014)

patterns of soil characteristics. Therefore, proposed indicators must be measured and assessed across a representative set of lands and management practices. As emphasised by Karlen et al. (2003), site-specific expertise may also be needed in order to weight various indicators into an aggregated index (Figure 2). An efficient indicator set should be used to inform land management decisions at specific sites and then be used to monitor trends in soil function after changing practices and over time.

Implementing useful and efficient indicators of soil quality requires robust scientific background combined with reliable practical sense to define consistent and informative indicators. In particular, difficulties arise when assessing interactions between processes and parameters. It is paramount to avoid overlapping indicators and unreliable measurements (Moebius-Clune et al. 2011). More research is needed to better understand and model the links between management – processes – soil quality.

Conclusion and research tracks

Soil quality is itself a field of active research to find fruitful approaches and reliable indicators. For example, new approaches were proposed in soil microbiology, such as taking into account functional ecology concepts, i.e. vigour, organisation, stability, suppressiveness and redundancy (Garbisu et al. 2011), or organisms rarely used, e.g. testate amoebae or diatoms (Heger et al. 2012), which are good bio-indicators (Payne 2013) and sensitive to farming practices (Heger et al. 2012). Functional traits of soil macro-invertebrates are also increasingly used (Yan et al. 2012). Another promising approach is the integration of farmers' knowledge (Barrios et al. 2006; Pauli et al. 2012; Rousseau et al. 2013), including to find indicating species. Finally, modelling can provide interesting perspectives (Torbert et al. 2008; Xue et al. 2010), especially to account for the temporal frame of dynamic processes and their evolution.

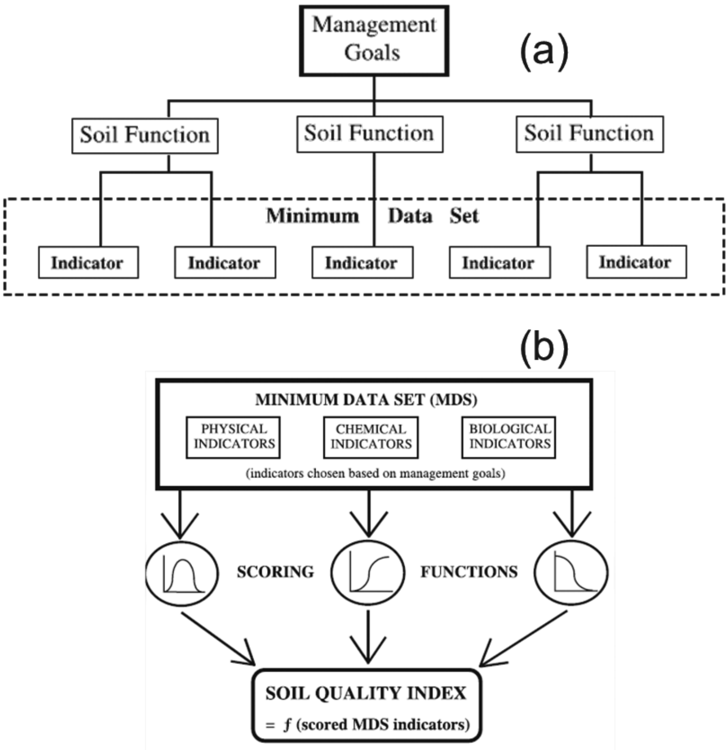

Figure 2. Processes to select and weight soil quality (SQ) indicators, according to functions and management goals (a) and using site-specific expertise to weight scores (b). Adapted from Karlen et al. (2003)

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Quantifying trends in soil fertility under oil palm: practical challenges and approaches

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Abstract

Monitoring of trends in soil fertility in space and time relies on sampling techniques that adequately represent soils in the field. Representative sampling in oil palm plantations is challenging due to high spatial and temporal variability. Currently used soil-sampling techniques, such as taking samples from the weeded circle and frond pile, have several deficiencies, both for the purposes of research and monitoring by managers. Here, we present (a) a practical method for obtaining representative composite soil samples, and (b) an approach for monitoring likely trends in two important soil fertility parameters—acidity and organic matter content—without the need for sampling the soil. The soil-sampling method involves taking many samples along a linear transect that crosses four or six rows and combining them into one sample. It accounts for tree-scale variability and enables monitoring across crop cycles. We suggest such sampling be carried out every 5–10 years along the same transect (slightly offset) by plantation managers. The approach for monitoring likely trends in soil acidity and organic matter content estimates the principal drivers of changes in these parameters: 'net acid addition rate' and organic matter addition rate. It uses data routinely collected by plantation managers, and a crop system model. We suggest such estimates could be carried out annually by plantation managers, enabling them to predict trends in soil fertility and likely effects of existing or proposed management practices.

Introduction

To assess the sustainability of oil palm cultivation, it is important to monitor trends in soil fertility over time. However, such monitoring is challenging because it is difficult to obtain representative samples in an efficient manner over useful spatial and temporal scales. In particular, substantial variability at the scale of individual palms, induced by plant characteristics and management practices, must be taken into account, in addition to field- and landscape-scale variability (Nelson et al. 2014). The most common method scientists and plantation managers use to do this is to take samples from the visible management zones; for example, in the weeded circle and under the frond pile (Rankine and Fairhurst 1998). Samples may also be taken at a particular point in relation to the palm; for example, in the inter-row, halfway between palms. As long as the sampling points remain consistent with respect to palm and management zone, those methods can be used to compare different areas or to monitor changes over time, within a plantation cycle. However, they have several disadvantages. Firstly, samples taken in any particular management zone do not tell us anything about processes in other zones, which may be important for productivity of the palm and fertility of the soil. For example, taking samples from the weeded circle and frond pile does not give any information

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about soil properties in the 'between zones' area, which comprises most of the plantation area and which is commonly the zone where fertilisers are placed. Secondly, soil properties might be expected to vary within each zone, so the position within each zone is important but is rarely documented. In cases where quantities per hectare (ha) are being calculated, all zones must be sampled representatively and their relative areas measured, neither of which are straightforward. Finally, sampling by visible zones is not suitable for monitoring changes that span more than one crop cycle, as the position of palms and zones changes, so results from one crop cycle cannot be compared with results from the previous cycle. To assess sustainability, monitoring of soil properties should be carried out over more than one crop cycle.

In view of these difficulties for monitoring soil properties in oil palm plantations over time, we devised two techniques for improving monitoring programs. The first technique is a method for obtaining composite soil samples that takes into account tree-scale variability over one or more crop cycles by repeated sampling along the same transect (slightly offset) to reduce error caused by field-scale variability (McKenzie et al. 2002). The second is a monitoring approach that does not require any soil analyses but, rather, quantifies the drivers influencing important soil properties using data routinely collected by plantation managers. We propose that the two techniques be used in combination to give timely and accurate assessments of soil fertility trends.

Methods

Obtaining a representative composite soil sample

We started with the premise that a sampling design will be most feasible and simple if sampling can be carried out by no more than two people and does not require them to make any calculations. To meet that specification, we assessed linear transects that started at one palm stem and ended at another palm stem, visible from the first (Figure 1). We assessed the ability of various transect lengths and orientations to adequately cover the systematic management-induced variations in soil properties that occur in oil palm plantations. The ability of the transects to sample known radial and patch (management-induced) patterns of variability in a representative manner was assessed by comparing the proportion of transect length traversing each radial or management zone to the areal proportions of those zones. The management zones considered were the area under the stem, the weeded circle, harvest path, frond pile, and the remaining area, which were assumed, for the purpose of assessment, to comprise 0.006, 0.140, 0.116, 0.116 and 0.623 of the plantation area, respectively, based on a trunk radius of 0.04*s*, weeded circle radius of 0.2*s* and frond pile and harvest path widths of 0.2*s*, where *s* is the spacing between palms planted in an equilateral triangular arrangement. Palm spacing, *s*, is normally between 8.50 m (160 palms/ha) and 10.25 m (110 palms/ha); commonly 9.0 m (143 palms/ha). Harvest paths are generally around 1.8 m wide where machinery is used for collecting fruit and spreading fertilisers, or around 0.4 m wide where machinery is not used. Radial position was divided into five zones, 0–0.125*s*, 0.125–0.25*s*, 0.25–0.375*s*, 0.375–0.5*s* and >0.5*s*, which comprise 0.057, 0.170, 0.283, 0.397 and 0.093 of the plantation area, respectively.

Monitoring trends in soil fertility without soil sampling and analysis

Soil fertility is a function of physical, chemical and biological factors and the complex interactions between them. However, extensive research indicates that soil pH and organic matter content are key parameters and are sensitive to management. We therefore devised means of calculating indicators of likely trends in these two parameters. To do so, we identified: (a) the main processes causing changes in the parameter (from the literature); (b) the data routinely collected by plantation managers that are relevant to those processes; and (c) additional data that may be necessary. For the calculations, we developed an oil palm module for the crop system modelling framework Agricultural Production Systems Simulator (APSIM). The model uses widely tested submodels for cycling of water, carbon and nitrogen and closely estimates palm growth and yield (Huth et al. 2014).

Results and Discussion

Obtaining a representative composite soil sample

Six transects satisfied the criteria for practical sampling (Figure 1). The longer the transect, the better the coverage of the palm unit. Longer transects in similar orientation (between the same two rows of palms) are possible, but it becomes difficult to visually identify the end palm, so we did not consider them further. Assuming that samples are taken at very small increments along the transect, the six-row transects provide the most representative coverage of the management-induced and radial zones (Figure 2). The four-row transects also provide reasonable coverage of the zones, especially the >60° transect for radial zones and the <60° transect for management zones. The two-row transects gave the least representative coverage of the zones. Assuming the six-row transect is used, 20–50 evenly spaced sampling points provide reasonably representative coverage of the radial and management zones (Figure 3). With 10 sampling points, some of the zones are missed entirely. To obtain a representative composite soil sample from agricultural fields for all soil tests, 40–60 cores are needed (Brown 1999) so we recommend 50 sampling points along the transect. Soil from each point should be combined into one composite sample for the transect. Alternatively, at each sampling point, the management zone could be noted and a separate composite could be made for each zone. However, this approach has the disadvantage that it will be difficult to interpret changes in soil properties when the size of the zones changes, particularly from one crop cycle to the next. It also requires more work and results in more samples to be analysed. The number of transects that should be sampled per field or management unit depends on field-scale variability and on the degree of precision desired.

Depth of sampling should also be considered carefully and should be consistent between samplers and over time. Sampling depths vary between plantation companies, but the 0–20 and 20–40 cm increments

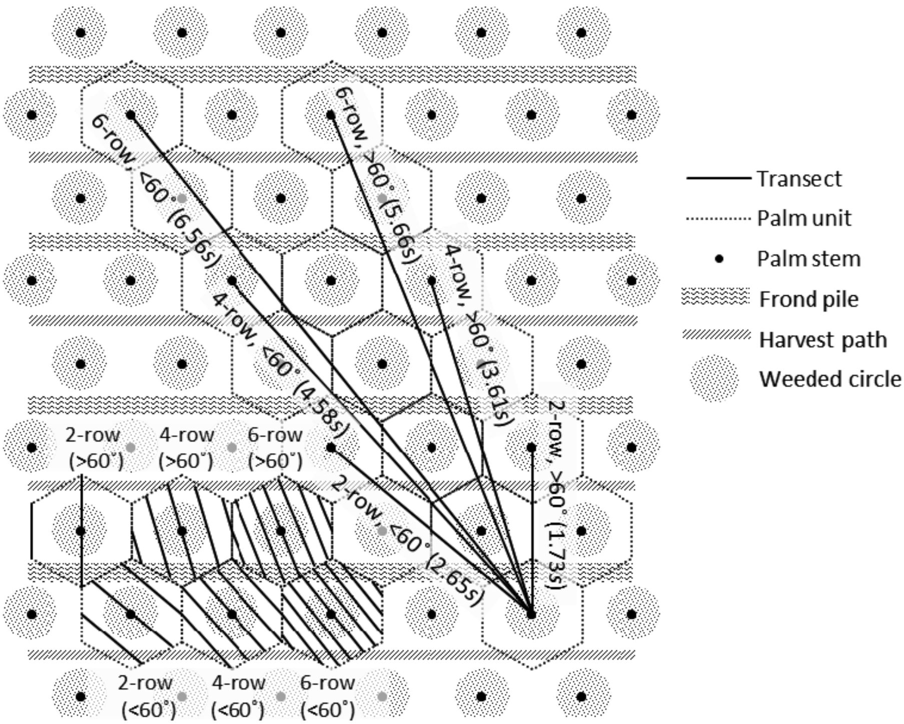

Figure 1. Section of an oil palm plantation, showing palms, management zones and orientation of six sampling transects, with their lengths in brackets (where s = palm spacing). Also shown are palm units traversed by the transects and (in lower left part of figure) the equivalent coverage of one palm unit by each transect.

recommended by Rankine and Fairhurst (1998) are suitable. Identification of the 'soil surface' (depth zero) is important, especially in the frond pile, where there is no clear break between litter and soil. It could be taken as the depth where roots are encountered, but this may be quite high in the frond pile and may change seasonally with wetness. We suggest choosing the depth at which fragments of fronds greater than 1 cm in size are no longer encountered.

Monitoring trends in soil fertility without soil sampling and analysis

Fertility of soils in the humid tropics tends to decline over time due to acidification, which is accelerated by agricultural practices. The rate of pH decline depends on the net acid addition rate (NAAR) and the pH buffering capacity of the soil. The NAAR depends on many processes, but the most important ones are the cycling and input–output balance of nitrogen and cations. Thus, for oil palm systems, the NAAR due to management is a function of: (nitrification and nitrate leaching) + (removal of cations in fresh fruit bunches) + sequestration of cations in additional biomass) – (application of mill by-products and liming agents) – (release of cations from decomposing residues) – (uptake of nitrate from nitrate-containing fertilisers) (Webb et al. 2015, these proceedings). These quantities may be calculated for management units on an annual basis using routine records of harvest, fertiliser application and weather, APSIM Oil Palm (parameterised for the management unit), and an estimate of legume cover crop stand (which is not currently a routine procedure). The value could then be compared between management units and years, relative to reference values (Figure 4).

Changes in soil organic matter content depend on inputs and outputs. Inputs are primarily plant residues and outputs are mostly due to mineralization to carbon dioxide. Inputs are the primary factor

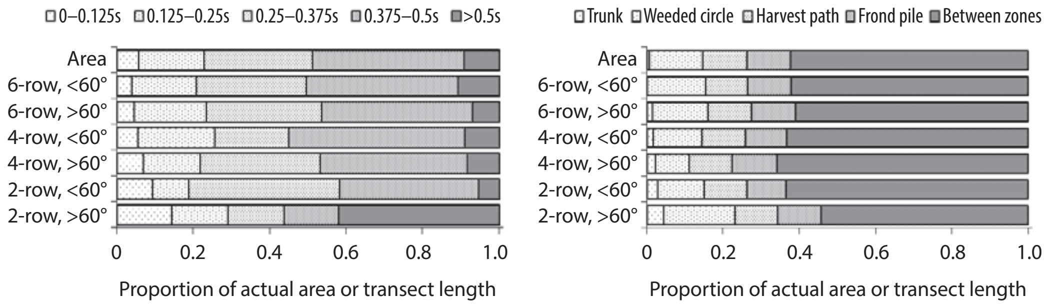

Figure 2. Proportion of the plantation area (top bar) and transect length in five radial zones (left) and five management zones (right), for six transects (see Figure 1 for length and orientation of transects)

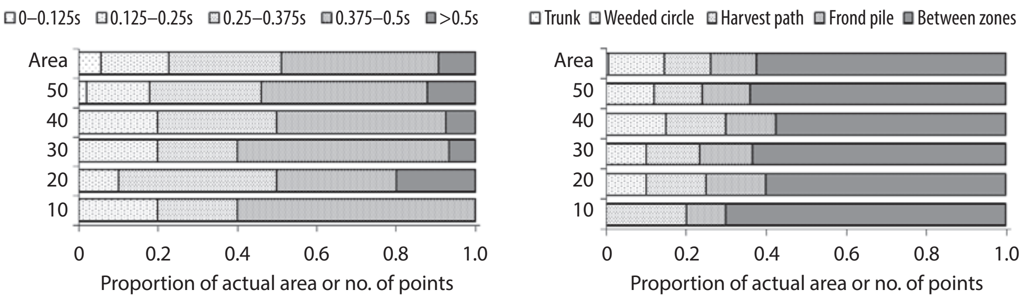

Figure 3. Proportion of the plantation area (top bar) and sampling points in five radial zones (left) and five management zones (right), for five sampling point densities (six-row, <60° transect, Figure 1)

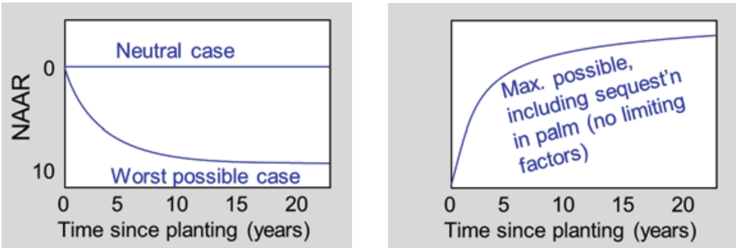

Figure 4. Hypothetical reference values for net acid addition rate (NAAR, arbaitrary units) (left) and organic matter (OM) inputs (right) over a crop cycle

and are more sensitive to management than outputs (Baldock and Nelson 2000). Input is a function of (pruned fronds) + (root death) + (cover crop leaf drop and root death) + (application of mill byproducts) + (felled palms, once per crop cycle) – (removal in fresh fruit bunches). These quantities may be calculated using the same data and similar techniques to those used for calculating NAAR.

Conclusions

We suggest a hybrid approach to long-term monitoring of soil fertility in oil palm plantations, comprising thorough soil sampling and analysis every 5–10 years, and annual evaluation of the main processes involved. Representative soil samples may be obtained using the transect method described here, with multiple transects being sampled in each management unit. The number of transects should be decided according to size and variability of the management unit, and transect locations should remain the same over time. Annual evaluation of the processes involved may be done using routinely collected data and a crop system model calibrated for the management unit in question. Those evaluations will enable trends to be predicted and relative effects of different management practices on the trend to be determined. The suggested approaches are based on well-understood principles and appear feasible. However, they are yet to be tested against actual trends in soil fertility.

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Synthesis and discussion

Introduction

Sustainable management of soil in oil palm plantings is becoming more important as the industry expands and intensifies. Recent soil-related research in the industry has broadened in focus to include the roles of soil other than supporting plant growth. This research effort is mainly motivated by the need to comply with the principles and criteria of the Roundtable on Sustainable Palm Oil (RSPO 2013) and general public awareness of agricultural environmental impacts, such as impacts on water quality or greenhouse gas emissions. However, this research has not yet developed into on-ground activities. The latest reviews on the subject by Chan (2000), Corley and Tinker (2003) and Fairhurst and Härdter (2003) may be outdated, given recent private and public research results. Therefore, a synthesis paper with a provisional title of 'Soil functions in oil palm plantations: challenges and principles for sustainability' was proposed to crystallise and make the best use of the knowledge revealed during the workshop.

The effects of management practices on soil properties and processes were discussed in reaction to oral presentations as well as during a working group session. Workshop participants broke into small groups and discussed the topics below with a focus on the effects of management practice on the atmosphere-, biosphere-, hydrosphere- and lithosphere-related functions of soil. Those discussions are summarised below.

In general discussion, it was noted that none of the papers mentioned micronutrients. However, micronutrient supply from the soil is likely to become limiting as oil palm systems age and so should be investigated further.

Effects of plantation establishment

Plantation establishment has a tremendous impact on soil condition. Impact mechanisms are linked to changes in soil condition due to the changes in the vegetation cover (or land use more generally) and to the operations themselves.

Changes in land use influence soil condition in all dimensions, from a component point of view as well as spatial and temporal variability point of view. The changing of land use, no matter what it was, implies changes in previous equilibrium of soil physical, chemical and biological properties. A radical land-use change will result in a severe change in soil condition; the more radical the land-use change, the more severe the soil condition change. Soil condition may be affected differently on the surface, at depth, and in short or longer terms. The changes will be the dynamic result of complex interactions at the interface between soil and atmosphere (notably due to the transition period when the soil may remain bare for some time), and within the soil (notably due to changes in soil porosity, soil moisture, soil biology etc.). In the case of re-planting (oil palm after oil palm), the impact of land use may be less severe, since it consists of a provisional change where transitory changes essentially correspond to differences in soil condition during immature and mature stages of the oil palm stand.

Finally, planting and re-planting operations also lead to direct impacts. The use of machines (compaction), trunk felling and chipping, digging the hole for planting, dealing with potential pests (e.g. *Ganoderma*), crop cover etc. will directly impact soil condition. These operations also create heterogeneity across the field, which will reinforce the variability of previously mentioned impacts.

Effects of harvesting and export

Harvesting and exporting fresh fruit bunches (FFB) from a plantation or smallholder block to the mill represents a movement of nutrients and organic matter from that block. How the block is managed will determine the consequence of this movement of nutrients and organic matter on soil quality (such as pH, fertility etc.).

In the process of harvesting FFB, lower fronds (and male flowers) must be pruned. These represent an addition of mineral nutrients and organic matter to the soil surface near the palm. However, excessive harvesting (unripe bunches) leads to excessive pruning. This can reduce the leaf area index such that there is less carbohydrate produced, resulting in low yield and possible stress on the palm. Because more light reaches the ground, the soil microclimate might change; for example, an increase in soil temperature.

The processing of FFB creates a number of by-products that may affect the environment in different ways. Among the by-products are empty fruit bunches (EFB), palm oil mill effluent (POME), expeller cake and ash. If palm kernel oil (PKO) is generated as well as crude palm oil (CPO), the loss of mineral nutrients in the oil exported from the mill is minimal—however, nutrients have been redistributed in the area served by that mill. If expeller cake is sold or palm kernels exported to be processed elsewhere, this represents a loss of mineral nutrients and organic matter from the area served by the mill.

EFB, POME, expeller cake and ash are potentially available for use on oil palm blocks. However, use of by-products usually only occurs in blocks in the vicinity of the mill and rarely are they used on smallholder blocks. Thus, this represents a relocation of nutrients from smallholder blocks and distant plantation blocks to those blocks close to the mill.

There are also negative effects of harvesting on the soil. As already mentioned, nutrients and organic matter are relocated within the mill catchment which means some areas lose nutrients because of FFB export.

Not all mill by-products are returned to the field. POME is sometimes put into settling ponds to reduce the biological oxygen demand (BOD) before being discharged in nearby rivers under strict guidelines. However, sometimes heavy rainfall results in settling ponds being breached and POME with high BOD entering waterways. POME settling ponds also produce methane which affects the atmosphere. However, in some cases, this methane is being captured and used to provide energy to the mill. Alternatively, the (excess) methane is burnt, thus reducing its effect as a greenhouse gas (GHG), as carbon dioxide has a lesser effect as a GHG than methane.

Traffic along the harvest path, especially with mechanisation, can cause compaction of the soil surface. This compaction will reduce infiltration and therefore increase run-off, reduce groundcover and thus soil protection, and reduce soil oxygen levels. Compaction is also caused by other mechanised field operations and is not limited to harvest operations.

Effects of application of fertilisers and other amendments

The main nutrient amendments are mineral fertilisers and the mill by-products. Mineral fertilisers are commercial chemical fertilisers, usually supplied as a single chemical compound. Some of the more commonly used mineral fertilisers are: urea, ammonium nitrate, ammonium chloride, ammonium sulfate, potassium chloride (muriate of potash), magnesium sulfate (kieserite), mono-ammonium phosphate, di-ammonium phosphate, single- and triple- superphosphate, and elemental sulfur. The most commonly used mill by-products are EFB and POME; although sometimes expeller cake and bunch ash maybe used. Mill by-products may also be composted prior to application and other amendments such as lime and charcoal may also be applied.

Timing of fertiliser application and placement of fertiliser in relation to the palm of is not always based on the most efficient use of fertiliser. Timing may be driven more by the arrival date of fertilisers and the lack of storage facilities than by palm physiology, productivity cycles or weather patterns. Similarly, placement in relation to the palm may be driven by management requirements (e.g. to check that fertiliser has actually been applied; hence the weeded circle, where it can easily be seen) rather than by the best position for efficient uptake by the palm.

While there is generally good understanding of optimal management of mineral fertilisers for soil fertility and palm nutrition, there is inadequate knowledge about how to optimise combinations of mineral fertilisers and mill by-products. In addition, it may be desirable to change the way plant diagnosis of nutrient imbalances is carried out when nutrients are primarily applied in mill by-products rather than mineral fertilisers.

Application of amendments has direct effects on soil physical, chemical and biological properties and processes, which then interact in many ways. The mineralisation rates of EFB and other organic amendments have important effects on the soil and palms. Of particular note is the effect on soil fauna, micro-organisms (mycorrhizae in particular) and roots. Root growth, turnover (and thus addition of organic matter to the soil) and specific root length are influenced by amendments, as well as wetness and root production rate, and depth within the profile. In addition, organic by-products can have other beneficial effects on soil properties, such as increasing soil nutrients, increasing pH, improving soil structure, increasing water infiltration, reducing the fixation of phosphorus and potassium in some soils, and increasing cation exchange capacity (CEC).

Application of mill by-products may also be detrimental to the soil. A lot of water is used in the processing of FFB and this results in the generation of POME. POME has many undesirable characteristics. Depending on how it is processed, it has differing environmental effects. If it is spread on palm blocks, it is usually spread on those close to the mill. Because of its high BOD, this can cause a decline in soil oxygen (if regulations are not followed) and, as it contains oils, it can cause soil surface sealing and thus waterlogging.

Through their effect on soil processes, which vary depending on the soil type and its intrinsic properties, application of amendments influences not only plant growth, but also the emission of GHSs, quality of water and erosion/production of sediment. All these processes and interactions are also influenced spatially and temporally. Less is known about peats than mineral soils. Accounting for this variability is important to assess process dynamics and hence to improve soil monitoring. Spatial variability changes through the crop cycle and must be analysed over time. Temporal variability occurs due to both the stage of the crop cycle and seasonal cycles.

Effects of weed and pest control

Weed and pest controls may affect the soil quality in several ways. First, the use of chemicals applied on plants or the soils may directly contaminate the soils due to their contents of active substances and heavy metals. Knowledge on the chemical risks associated with weed and pest control chemicals is incomplete: How toxic are the molecules? How long do they stay in the soil? What about the derived substances from decomposition of the active substance; are they also dangerous? As with fertiliser applications, the spatial and temporal distribution of the application of these chemicals may play an important role in influencing the final efficiency of the treatments and the associated risks in terms of leakage, interactions, resilience etc. In terms of weed control, common best practices consist of selective spatial applications around the palm circle and in the harvest pathway, often applied manually. Applications are done regularly over the cycle in a systematic way but variable applications depending on the actual weed development may lead to some reduction in total applied products. Moreover, selective applications may limit the trade-off between weed control and flora biodiversity in the plantations. There are also other practices, including more or less intensive blanket application, done manually or mechanically. In all cases, the spatial and temporal variability will affect both the treatment efficiency and the impact on soil quality. Moreover, it is crucial to account for the temporal dimension due to the evolution of the chemical substances (fate and exposure) leading to potential impacts varying in time.

Besides the direct impact of the chemical substance, indirect impacts are linked to the physical and biological influences of these substances or mechanical operations necessary for their application. The first influence is related to the physical properties of the soil. The soil cover, erosion and run-off risks will be affected by the destruction of the weed cover by the treatments. Moreover, some substances may react with soil and influence aggregate stability and other properties. Finally, the chemicals are also likely to affect soil biology. The soil fauna may be directly affected by the chemicals or indirectly through the destruction of habitats. There is still a lack of knowledge on the overall integrated impacts on the soil biota and fauna, the soil organic matter and the links with soil functions. Some research direction that pursues the goal of developing soil bio-indicators that would account for all these phenomena is required.

Future collaborative possibilities

A number of possible projects for collaboration were discussed:

1. Drainage and water management
2. How to get representative measures of the root system
3. Soil organic carbon—what should be the target for carbon (C) sequestration in each soil type?
4. What is the soil microbial community? What is its functional role?

5. Enhancing APSIM with new modules covering C dynamics and GHGs. Will need to set up a way for data exchange to get calibration data
6. Indicators of soil quality and how that will impact on management strategies
7. A methodology for efficient and representative soil sampling.

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