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prepared by	William Erskine and Rob Williams (University of Western Australia), and Tony Page (University of Sunshine Coast)
co-authors/ contributors/ collaborators	With MAF and UNTL colleagues
approved by	Eric Huttner (CIM) and James Quilty (SLM)
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1 Acknowledgments

AI-Com project ran from Oct 24, 2016, to Dec 31, 2022.

The Governments of Timor-Leste and Australia collaboratively funded AI-Com with Australian funding through the Australian Centre for International Agricultural Research (ACIAR). The Centre for Plant Genetics and Breeding (PGB) of The University of Western Australia (UWA) implemented the project. The University of the Sunshine Coast (USC) led the research on sandalwood and forage tree legumes (FTL). The assistance of all partners is gratefully acknowledged.

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Finally, it must be acknowledged that the success of the program is directly attributed to the dedication and hard work of the in-country AI-Com Team led by Rob Williams, including Luis Almeida, Detaviana Madalena Guterres Freitas, Joaquina Barreto and Carla De Silva, and the many Timorese staff, from national coordinators, and local research, and various program support staff. The MAF and non-MAF staff were based in Dili and in the municipalities. MAF and UNTL in turn received valuable guidance from the farming community.

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Abbreviations

CDU	Charles Darwin University
CIAT	International Center for Tropical Agriculture
CMV	Cucumber mosaic virus
ETA	Escola Teknik Agrikultura
FGD	Focus Group Discission
FTL	Forage Tree Legume
HH	Household
HW	Heartwood

ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IITA	International Institute for Tropical Agriculture
MAF	Ministry of Agriculture and Fisheries
MTR	Mid-Term Review
NRM	Natural Resources Management
ODK	Open Data Kit (software)
SoL	Seeds of Life
TL	Timor-Leste
USC	University of the Sunshine Coast
UNTL	Universidade Nacional Timor Lorosa'e
UWA	University of Western Australia
WV	World Vision
$	US $

2 Executive summary

The Government of Timor-Leste is focusing on improved nutrition and rural income – a shift from its former emphasis on food security. Thanks to oil revenue, there is a trend toward urbanisation in the country creating new markets for agricultural products, and hence opportunities for local farmers to fill new demands. Concurrently, improvements in infrastructure (roads and electrification - including opening new opportunities to access water) allow consideration of diversifying agricultural production.

The AI-Com project, which ran from October 2016 to Dec 2022, addressed two broad avenues of research: Firstly, cropping intensification to produce legumes and grain for an emerging stock and food processing industry and secondly the production of selected non-timber tree products (fodder from tree legumes and their companion sandalwood) to diversify farm incomes. We also researched the social context upon which the uptake of such innovations depends.

The project was implemented by The University of Western Australia (UWA) with the University of the Sunshine Coast as the key Australian partner on agroforestry. In-country the Ministry of Agriculture and Fisheries (MAF) and the National University of Timor Lorosae (UNTL) were the major research partners. The NGO World Vision played a development role in the project.

Soil and plant nutrition was a thrust of the project, which identified in a fertiliser survey that, while fertiliser use (organic and inorganic) for cropping is low overall in Timor-Leste, barriers to increased use are surmountable. The residual impact of inorganic fertiliser to rice was found neutral or positive, NOT Negative.

Rice-husk biochar almost universally increased crop yields in Timorese soils. Biochar can be combined with chemical fertilisers and cow manure to benefit from the additive effect, and sometimes the synergistic effect of the combination. Biochar is economic to make and be sold for horticulture production, and sweet potato production. A diverse range of soils exhibited a positive response in peanut yield to biochar, SP36 and Zn. Fortified biochar (Biochar Plus) increases the benefit, and therefore reduces the recommended dose of biochar use in Timor-Leste.

Regarding cropping, a survey emphasised the value of the low-labour mungbean system to households through increased income, decreased women's labour and increased soil fertility.

Following an evaluation of legume options, promising lines of common bean, cowpea and winged bean were identified for varietal release which now require seed multiplication.

The project identified red rice as an alternative crop to white rice to plant on spring-fed irrigated land while farmers purchase imported lower-value white rice.

Common beans, onions and carrots are traditionally grown in Timor-Leste in areas above 1000 m above sea level. The project showed that these crops can be profitably produced in the lowlands during the cooler dry season of April to October.

Aflatoxin was found in maize and peanut farm samples and in the blood of women and children, but the consumption of aflatoxin contaminated grain is not considered a causative factor in the current level of malnutrition and stunting affecting Timor-Leste children.

Regarding sandalwood and their forage tree legume (FTL) hosts, The project clearly demonstrated that many households are acutely aware of the high value and benefits derived from sandalwood and expressed strong interest in planting the species for income generation. Improved forestry extension can address many of the respondent-identified risks which were biophysical (lack of water, pests, livestock, and fire destruction). Legal marketing of planted sandalwood, which is currently prohibited, can help growers maximise benefits from their investments and provide a market signal to stimulate wider

planting of sandalwood among smallholders. The main constraints found for diversifying into sandalwood growing included limited access to labour, germplasm, markets and agricultural extension services/knowledge exchange systems. Household adoption of sandalwood production as an alternative livelihood strategy, requires confidence that it can be commercially viable over the life of the crop. In a financial analysis comparison of three modelled production systems, combining sandalwood production with FTL and cattle production was the most profitable of the assessed scenario's and compatible with existing production systems in Timor-Leste.

Through a systematic study of heartwood formation and oil quality in sandalwood, the sampled trees had consistently high oil quality, within or exceeding the international standard for *S. album*. But the study also found only modest levels of heartwood and oil yield. Further research is required to understand the factors that influence variation in heartwood and oil development to optimise production and inform domestication.

Insights from the project that are likely to lead to substantial benefits are: 1. No negative effects of fertiliser were observed and farmer are willing to use fertiliser if they are confident of benefit; 2. Biochar input increases productivity in horticulture and its manufacture is a good basis for economic activity; 3. Many soils seem responsive to addition of P and Zn; 4. Low labour mungbean saves time and increases profit; 5. Common bean and winged bean lines have been identified for varietal release for crop intensification; 6. Use of quality topsoil and GA3 improves sandalwood seedling performance; 7. Sandalwood in conjunction with fodder tree legumes is a viable option for farmers.

There has been early adoption of some of the project goods, with hundreds of hectares of low labour mungbean being planted, and about an extra 100,000 more sandalwood seedlings being prepared each year than would have been possible without the improved nursery practices.

Several of the insights support greater nutrition-sensitive food system development, increasing the availability of legume grain (low-labour mungbean, varietal selection of common and winged bean), increased vegetable production through use of biochar, and contributions to livestock production through leguminous fodder trees as sandalwood hosts.

Perhaps the greatest legacy from the project will be through project participants having become better researchers, more able to identify suitable innovations, rigorously assess them, and provide unbiased authoritative guidance to interested parties. Many project participants in AI-Com (and SoL earlier) nurtured the transformation of innovation ideas to adoption by farming families, through careful testing on station and farms. This success further strengthens the argument for support of research within the participating institutions. Capacity building has not been restricted to project participants and was apparent within others with connection to UNTL and MAF, such as extension personnel and students. Australian participants also gained a wealth of experience and new insights.

3 Background

Background

Timor-Leste is among the poorest and most food insecure countries globally. In the 2020 Global Hunger Index, Timor-Leste (T-L) scored 37.6, making it the second lowest ranked country globally (Grebmer et al., 2020), and in the 2021 Global Nutrition Report (Anon., 2021), Timor-Leste has the second highest child (under the age of five) stunting rates worldwide. Approximately 79% of the labour force in TL is engaged in agricultural activities with the majority relying exclusively on low input/output subsistence farming. Seeds of Life (SoL3) project (CIM-2009-049) established a national seed system and has disseminated higher yielding varieties now adopted by more than 40,000 farmers over the country. The priority of the Government of TL is now to move from addressing food security toward improved nutrition and increased rural income. In recent years, thanks to the oil revenue, TL has urbanised, with about 300,000 people now living in or around Dili. The expansion of the government and construction sector has created new markets for agricultural products, thereby creating an opportunity for local farmers to fill that demand. At the same time, slow but steady improvement in infrastructure (electrification and roads) makes it realistic to consider diversifying production. The recent electrification of most of the country is opening new opportunities to access shallow groundwater. This project has undertaken research required to underpin opportunities for farmers to re-focus from subsistence onto income-generating farming.

Justification

Following extensive consultation by the SoL3 program, two broad opportunities identified for productive research were i) cropping intensification to produce much needed legumes and grain for an emerging stock and food processing industry and ii) production of selected non-timber tree products (tree legume fodder and their companion sandalwood, native to T-L) to diversify farm income and act as a buffer to climate variability. The approach was to contribute to environmental sustainability and increase rural incomes. Their adoption is likely to require cultural change within the community, as well as the reliable identification of appropriate species, varieties, agronomic methods and sustainable water and land management practices. The research therefore encompassed socio-cultural as well as economic and technical aspects in the relevant research areas. It was undertaken in two defined agro-ecological zones, covering a quarter of the country's population.

4 Objectives

The aim of the AI-Com project was to improve agricultural productivity and profitability in pilot communities by a) addressing technical and social impediments to annual crop intensification and b) establishing fodder tree legumes and sandalwood as a sustainable income source and land management practice. The following objectives addressed the aim:

Objective 1. To understand community decision-making for natural resources management (NRM) and to pilot a cycle of land use practice change

Objective 2. To understand and develop intensive irrigated cropping systems that can be applied to sustainably utilise limited spring-fed irrigation water in mid-altitude and groundwater on the South coast.

Objective 3. To understand and develop crop management packages to intensify annual rainfed cropping and increase the financial viability of maize, peanut, cassava and food legume producers.

Objective 4. To design and evaluate methods and practices for communities to increase forage supply from forage tree legumes (FTL) and sandalwood production to provide both short-term and long-term economic opportunities.

The unlocking of land use practice change through Objective 1 (primarily involving social science) is a pre-requisite for activities in Objectives 2-4, in which many potential innovations involve alterations to land management and require community involvement (e.g. irrigation use, grazing management for dry-season cropping and tree planting).

Capacity building was embedded within all four objectives to retain focus on the objectives and our principal approach was through learning-by-doing, which we found in SoL3 to be effective.

5 Methodology

Details of methodology used in AI-Com research are variously available in Annual Reports, other reports and scientific publications. Space constraints of the Final Report dictate only scaffold coverage of methodology in the following section.

5.1 Objective 1. To understand community decision-making for natural resources management (NRM) and to pilot a cycle of land use practice change

Activity: *Selection of communities in target zones* and 1.2 *Design and Implementation of household natural resource management survey*

Baseline household socio-economic and natural resource management (NRM) surveys were conducted in four communities in Maliana in 2018 and three communities in Natarbora in 2019 (See Map – Figure 1). The studies used a mixed-methods approach by drawing on quantitative and qualitative research methods comprised of a household (HH) questionnaire, resource mapping and focus group discussions (FGD). The questionnaire was pre-tested, and this included familiarization with tablet data entry using ODK software. The interview group was gender-balanced, and comprised AI-Com, MAF staff and students from UNTL. A total of 125 HHs (60 males and 65 female heads of HHs) were surveyed representing 30% of all HHs in 2018, while in 2019 the survey had 212 respondents.

We originally planned to select sucos for survey in 2020. However instead, and as mentioned in the 2019 Annual Report under Section 6 *Variations to future activities*, the socioeconomic team focused on completion of the report on 2019 sucos and implementing a new fertiliser study and the animal control survey (see below Activity 1.4).

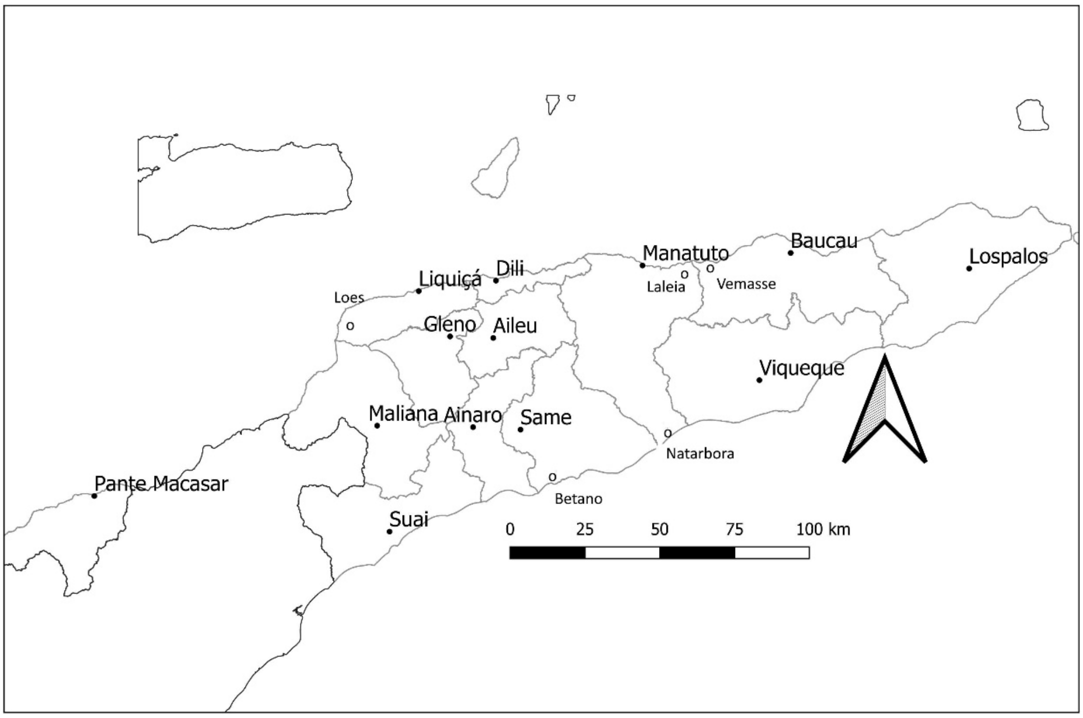

Figure 1. Map of Timor-Leste showing municipality boundaries and their capitals and key project field sites.

The research in AI-Com in Timor-Leste is covered by UWA Human Research Ethics protocol RA/4/20/1031 entitled ‘Agricultural Innovations for Communities for Intensified and Sustainable Farming Systems in Timor-Leste (AI-Com)’.

Activity: *NRM concepts and practices (including fire management) introduced to participating farmers through on-farm demonstrations and drawing on participatory research tools*

Not commenced

Activity: *Bi-annual evaluations by communities of novel land use and fire management practices to determine economically sustainable land management compared with current methods*

<u>Participatory land use planning (PLUP) evaluation</u>: In 2019 the socio-economic team undertook an evaluation of the impacts of PLUP including prohibition (*tara bandu*) [previously undertaken by the NGO RAEBIA] on conservation agriculture and velvet bean adoption on the south coast (Natarbora, Fatuberliu and Same) (see Section *Opportunities* in 2018 Ann. Report). Using this opportunity we short-circuited the need to undertake PLUP and then wait for evaluation. The survey was to understand the drivers motivating farmers to trial conservation agriculture (CA) technology (i.e. maize-velvet bean intercropping developed by SoL project) on the south coast and to examine if PLUP increased maize production in villages because of improved animal control. Both quantitative and qualitative methods were used through a household survey, focus groups and semi-structured interviews covering a total of 374 respondents.

<u>Farmers’ Perceptions and Use of Inorganic Fertiliser Survey</u>: AI-Com’s agronomic trials showed major responses to fertiliser application in a range of crops. The adoption of inorganic fertilisers and new inputs, such as fortified biochar henceforth called Biochar Plus, can increase domestic food production and conserve soils. However, Timorese farmers are known to use minimal inputs, including inorganic and organic fertilisers. So, the socioeconomic team conducted a survey to explore farmer attitudes towards using inorganic fertilisers and their application in 2020. A total of 157 households participated in the household questionnaire (25% current users, 25% former users and 50% non-users) and 15 key informants were interviewed. Two villages in Manatuto Municipality and one community in Bobonaro Municipality were selected for the survey.

<u>Survey on Animal Control Practices applied during the Dry Season</u>: Building on the HH NRM baseline survey results, which showed free grazing animals as a challenge to cropping during the dry season, in 2020 the socio-economic team undertook additional research on animal control practices in communities surveyed in 2019 (Natarbora Municipality). The survey was to identify current animal control practices applied in the target villages and to understand effective ways to control animals during the dry season. The sample of participants was purposely selected to comprise those who grow crops during dry season, including those who trialled mungbean after rice with AI-Com, horticulture farmers, livestock owners, and local political and ritual leaders.

Following-up, we conducted seminars on Animal Control Practices applied during the Dry Season in the three previously-surveyed villages and the neighbouring village of Abat Oan in lowland Natarbora during 2021 to disseminate the findings from the surveys, discuss with the broader community what they perceive as effective ways to improve livestock control practices in the village; and share information [facilitated by ACIAR project LPS/2014/038 Redi Kamodi (*Karau ba moris diak* or “Cows for Better Life”)] on how to raise and fatten cattle, build market linkages and prevent animal-related diseases from spreading to humans.

<u>Farmer perceptions of trees (specifically sandalwood) in lowland and upland areas</u>: This study used a mixed methods approach by drawing on a livelihood-focused questionnaire; agroforestry-focused questionnaire; focus group discussions (FDGs), key informant

interviews (KIIs), literature review of relevant legislation and policies related to tree planting and marketing, and synthesis of key data within the TL Agricultural Census 2019 (General Directorate of Statistics, 2019). Livelihood interviews were implemented randomly across 169 households in Natarbora and 125 in Maliana. FGDs were conducted with groups of individuals that were selected to represent the community in each of the four agroforestry-focused study areas. The goal of interviewing local key informants (e.g. village heads and community elders) was to understand whether community members have knowledge on national legislation and policies concerning trees in general and sandalwood.

The results derived from the mixed methods were combined according to their contribution to the capitals and capabilities within the analytical framework for evaluating rural livelihoods (Bebbington, 1999). With respect to livelihoods, people often combine a range of activities in a complex bricolage of enterprises (Scoones, 2009). Of interest is whether smallholder farmers in Timor-Leste consider tree farming as a viable option to incorporate into their portfolio of livelihood activities. We also considered whether external conditions are supportive, obstructive or neutral. We evaluated interview responses in the context of physical, human, social and financial capitals and the policy, regulatory and market environment. The capitals in this framework are assets that give smallholders the capability to be and to act to sustain livelihoods (Bebbington, 1999).

<u>Socio-Economic evaluation of low labour mungbean</u>: An evaluation of the low labour mungbean system was conducted in 2022 on the south coast in Manatuto and Manufahi Municipalities where the innovation was introduced since 2018 and 2020. The team (AI-Com and MAF) implemented the survey to understand farmer knowledge, perceptions and practices in applying the low labour mungbean system under varying field conditions/ locations. A mixed methods approach was used employing the methods of HH questionnaire and FGD with separate men's and women's groups. Target participants were farmers who had adopted low labour mungbeans and the total number of participants involved was 60.

<u>The impact of women's access to agricultural extension on cropping practices in Timor-Leste:</u> We studied the impact of the SoL3 programs on women's participation in extension and households' agricultural practices. We used the midterm evaluation data of a nationwide agricultural intervention program (Seeds of Life) that aimed to augment women's access to extension service through a community-based seed multiplication initiative to identify if there was a gender gap in access to extension in Timor-Leste.

Activity: *Value chain analyses conducted for selected crops with a market demand*

See Activity Market analysis for selected crops - below.

Activity: *Establish an online database/server with SoL archival information on climate, soils, mapping and other information*

See Section 6 Table of Achievements and Section 8.4 Communication and dissemination activities.

5.2 Objective 2.To understand and develop intensive irrigated cropping systems sustainably utilising limited spring-fed irrigation water in mid-altitude and groundwater on the South coast

Activity: *Increasing rice yields sustainably*

UNTL: Following-on from trials showing the dramatic effects of fertilisers - such as N as urea, P as superphosphate and rice-husk biochar - on the yield of a range of crops following rice in the dry season of Year 1 at Vemasse, a series of experiments were undertaken on rice at Vemasse (also by UNTL students and staff) during 2019. The topics investigated include plant spacing, frequency of weeding, varieties, application of rice-husk biochar and inorganic fertilisers and impact of time of harvesting on rice milling quality. Detailed reports were written by UNTL final-year students as part of their assessment and individual lecturers contributed to a stand-alone publication (Guterres and Gusmao 2020).

In a second season of UNTL rice trials (2020) the response of two rice cultivars (red rice and Nakroma (SoL cultivar) to rice-husk biochar and inorganic fertiliser (N, P & K) was investigated. The study took place in Laleia (Manatuto) on the North Coast and included 11 trials comprising a complementary set of factorial experiments.

MAF: The effects of rice-husk biochar on rice in irrigated areas outside Vemasse, was investigated by MAF in 2019 using a series of 25 on-farm trials. The trials included 5 trials in Batugade - in the west, Bobonaro, an Eastern rice growing area – Laga (5), Baucau - and a southern rice growing area – three sucos in Viqueque (5 trials in each). There were four treatments at each location: 1. Control, 2. Farmer's system of application (in most cases this was no additional application of any soil amendment or fertiliser), 3. Rice-husk biochar (10 t/ha), and 4. Biochar (20 t/ha) replicated three times. In Viqueque all biochar was applied at planting, whereas in Batugade and Laga the application was split with one tenth applied at planting and the remainder at flowering.

As follow-up and as proposed by the Mid-term Review (MTR), to determine the minimum effective rate of rice husk biochar in 2020 we studied a range of application rates (0, 5, 10 & 20 t/ha) on rice. Each site consisted of a replicated trial of four biochar rates with three replicates.

To understand the yield response of red and white rice cultivars to added inorganic fertiliser, further research was conducted in 2021 on the yield response of two red and two white cultivars to added inorganic fertiliser in the west and central areas of the country. Trials were established in the irrigation areas in Maliana and Manatuto with three farmers in each area. The hypothesis was that the rice response previously observed in Baucau would be replicated in Maliana and Manatuto. The trial comprised the factorial combination of 4 rates of fertiliser and four varieties. The rates of fertiliser (urea and SP36) were based on the recommended rates of application of Good Agricultural Practices (GAP) (i.e. 50 kg urea & 50 kg phosphate [SP36] per ha). The experiment used the rates of 0, 1, 2 and 4 times the recommended GAP rates. Cultivars comprised two red (Goa1, Inpari24) and two white (Nakroma, IR64) rice varieties.

Residual Impact of Urea and Superphosphate impact on rice yield: Although resistance to the use of inorganic fertiliser is lessening, the residual impact of urea and superphosphate is often questioned. On-farm experiments were designed to investigate the residual impact of applied urea and superphosphate on the following rice crop in two subdistricts. The research comprised a replicated trial of two treatments (nil and 50kg Urea + 50 kg/ha Superphosphate [the recommended rates]) repeated on 5 farmers' fields in Laga and second set of 5 famer's fields in Baucau. At each site, there were two paired rice bays, each bay acting as a replicate. Fertiliser was applied to the 2021 rice crop and yield of the rice was measured from the four plots at 10 sites. Rice was grown as normal in 2022 with no further amendments or fertiliser applied and harvested in 2022 to assess the residual impact of the 2021-applied fertiliser.

Activity: *Alternative crops on spring-fed irrigated land:*

To test non-rice crops in rice areas during the rice cropping season was more difficult than initially anticipated, as water control and land preparation issues making it difficult to undertake research in small areas. Research on non-rice crop alternatives was not pursued further.

However, the alternative of growing a red rice variety was tested as an alternative to white rice. This was proposed in the MTR. For this comparison, Nakroma - released white rice cultivar - was tested against a MAF-tested red variety Goa 1. Details are presented in Several of the UNTL-conducted trials in Activity (above) included the comparison of red v. white rice variety.

Activity: *Crops after rice*

Dry Season 2017 - In irrigated areas, horticulture yields are limited by low soil fertility. A series of eight agronomic trials involving a total of five species (mungbean, soybean, sweet corn/maize, tomato and chili pepper) were conducted by final year students supervised by UNTL faculty (Guterres et al. 2019). They were late-sown in the 2017 dry season at the UNTL Vemasse site on land previously cropped with paddy rice for some years using low inputs. Treatments examined were various combinations of rice husk biochar, super-phosphate-36 (SP36) and cow manure.

Trials in 2017 showed large responses to the application of soil amendments rice-husk biochar and inorganic fertiliser N and P to both rice and horticultural crops, with a greater economic return from the horticultural crops. Biochar Plus was formulated as a combination of rice-husk biochar with low levels of N and P (2%N and 1%P) (as indicated in 2019 Annual Report - Section 6 *Variations to Future Activities*). A set of experiments in Laleia were conducted by UNTL on horticultural crops evaluated different rates of Biochar Plus (0, 1, 3 and 5 t/ha) in 2019.

As follow-up, MAF explored biochar use on high-value vegetable crops at three sites (Aileu, Triloka and Caibada) in 2019. Fertiliser treatments were 1. Control, 2. Local fertiliser - cow manure at 1200 kg/ha, 3. Rice-husk biochar (30 t/ha), 4. Superphosphate (SP-36) at 80 kg/ha, and 5. Biochar + SP-36. The specific crops varied across sites depending on local usage as follows: Aileu and Triloka (chilli pepper, tomato, sweet corn, soybean, and yard-long bean); and Caibada (chilli pepper, sweet pepper, Phaseolus green beans, carrots and cabbages). A pot soil incubation experiment was conducted with biochar using soil from the most biochar-responsive site. Briefly, this incubation experiment tested the impact of added biochar on soil pH and availability of soil nutrients as soil was collected and placed in 20 cm pots that were then exposed to the elements in Dili MAF compound. Treatments were rates of biochar application, rates were equivalent to 0, 5, 10 and 20 t/ha with five replicates. Analyses of soil at the three trial sites and the soil incubation experiment were conducted at UWA and the MAF soils laboratory.

Second incubation experiment of 15 soils (2021): As follow-up to the first incubation experiment on a single acid soil, a second incubation experiment was established. This comprised 15 agricultural soils of diverse origins, and three rates of biochar application (0, 5 and 20 t/ha). Monthly soil samples were taken from the pots. The samples are currently at UWA awaiting analysis.

In 2021, as part of Acacio Guterres' PhD thesis at Charles Darwin University (CDU), an experiment was conducted to compare the impact of Biochar Plus (rates: 0, 1 and 3 t/ha) on horticultural yields over eight horticulture species (cabbage, capsicum, cucumber, eggplant, bok choi, rock melon, tomato and watermelon) in Maliana.

The application of Biochar Plus looked very promising both on rice and also dry-season crops. But optimal rates of application were unknown, as is the interaction of biochar with other agronomic practices. A set of three experiments was conducted by UNTL students on rock melon in Maliana in 2021 during the COVID pandemic. Each experiment was a replicated factorial experiment of two factors with three replicates. In all experiments, the first factor was the dosage of Biochar Plus (0, 1, 3 & 5 t/ha) and one other agronomic factor, which were variously plant spacing, the use of different types of mulch and impact of terminal drought.

Earlier research by UNTL showed strong positive response to biochar application across many crops at the Vemasse Egidio site and the Laleia site. However, at a very similar site (Vemasse Brigida) there was a non-significant response to added biochar. A pot trial consequently examined the consistency in response to biochar across soil from four previously examined sites, and the new Maliana site. The pot trial was conducted at UNTL Hera. The experiment was a factorial design of four soils and four rates (0, 5,15, 25 and 35 t/ha) of biochar application with five replicates. The test species was mungbeans. The four soils were tested for N, P K status with a portable soil kit from Indonesia.

To identify possible alternative sources of biomass for biochar and assess their influence on crop productivity - as proposed by the MTR, a pot trial was conducted at Maubisse to compare the impact of coffee husk biochar with rice husk biochar. The trial was on four crops (potatoes, common beans, small red onions and garlic) using local soil - grey heavy clay, with pH_{H2O} ~8.0 - with application rates of biochar equivalent to 0, 10 and 20 t/ha.

Low labour mungbeans: Small areas of mungbeans are typically grown in the second wet season in upland fields on the south coast. Beans are not generally planted in rows but planted at random using a dibble stick. To enable crop intensification following paddy rice, relay sowing of mungbeans into standing rice was investigated by staff of the Natarbora Agricultural College and MAF in 2017/18. In 2019 they tested a farmer-modified low-cost method to increase mungbean yields at four sites. The system comprised chemical weed control (glyphosate to control weeds prior to planting and no in-season weeding) and broadcasting mungbean seed. Trials were in a randomised complete block design with 3 replicates. Treatments were a factorial combination of two methods of crop establishment, broadcast sowing and planting seed using a dibble stick and two varieties (Kuikae and local).

Given the success of the low labour method of mungbean production after rice in 2019/20, the method was expanded into a demonstration mode in the irrigated rice area at Betano among farmers with limited water, who had asked for technical assistance from MAF extension agents. AI-Com used this opportunity to demonstrate the package of low labour input mungbean production with MAF released short season mungbean varieties. A number of crops were established in mid-June 2020 over ~2 ha. The activity was part of the MAF COVID response. Part of the area was planted by dibble stick, and part broadcast, as per the package of low labour mungbeans system.

In 2021 the low labour mungbean research was followed up in the rice area - Akadiru in Betano. Sowing was in June with harvest in October 2020. A total area of 6 ha was sown with the two MAF-released varieties Lakateu and Kiukai. The demonstration was implemented to compare differences between systems of mungbean management. There were two sowing methods (planting with dibble stick versus broadcast seed on wet soil), and two ways to manage weeds (cultivation versus glyphosate application prior to planting). As this was demonstration/research with six farming families, each farmer chose his/her own combination of planting and weed control.

Activity: *Small-scale irrigation dry-season options for south coast*

To extend legume options we introduced and evaluated germplasm from international centres as follows: common beans from CIAT with CMV resistance (62 accessions), short-season determinate pigeon peas (10 acc.) from ICRISAT at Betano (Manufahi), and short-season cowpeas (24 acc.) from IITA.

Thereafter, a series of replicated multilocation, multi-year trials of common bean germplasm (local and introduced) were conducted by MAF in 2017 through to 2022 (see respective Annual Reports).

Short-season cowpea: The 24 introduced lines were yield tested in the first two years and promising lines selected. Despite the promise of some lines, seed was then lost.

Winged bean: In 2011-2013 the SoL program tested introduced winged bean genotypes on-station and three lines (one each from Papua New Guinea, Indonesia and Thailand) were selected for evaluation in 65 on-farm trials in six Municipalities. MAF began to multiply seed of these three varieties to release as varieties, but the seeds were admixed. AI-Com supported the purification of the genotypes, but this proved more difficult than expected. Purification from single plants of the elite lines was required. Seed increase and confirmatory trials were continued.

There has been progress in developing APSIM (Agricultural Production Simulator) skills in MAF as part of AI-Com. Two researchers worked through the APSIM introductory lessons in 2018. Leveraging on the visit of Kimberly Pellosis (Crawford Fund), a workshop was held in 2018 focusing on maize production on the South coast. We used APSIM to simulate maize yield for a range of mulching rates, planting date and plant densities for each of 13 years.

In 2019 simulations were run on APSIM for a range of plant densities and sowing dates for mungbean and common bean. The simulations used Betano soil and weather data from 2006 to 2017. The factors were planting month (December to June) and 5 plant densities (10, 20, 30, 40 and 50 plants/m^2). Planting for each month, in each year was simulated of 25 mm of rain in a three-day period.

Activity: Novel crops after rice: Research with NGO - World Vision (WV)

We studied the impact of soil amendment with rice-husk biochar in combination with cow manure on orange-fleshed sweet potato in four municipalities. This was started in 2020 at 13 locations and repeated in 2021 at 40 locations (10 sites/municipality). Each site was a non-replicated experiment with four treatments: 1) control, 2) 10 t/ha manure added, 3) 10 t/ha rice-husk biochar added and 4) Both rice husk biochar and cow manure added, both at 10 t/ha. The residual impact of biochar and cow manure on sweet potato yields was investigated in In 2021 and 2022, by planting sweet-potato in the same plots as the first year. In the final year, 26 of the original 40 sites were successfully harvested across three districts.

Activity: Market analysis for selected crops

Value chain research on commodities was started with two UNTL final-year student projects on gross margins and the returns on farm labour of dry season crops grown in Vemasse. Using 2017 agronomy student data (See Activity 2.3 above), one student studied the application of phosphate (SP-36) and rice-husk biochar to maize and chilli pepper. The other student researched mungbean and tomato responses to SP-36 and biochar.

Continuing with UNTL student projects on one of the steps of value chain analysis, students evaluated gross margins and return on labour of a set of six trials from UNTL horticultural experiments in Laleia 2020 - See 2.3 above.

Partial budget and gross margin analyses were also conducted within Acacio's PhD thesis crops - See 2.3 above.

Market analysis was conducted on Seeds of Life data for maize. This study examined the role of high-yielding maize varieties as one of the key drivers of smallholder farmers' market participation in a highly subsistence rural economy. The analysis was based on the End-of-Program Survey data collected by the Seeds of Life program in 2016 covering 700 households in rural Timor-Leste (See Section 7 *Results and Discussion* of Activity 1.

Activity: Complete a series of factorial pot trials of biochar, P and Zn with a wide range (30) of TL soils. Completion includes soil analysis at UWA (Extension activity)

National peanut pot trial of 45 soils in 2021: To test the hypothesis that biochar increases plant growth and yield by increasing plant available P, Zn and possibly K, a set of pot trials were set up around the country. The same experiment was conducted at 15 sites. Each site included three soil types. In each soil type a factorial pot experiment with peanuts was implemented in a factorial combination of three rates of biochar (equivalent to 0, 5 and 20 t/ha), 2 rates of SP36 (0 and 15 kg P/ha) and 2 rates of added Zn (0 and 5 kg Zn/ha using a commercial source of Zn which was a combination of Zn and Mn sulphate (17%Zn, 15%Mn and 5% S). This provided 12 treatments per soil type, each of which was replicated three times. Soils of each of the sites were sampled and sent to UWA for analysis to allow the plant response to be correlated with soil chemistry. Soil samples from the pots were analysed on a Mehlich 3 extract at Southern Cross University in Lismore, NSW.

A number of the soils were replanted with mung beans to determine the residual impact of rice-husk biochar, Zn and SP36.

See Activity above

Activity: Complete on-farm research on low-labour mungbeans after rice with growers and continue system scale-up on the South Coast (*Extension)*

See Activity above

Activity: *Complete second year of multi-year rice fertiliser trials (Extension)*

See Activity above

Activity: *Annual testing of promising elite legumes, for potential release. (Extension)*

See Activity above

5.3 Objective 3. To understand and develop crop management packages to intensify annual rainfed cropping and increase the financial viability of maize, peanut, cassava and food legume producers

Activity: *On-farm agronomic trials with mungbean, winged bean, dry bean and yard-long bean/cowpea and soybean to assess production and profitability*.

Trials of intercropping maize and beans conducted in 2017/18 were reported in the relevant Annual Reports and are not repeated here as they did not lead to impacts.

Activity: On-farm experimentation with commercial/semi commercial growers to assess the effect of lime, superphosphate and urea on maize production and profitability.

Although initial research was planned with MAF researchers, MAF conducted maize fertiliser rate trials with their own resources. AI-Com increased the scope of the research by investigating the impact of biochar on maize and other wet season crops (as flagged in 2019 Annual Report under Section 6 *Variations to Future Activities*). To investigate the impact of added biochar on yields of maize, sweet potato and peanuts in the wet season, a series of on-farm experiments was conducted in Baucau and Maliana in 2019.

In 2021 using the most-responsive crop, four sweet potato varieties were tested at five rates of Biochar Plus application (0, 0.5, 1, 2 and 4 t/ha) at two locations. The four varieties were MAF released varieties: two white fleshed (Hohrae 1 and 2), one orange (Hohrae 3) and a purple-fleshed sweet potato (Sia TL).

A further experiment in 2021 tested the impact of biochar (0, 0.5, 1, 2 and 4 t/ha) with added P (0, 5, 10, 20 and 40 kg P/ha) on various legumes - peanuts, soybean and mungbeans on the Baucau plateau.

We tested the residual effect of a single application of rice husk biochar (20 t/ha) to an acidic weathered soil on the Baucau plateau. The trial started at Triloka in 2018, see Activity 2.3 with the site selected because of a large response in 2017 to soil amendment with rice-husk biochar (Annual Report 2019). The site was monitored until 2022. The single application fertiliser treatments applied in 2018 were 1. Control, 2. Local fertiliser - cow manure at 1200 kg/ha, 3. Rice-husk biochar (30 t/ha), 4. Superphosphate (SP-36) at 80 kg/ha, and 5. Combination application - Biochar + SP-36. The specific crops were chilli pepper, tomato, sweet corn, soybean, and yard-long bean. The design was split-plot with crops as main plots and fertiliser in sub-plots in three replications. Each subsequent season the crops were rotated in a fixed sequence. Yields and soil pH were measured at harvest each year.

Activity: On-farm experimentation with cassava.

Not commenced - see Section 6.3.3

Activity: Development of composite sampling techniques for aflatoxin detection with commercial maize and peanut growers.

Aflatoxin testing by QuickTestTM was introduced based on SoL research and was followed up by AI-Com. In 2019 - a particularly wet season- a total of 260 samples of maize and peanut harvest bags were collected from farms and analysed for aflatoxin level using QuickTestTM.

Activity: Adoption/Impact evaluation across innovations in Objectives 2 & 3.

See Activities in 1.4.

5.4 Objective 4.To design and evaluate methods and practices for communities to increase forage supply from forage tree legumes (FTL) and sandalwood production to provide both short-term and long-term economic opportunities

The sandalwood and FTL research was led by the University of the Sunshine Coast

Activity: Site suitability & FTL/sandalwood agroforestry demonstrations

Heartwood Oils: Approximately 15 trees were evaluated within each of 11 locations across 10 administrative posts. The trees sampled from these areas were considered to be representative of the remaining trees within the wild population. Selection of sampled trees was restricted to those with basal diameter of at least 10 cm (range 10 to 33.2 cm). A minimum distance of 20 m was used between individual trees, so as to reduce sampling genetically related trees, particularly clonal root suckers. Data collected from each site included information on slope (aspect and gradient), while data collected for individual trees included tree age (estimated using local inputs), tree dimension (tree & bole (single main stem of tree) height, canopy spread, stem diameter), plant recruitment (seedlings and suckers), sun/fire scorch (aspect & depth), pests and disease (galling, caterpillars, root rot, scale) and human-induced physical damage (heartwood check, where people make significant cuts into the main stem to check for the presence of heartwood)(pest severity score was determined through subjective evaluation of abundance of 1 (low) to 5 (high)). One bark-to-bark wood core (5.15mm diameter) was extracted (Haglöf Increment Borer 300-2T) from each tree sampled at a height of 0.2 m above ground level (AGL) and where heartwood development was prominent subsequent cores were taken at 0.7 and 1.3 m. Heartwood mass (kg) was calculated based on heartwood diameters at 0.2 and 0.7 m and an air-dried wood density 940 kg m^{-3}. Heartwood oil yield and composition was quantified through gas chromatography mass spectrometry (GCMS).

Genetic variation: A molecular marker study was conducted to examine the diversity and relatedness among individual trees in natural and planted Santalum album trees from Timor-Leste. These trees form the base population, which is both the target of a conservation program and the genetic resource on which domestication of the species is based. The collection represented 15 separate seed sources or putative provenances, with some samples collected from in situ wild trees and/or plantings and some from an ex situ conservation stand (ETA-N). The leaves were sent to Australia for analysis. DNA was extracted from leaf tissue samples and then assayed using the DaRTseq medium density protocol at Diversity Arrays Technology Pty. Ltd Canberra. This yielded a total of 61,120 single nucleotide polymorphism (SNP) markers for 402 trees from Timor-Leste, which are the focus of this report, and 379 S. album and other sandalwood taxa from Fiji and Tonga. Filtering of SNP loci by call rate and minor allele frequency left 9700 SNPs with a call rate of 95%. This marker panel was regarded as excellent in terms of both marker density (number of markers) and marker reliability for genetic diversity and pedigree reconstruction work.

Activity: Nursery research with MAF to develop quality seedling production systems for transfer to community-based nursery

A series of nursery experiments were conducted to evaluate (a) the effectiveness of gibberellic acid on seed germination rates, and (b) nursery potting media. Additional observational and diagnostic research was carried out to identify the causal mechanisms and/or agents for seedling wilt, damping off and dieback observed in sandalwood nurseries. Australian plant pathologists (AQIS) who examined affected plant samples from the Natarbora nursery.

Activity: Establishment of sandalwood seed stand(s) representing the species geographical range (revised activity)

A field trial was established to examine the fresh forage production capacity of the FTLs and growth performance of sandalwood when grown in combination. The experiments utilised *Leucaena* and *Sesbania* as within-row (intermediate) and *Casuarina equisetifolia* as between-row (long-term) hosts. The experiment was conducted within rain-fed cropping land along the south coast (Natarbora) The experiments were designed to examine the effect of intermediate host trees planted between the sandalwood line plots. The experimental unit used in the trial was a 3-tree line plot of sandalwood (1m between each of the three sandalwood) that is flanked by one of two intermediate hosts (FTLs *Sesbania* and *Leucaena*) spaced at 4m apart.

The first trial was established on 16th May 2019, accommodating a total of 42 x 3-tree sandalwood line plots (126 trees) for each of the FTL treatments, with 16 x 3-tree sandalwood line plots (48 trees) buffers between the treatments. The total stocking rate of this system was 416/ha FTLs, 200/ha *Casuarina* and 1200/ha sandalwood thinned to 400/ha.

Analysis of sandalwood growth and forage production was conducted by unbalanced analysis of variance. The design is unbalanced due to there being three types of host tree configurations, all not equally replicated. The three configurations of host trees are between 1) *Sesbania*, 2) *Leucaena* and 3) *Sesbania* and *Leucaena* trees. The nature of the design is that there is always one less of treatment 3 (between *Sesbania* and *Leucaena*) in each column than there are of between host trees of the same species. An ANOVA modelled time of observation as repeated measure (within-subjects-effect) and the combination of (1) row (2) host and (3) line-plot position as between-subjects-effect. Binomial logistic regression was carried out for survival at each time of observation to determine the effect of row, host, and line-plot position. A linear regression was used to determine the effect of FTL forage production on sandalwood growth at the line-plot level.

Activity: Survey of sandalwood producers and interviews with experts and key informants to understand key factors affecting the economic and financial viability of sandalwood investment.

A financial model was developed based on data sourced from a systematic literature review, which were validated and supplemented with information sourced from practitioners in Timor-Leste and Australia. Among the experts consulted were national and international researchers, business owners, sandalwood growers, government officials and farm managers. The financial model was developed in Microsoft Excel and was partly based on financial models for sandalwood in the Pacific (Harrison & Harrison, 2016) and FTL production in Indonesia (Waldron et al., 2019). To evaluate the financial viability of the proposed plantings we used a discounted cash-flow analysis (Cubbage et al., 2016; Herbohn, 2002). We calculated the net present value (NPV), land expectation value (LEV) and internal rate of return (IRR) as measures of financial profitability.

Forage sourced from hedged FTLs on a 120-day harvest rotation were used in a cut and carry system and fed to penned Bali bulls twice each day throughout the grazing season. Cattle were purchased at 150 kg liveweight (LW) and turned off at 235kg LW. Prices used in the model were those listed by TOMAK (2016) where bulls < 200 kg LW, 200 to 250 kg LW and > 250 kg LW were valued at $2.00 kg, $2.50 and $2.70/kg LW at sale respectively.

Sandalwood silvicultural practices in the model include: fertilization at planting (50 g/tree) and annually (100 g/tree) until year four, weeding of sandalwood up to year seven, and pruning up to year four. (Ota et al., 2021) considered that 0.25 kg of seeds could be harvested per tree to be sold from year nine. Labour requirements were based on (Harrison & Harrison, 2016). The model assumed a mean annual increment of stem diameter growth at 300 mm (cm) of 1.0 cm.year-1 and a rotation of 20 to 25 years. Heartwood production was calculated based on the regression model of Brand et al. (2012), where 9.7 and 16.9 kg/tree are harvested at 20 and 25 years respectively. Pricing followed that for S. yasi in Fiji ranging from USD 45 to 70 for butts, USD 32 to 42 for logs and USD 14 to 23 for minor pieces. The relative proportion of these products produced in a planted S. album tree was 17.2% for butts, 51% for logs (0 to 1 m trunk) and 31% for minor pieces (1 to 3 m) (Brand et al., 2012).

The financial model was used as the basis to investigate the performance of three different scenarios: (1) sandalwood combined with FTL and cattle production, (2) sandalwood production alone (at two different rotation lengths) and (3) FTL and cattle production alone.

6 Achievements against activities and outputs/milestones

Objective 1. To understand community decision-making for natural resources management (NRM) and to pilot a cycle of land use practice change

Activities	**Outputs/ milestones**	**Application of outputs**
1.1. Selection of communities in target zones	Criteria and process for community selection developed. Authorizations from stakeholders negotiated including community leaders and UWA Ethics Committee. For household natural resource management survey we selected four pilot communities in Maliana as Cohort 1 communities in 2018 and three Cohort 2 communities in Natarbora in 2019. In lieu selecting communities for survey in 2019/20 (see 2019 Ann. Report under Section *Variations to future activities)*, the socioeconomic team implemented a new fertiliser study and the animal control survey (see below - 1.4). Reports on community selection available.	Important to all other Activities
1.2 Design and Implementation of household natural resource management survey (Cohort 1 - 2017 and Cohort 2 - 2018)	Questionnaire developed, piloted, and enumerators trained. Sampling scheme tested. Training given to participants on PRA and gender analysis. Reports of 2018 Maliana and 2019 Natarbora household natural resource management surveys available. Gender-disaggregated survey data stored in database. Local natural resource assets, past and current land uses, land tenure, and NRM practices identified and incorporated into database. Main crop production systems, farming practices and seasonality, household economic and non-economic activities engaged by men and women within households identified and incorporated into database.	Basis for research toward Objectives 2-4 Assists full gender involvement in innovations Acts as baseline for subsequent adoption & impact research

1.3. NRM concepts and practices (including fire management) introduced to participating farmers through on-farm demonstrations and drawing on participatory research tools	Not commenced - as indicated in 2019 Annual Report in *Section 6 Variations to future activities*	
1.4. Bi-annual evaluations by communities of novel land use and fire management practices to determine economically sustainable land management compared with current methods	In 2018 2 we undertook an evaluation of the impacts of participatory land use planning (PLUP) including prohibition (tara bandu) [previously undertaken by RAEBIA - See Section 8 in 2018 Annual Report] on conservation agriculture and velvet bean adoption on the south coast. The survey was to understand the factors motivating farmers to trial conservation agriculture (CA) technology and to examine if PLUP increased maize production in participating villages from improved animal control. PLUP activities neither improved animal control nor impacted maize yield. More broadly, this result questioned the value of further research on PLUP, which was discontinued. In 2019 AI-Com implemented a new fertiliser study and an animal control survey. In 2019/20 AI-Com developed a on community forage tree especially sandalwood production. Reports available on all surveys.	Methodology useful to other projects. Community empowered for other development
1.5 Value chain analyses conducted for selected crops with a market demand	Throughout the project, contact was maintained with TOMAK and MDF, who had undertaken gross margin analysis of key commodities. Relevant information was sourced from existing studies. Analysis of cassava revealed it was a commodity not worth researching. By contrast, gross margin analysis showed the value of further research on mungbeans, peanuts, maize, beans and red rice. AI-Com research on value chain analysis of commodities was not commenced.	Targeting of commodities under Objectives 2 & 3
1.6. Establish an online database/server with SoL archival information on climate, soils, mapping and other information enabling improved characterisation and assessment by development managers at farm, village and municipal levels	During the project we maintained the Seeds of Life (SoL) web page (http://seedsoflifetimor.org/) as a resource and have updated the publication list. An AI-Com website (https://AI-Com.tl/) was started for program use. The new site www.agri.tl has been purchased for use as a library repository site.	Use by AI-Com researchers for Objectives 2-4. Use by other researchers and development projects
1.7 Incubate commercial production of Biochar Plus with a rice miller in East of TL (Baucau), and support Maliana Biochar Plus producer *(Extension period activity)*	Reports available: • Biochar Plus Business Case Study • Biochar Plus Business Incubation, Maliana	Farmers using Biochar Plus achieve increased yields in Maliana and Baucau districts

1.8 Community research to understand social costs and benefits of low labour mungbeans. *(Extension)*	Report available on Socioeconomic Survey of Low Labour Mungbean System	Knowledge of social restrictions around cattle, and herbicide use will enable improved scale up of technologies

Objective 2. To understand and develop intensive irrigated cropping systems sustainably utilising limited spring-fed irrigation water in mid-altitude and groundwater on the South coast

Activities	**Outputs/ Milestones**	**Applications of outputs**
2.1. Increasing rice yields sustainably: Replicated experimentation testing the effect of biochar, bio-fertilisers, rice planting and seedling systems and ages, inorganic fertiliser, and residual effect of green manures on rice growth and yield.	Field trials to increase rice yield by fertilisation with N, P K, or biochar were conducted at Vemasse by UNTL (Phases 2 & 3), and then by MAF in Maliana and Manatuto. Overall, yield increases from added P and biochar were linear, while N response was polynomial. Because of the higher price of red rice than white there was a greater $ return for kg fertiliser on red rice. Results are in Annual Reports 2019, 2020 and 2021.	Households in pilot communities adopt new management practices.
2.2. Alternative crops on spring-fed irrigated land: On-farm experiments comparing the gross margin of rice, soybean and other crops using local and improved agronomy. Residual impact of herbicides on soil land crops in Betano.	One option for alternative crops on spring-fed irrigated land is for farmers to grow red rice and to purchase imported white rice. Overall, despite little difference in productivity of existing white and red rice varieties, the economic return was higher from red rice due to its higher price - especially with fertiliser application. (Annual Reports 2020 & 2021) Soils sprayed with 1,5,10 and 100 times recommended dose of Glyphosate and Paraquat had no impact on peanuts planted directly after spraying. After 4 months, there was impact of Atrazine on second -crop germination. Soil health as measure by bacterial count and respiration were also unaffected by any herbicide.	

2.3. Crops after rice: On-farm experiments with farmers to identify the best timing for relay sowing of mungbean and other crops into maturing/mature rice crops. Crop modelling with APSIM will be used to extrapolate field data to other years and other climate scenarios.	Agronomic trials on locally important vegetable crops were conducted with various fertilisation combinations of rice husk biochar, phosphate (SP36) and cow manure at three sites with low-nutrient soils to identify soil constraints. A pot soil incubation trial with biochar levels was also undertaken for the acid site. In summary, increases in mean vegetable yields among the highest recorded in the literature, were found from fertilising with biochar and phosphate individually and in combination in three low nutrient soils contrasting in pH. The responses were primarily from the alleviation of soil deficiencies in P and Zn. (Annual Report 2019 & 2020). As part of Acacio Guterres' PhD thesis with CDU, an experiment was conducted to compare the impact of Biochar Plus on horticultural yields over eight horticulture species (cabbage, capsicum, cucumber, eggplant, bok choi, rock melon, tomato and watermelon) in Maliana. All species produced a significant increase in yield with the application of 1 and 3 t/ha of Biochar Plus. The optimal rates of application of Biochar Plus were unknown on rice soils between rice crops, as was its interaction with other practices. Three experiments were conducted by UNTL final year students on rock melon in Maliana in 2020 dry season. In all trials there was a positive response in rock melon yield to the addition of Biochar Plus, and the second factor. But no significant interactions between factors.	Contributes to the discussion on possible negative impacts of herbicides on Timorese soils.
2.4. Small-scale irrigation dry-season options for south coast: Replicated field trials at Betano research station and field trials with neighbouring farmers on time of sowing and irrigation trials on common bean, pigeon pea, lablab, cowpea, yard-long and winged beans into the dry season. On-farm experiments will compare costs and production of above crops for both human consumption and animal fodder. A comparison between trickle irrigation and hand watering from wells for high value crops will be made.	Selection of best dry season crops for groundwater irrigation on the south coast: Multilocation, multi-year trials of common bean germplasm were conducted by MAF in 2018-2021 (see respective Annual Reports). Three common beans (one local & two introduced) are to be presented to variety release committee. Multiyear trial of winged bean was conducted by MAF. Two winged beans are to be presented to variety release committee. APSIM modelling was used to evaluate the impact of mulch, plant density and planting date of maize and beans at Betano. Luis Almeida (ARSF) in flanking research: *How can we engage rural youth of Timor-Leste in farming?* Trials showed that, when farmers access water on their own farm in combination with Biochar Plus application to produce horticultural crops such as capsicum, shallot and carrot, they generate more profit compared to the common practice of growing maize. (ARSF Final Report 2022)	

2.5 Novel crops after rice. Research to be conducted by World Vision (WV) TL	Field trials were conducted by WV of the application of biochar and cow manure on sweet potato yield over three years. After three years, there was still a large response to a single application of biochar and cow manure. Large synergy between the two was observed.	
2.6 Market analysis for selected crops using value chain approach.	Partial budget and gross margins research were conducted by UNTL students/staff using UNTL data Biochar and Biochar Plus using agronomic data from the dry season at Vemasse - Activity 2.3 above. As part of Acacio Guterres' PhD thesis, in an experiment comparing the impact of Biochar Plus on horticultural yields of eight horticulture species, partial budget analysis showed that the increased yields in all species produced an attractive economic return for all species, with an increase in return from $2 per kg Biochar Plus from capsicum to $44 per kg for watermelon. (See Activity 2.3)	Reports on production, consumption, price trends
2.7 Complete a series of factorial pot trials of biochar, P and Zn with a wide range (30) of TL soils. Completion includes soil analysis at UWA (Extension)	To test if biochar increases plant growth and yield by increasing plant available P, Zn and possibly K, a set of pot trials with peanut were implemented around the country on 22 soils. Peanut yield increased significantly with added biochar in 20 of the 22 soils tested (91%). Yield also increased in response to added SP36 and Zn sulphate in 15 and 10 soils, respectively (68 and 45% respectively).	Knowledge of the mechanism of biochar impact on yield will guide future soil fertility guidelines
2.8 Complete on-farm research on low-labour mungbeans after rice with growers (including testing crop establishment methods) and continue system scale-up on the South Coast *(Extension)*	Mungbean is typically grown in the second wet season in upland fields on the south coast of Timor-Leste. In 2019 & 2020 we tested a farmer-modified low-cost method to increase mungbean profitability by reducing labour input. The system comprised chemical weed control (glyphosate prior to planting and no in-season weeding) and broadcasting mungbean seed. (See Annual Reports from 2019). Extension and adoption of the system started in 2020/21. Publication available: Socio-Economic Evaluation of Low Labour Mungbean System	Best practice of low-labour mungbean practice identified
2.9 Complete second year of multi-year rice fertiliser trials *(Extension)*	See Activity 2.1 above.	Increase farmer knowledge of multi-year response to Urea and SP36
2.10 Annual testing of promising elite legumes, for potential release. *(Extension)*	See Activity 2.4 above.	Varieties of common bean and winged bean considered for release

Objective 3. To understand and develop crop management packages to intensify annual rainfed cropping and increase the financial viability of maize, peanut, cassava and food legume producers

Activities	Outputs/ Milestones	Applications of outputs
3.1. On-farm agronomic trials with mungbean (sowing trials in maize intercrops at various growth stages), winged bean (plant density in maize & cassava intercrops), dry bean and yard-long bean/cowpea and soybean to assess production and profitability.	Other sections Trials of intercropping maize and beans conducted in 2018/2019 were reported in Annual Reports	Households in pilot communities adopt new management practices. Through field days on-farm trials will be used as demonstration for farmers and staff of NDAHE, development projects and NGOs to disseminate technology more broadly in target Districts & beyond
3.2. On-farm experimentation with commercial/semi commercial growers to assess the effect of lime, superphosphate and urea on maize production and profitability. Guided by soil tests of pH and available P, dose rates of triple superphosphate, urea and lime will be applied.	Initial planning for this activity was conducted with MAF researchers. MAF conducted these rate trials with their resources. Consequently AI-Com stopped planning research on the issue. AI-Com investigated the impact of biochar and Biochar Plus (see 2020 Annual Report, as flagged under Section 6 *Variations to Future Activities*) on wet season crops on the Baucau plateau - identified as with very infertile, acid soil. In 2020 the application of biochar alone on sweet potatoes in Baucau was cost effective as 1 kg biochar would produce $0.3 of sweet potato. In 2021, four sweet potato varieties were tested at five rates of Biochar Plus at two locations. The addition of Biochar Plus dramatically increased sweet potato yields above the control with the addition of 1 t/ha producing a return of 2 to 3 $ per kg of Biochar Plus added. Also on the Baucau plateau we tested the impact of biochar with added P on legumes - peanuts, mungbeans and soybeans. The addition of biochar and SP36 significantly increased yield of all the legumes with the yields of soybean and peanut among the highest recorded in Timor-Leste. (See 2021 Annual Report)	
3.3. On-farm experimentation with cassava to include the effects of plant spacing and fertiliser rates on sustainable production and profitability for industrial use.	Leveraging TOMAK gross margin analyses on rice, maize, cassava, mungbean, soybean and peanuts, all these commodities were confirmed as promising for research and development in TL, except	

	cassava which was found lacking in potential for improvement due to its high production costs. (See Activity 1.5 above). As a result we aborted AI-Com's plans for research on cassava. (See *Section 6 Variations to future activities* in Annual Report 2018)	
3.4. Development of composite sampling techniques for aflatoxin detection with commercial maize and peanut growers. Composite sampling regimes for aflatoxin testing will be evaluated in both livelihood systems with intensive sampling of individual and composite samples, for which we will seek commercial seed lots.	Aflatoxin testing by QuickTestTM was introduced based on SoL research. Field samples of maize and peanut bags were collected by AI-Com and analysed by QuickTestTM. The range among samples was from 0.05 to 748 ppb of aflatoxin. The season was very wet, hence the high contamination levels. The pattern of extensive variation between bags within farms necessitates testing every bag precluding the introduction of a smart, reduced testing/sampling regime. Publication available on aflatoxin sampling of harvested grain.	
3.5. Adoption/Impact evaluation across innovations in Objectives 2 & 3. a) Preparation for baseline survey – design of sampling scheme, training of enumerators, design and pretesting of questionnaire. b) Conduct household survey to generate baseline data. c) Preparation for longitudinal surveys d) Statistical methods used to analyse the project impact based on baseline and longitudinal surveys. This activity will also be used to mentor TL socio-economist in statistical analysis. e) Key stakeholder engagement to identify issues to investigate further, design of in-depth interview guide and sampling design, selection and interview of key informers, data management and analysis.	Progress in conducting household natural resource management baseline surveys is described under Activities 1.1 and 1.2 above. Report available on Socio-economic evaluation of low labour mungbean system including aspects of adoption. See Activities 1.4 and 1.8	Will inform project researchers, other researchers and development projects

f) Identify enabling policy and institutional options by having personal interviews with key officials in relevant departments in the Ministry of Agriculture and representatives of relevant non-governmental organizations. g) Analysis of determinants of market participation using the survey data (Baseline and longitudinal data).	Not commenced	

Objective 4. To design and evaluate methods and practices for communities to increase forage supply from forage tree legumes

Under Objective 4 there were several changes in the research plan that are explained at more length in the 2018 Annual Report under Section 6 Variations to Future Activities. This part of the activity table uses the revised activities.

Activities	Outputs/ Milestones	Applications of outputs
2.1. Increasing rice yields sustainably: Replicated experimentation testing the effect of biochar, bio-fertilisers, rice planting and seedling systems and ages, inorganic fertiliser, and residual effect of green manures on rice growth and yield.	Field trials to increase rice yield by fertilisation with N, P K, or biochar were conducted at Vemasse by UNTL (Phases 2 & 3), and then by MAF in Maliana and Manatuto. Overall, yield increases from added P and biochar were linear, while N response was polynomial. Because of the higher price of red rice than white there was a greater $ return for kg fertiliser on red rice. Results are in Annual Reports 2019, 2020 and 2021.	Households in pilot communities adopt new management practices.
2.2. Alternative crops on spring-fed irrigated land: On-farm experiments comparing the gross margin of rice, soybean and other crops using local and improved agronomy. Residual impact of herbicides on soil land crops in Betano.	One option for alternative crops on spring-fed irrigated land is for farmers to grow red rice and to purchase imported white rice. Overall, despite little difference in productivity of existing white and red rice varieties, the economic return was higher from red rice due to its higher price - especially with fertiliser application. (Annual Reports 2020 & 2021) Soils sprayed with 1,5,10 and 100 times recommended dose of Glyphosate and Paraquat had no impact on peanuts planted directly after spraying. After 4 months, there was impact of Atrazine on second -crop germination. Soil health as measure by bacterial count and respiration were also unaffected by any herbicide.	

2.3. Crops after rice: On-farm experiments with farmers to identify the best timing for relay sowing of mungbean and other crops into maturing/mature rice crops. Crop modelling with APSIM will be used to extrapolate field data to other years and other climate scenarios.	Agronomic trials on locally important vegetable crops were conducted with various fertilisation combinations of rice husk biochar, phosphate (SP36) and cow manure at three sites with low-nutrient soils to identify soil constraints. A pot soil incubation trial with biochar levels was also undertaken for the acid site. At this acid site, biochar addition increased mean yield across crops by 230% over the unfertilised control. The combination of biochar with SP36 lifted mean yield to 387% over the control. In the neutral site (pH 7.3) and alkaline (pH 7.9) site, soil amendment with biochar lifted mean yield by > 170% over the control across locations. The use of biochar with phosphate increased yields by ~240% above control across locations. Soil analysis revealed that soil constraints alleviated by biochar amendments were mainly from P and Zn deficiencies. In conclusion, increases in mean vegetable yields among the highest recorded in the literature, were found from fertilising with biochar and phosphate individually and in combination in three low nutrient soils contrasting in pH. The responses were primarily from the alleviation of soil deficiencies in P and Zn. (Annual Report 2019 & 2020). As part of Acacio Guterres' PhD thesis with CDU, an experiment was conducted to compare the impact of Biochar Plus on horticultural yields over eight horticulture species (cabbage, capsicum, cucumber, eggplant, bok choi, rock melon, tomato and watermelon) in Maliana. All species produced a significant increase in yield with the application of 1 and 3 t/ha of Biochar Plus. The optimal rates of application of Biochar Plus were unknown on rice soils between rice crops, as was its interaction with other practices. Three experiments were conducted by UNTL final year students on rock melon in Maliana in 2020 dry season. In all trials there was a positive response in rock melon yield to the addition of Biochar Plus, and the second factor. But no significant interactions between factors. Overall, based on one kg of Biochar Plus producing 9 kg of rock melon, the average response was one dollar of Biochar Plus producing $36 of rock melons.	Contributes to the discussion on possible negative impacts of herbicides on Timorese soils.
2.4. Small-scale irrigation dry-season options for south coast: Replicated field trials at Betano research station and field trials with neighbouring farmers on time of sowing and irrigation trials on common bean, pigeon pea, lablab, cowpea, yard-long and winged beans into the dry season. On-farm experiments will compare costs and production of above crops for both human consumption and animal fodder.	Selection of best dry season crops for groundwater irrigation on the south coast: Multilocation, multi-year trials of common bean germplasm were conducted by MAF in 2018-2021 (see respective Annual Reports). Two common beans (one local & one introduced) are to be presented to variety release committee. Multiyear trial of winged bean was conducted by MAF. Two or three winged beans are to be presented to variety release committee.	

A comparison between trickle irrigation and hand watering from wells for high value crops will be made.	APSIM modelling was used to evaluate the impact of mulch, plant density and planting date of maize at Betano. Simulations of a complex virtual experiment (7 sowing windows, 5 plant densities, 13 years). Luis Almeida (ARSF) in flanking research: *How can we engage rural youth of Timor-Leste in farming?* Trials showed that, when farmers access water on their own farm in combination with Biochar Plus application to produce horticultural crops such as capsicum, shallot and carrot, they generate more profit compared to the common practice of growing maize. (ARSF Final Report 2022)	
2.5 Novel crops after rice. Research to be conducted by World Vision (WV) TL	Field trials were conducted by WV of the application of biochar and cow manure on sweet potato yield over three years. After three years, there was still a large response to a single application of biochar and cow manure. Large synergy between the two was observed. Yields in year three were reduced due to sweet potato weevil.	
2.6 Market analysis for selected crops using value chain approach.	Partial budget and gross margins research were conducted by UNTL students/staff using UNTL data Biochar and Biochar Plus using agronomic data from the dry season at Vemasse - Activity 2.3 above. As part of Acacio Guterres' PhD thesis, in an experiment comparing the impact of Biochar Plus on horticultural yields of eight horticulture species, partial budget analysis showed that the increased yields in all species produced an attractive economic return for all species, with an increase in return from $2 per kg Biochar Plus from capsicum to $44 per kg for watermelon. (See Activity 2.3)	Reports on production, consumption, price trends
2.7 Complete a series of factorial pot trials of biochar, P and Zn with a wide range (30) of TL soils. Completion includes soil analysis at UWA (Extension)	To test if biochar increases plant growth and yield by increasing plant available P, Zn and possibly K, a set of pot trials with peanut were implemented around the country on 22 soils. Peanut yield increased significantly with added biochar in 20 of the 22 soils tested (91%). Yield also increased in response to added SP36 and Zn sulphate in 15 and 10 soils, respectively (68 and 45% respectively).	Knowledge of the mechanism of biochar impact on yield will guide future soil fertility guidelines

2.8 Complete on-farm research on low-labour mungbeans after rice with growers (including testing crop establishment methods) and continue system scale-up on the South Coast *(Extension)*	Mungbean is typically grown in the second wet season in upland fields on the south coast of Timor-Leste. In 2020/21 we tested a farmer-modified low-cost method to increase mungbean profitability by reducing labour input. The system comprised chemical weed control (glyphosate prior to planting and no in-season weeding) and broadcasting mungbean seed. (See Annual Reports from 2019). Extension and adoption of the system started in 2020/21. Publication available: A Socio-Economic Evaluation of AI-Com's Low Labour Mungbean System	Best practice of low-labour mungbean practice identified
2.9 Complete second year of multi-year rice fertiliser trials *(Extension)*	See Activity 2.1 above.	Increase farmer knowledge of multi-year response to Urea and SP36
2.10 Annual testing of promising elite legumes, for potential release. *(Extension)*	See Activity 2.4 above.	Elite varieties of common bean and winged bean considered for release

Objective 3. To understand and develop crop management packages to intensify annual rainfed cropping and increase the financial viability of maize, peanut, cassava and food legume producers

Activities	**Outputs/ Milestones**	**Applications of outputs**
3.1. On-farm agronomic trials with mungbean (sowing trials in maize intercrops at various growth stages), winged bean (plant density in maize & cassava intercrops), dry bean and yard-long bean/cowpea and soybean to assess production and profitability.	Other sections Trials of intercropping maize and beans conducted in 2018/19 were reported in Annual Reports	Households in pilot communities adopt new management practices. Through field days on-farm trials will be used as demonstration for farmers and staff of NDAHE, development projects and NGOs to disseminate technology more broadly in target Districts & beyond
3.2. On-farm experimentation with commercial/semi commercial growers to assess the effect of lime, superphosphate and urea on maize production and profitability. Guided by soil tests of pH and available P, dose rates of triple superphosphate, urea and lime will be applied.	Initial planning for this activity was conducted with MAF researchers. MAF conducted these rate trials with their resources. Consequently AI-Com stopped planning research on the issue. AI-Com investigated the impact of biochar and Biochar Plus (see 2020 Annual Report, as flagged under Section 6 *Variations to Future Activities*) on wet season crops on the Baucau plateau - identified as with very infertile, acid soil. In 2020 the application of biochar alone on sweet potatoes in Baucau was cost effective as 1 kg biochar would produce $0.3 of sweet potato. In 2021, four sweet potato varieties were tested at five rates of Biochar Plus at two locations. The addition of Biochar Plus dramatically increased sweet potato yields above the control with the addition of 1 t/ha producing a return of 2 to 3 $ per kg of Biochar Plus added. Also on the Baucau plateau we tested the impact of biochar with added P on legumes - peanuts, mungbeans and soybeans. The addition of biochar and SP36 significantly increased yield of all the legumes with the yields of soybean and peanut among the highest recorded in Timor-Leste. (See 2021 Annual Report)	

3.3. On-farm experimentation with cassava to include the effects of plant spacing and fertiliser rates on sustainable production and profitability for industrial use.	Leveraging TOMAK gross margin analyses on rice, maize, cassava, mungbean, soybean and peanuts, all these commodities were confirmed as promising for research and development in TL, except cassava which was found lacking in potential for improvement due to its high production costs. (See Activity 1.5 above). As a result we aborted AI-Com's plans for research on cassava. (See *Section 6 Variations to future activities* in Annual Report 2018)	
3.4. Development of composite sampling techniques for aflatoxin detection with commercial maize and peanut growers. Composite sampling regimes for aflatoxin testing will be evaluated in both livelihood systems with intensive sampling of individual and composite samples, for which we will seek commercial seed lots.	Aflatoxin testing by QuickTestTM was introduced based on SoL research. Field samples of maize and peanut bags were collected by AI-Com and analysed by QuickTestTM. The range among samples was from 0.05 to 748 ppb of aflatoxin. The season was very wet, hence the high contamination levels. The pattern of extensive variation between bags within farms necessitates testing every bag precluding the introduction of a smart, reduced testing/sampling regime. Publication available on aflatoxin sampling of harvested grain.	

3.5. Adoption/Impact evaluation across innovations in Objectives 2 & 3. a) Preparation for baseline survey – design of sampling scheme, training of enumerators, design and pretesting of questionnaire. b) Conduct household survey to generate baseline data. c) Preparation for longitudinal surveys – identification and listing of indicators to be monitored and monitoring methods, design of survey tool and data entry template, collection of repeated data from participants on key indicators on annual basis. d) Statistical methods used to analyse the project impact based on baseline and longitudinal surveys. This activity will also be used to mentor TL socio-economist in statistical analysis. e) Key stakeholder engagement to identify issues to investigate further, design of in-depth interview guide and sampling design, selection and interview of key informers, data management and analysis.	Progress in conducting household natural resource management baseline surveys is described under Activities 1.1 and 1.2 above. Report available on Socio-economic evaluation of low labour mungbean system including aspects of adoption. See Activities 1.4 and 1.8	Will inform project researchers, other researchers and development projects

f) Identify enabling policy and institutional options by having personal interviews with key officials in relevant departments in the Ministry of Agriculture and representatives of relevant non-governmental organizations. g) Analysis of determinants of market participation using the survey data (Baseline and longitudinal data).	Not commenced	

Objective 4. To design and evaluate methods and practices for communities to increase forage supply from forage tree legumes (FTL) and sandalwood production to provide both short-term and long-term economic opportunities

Under Objective 4 there were several changes in the research plan that are explained at more length in the 2018 Annual Report under Section 6 *Variations to Future Activities*. This part of the activity table uses the revised activities.

Activities	Outputs/ Milestones	Applications of outputs
4.1 Site suitability & FTL/sandalwood agroforestry demonstrations Develop farm designs that incorporate crops, animals and sandalwood for participatory testing to optimise sandalwood and fodder productivity.	Demonstration plots established, and FTLs providing fodder and host of sandalwood. Publication - Almeida et al. 2022 Extension manual available for FTL/Sandalwood agroforestry Publication - Page et al. 2018	Pilot communities adopt innovations. NDAHE, development projects and NGOs disseminate technology broadly in target Districts & beyond. Improved cattle production. Information about sandalwood agroforestry in T-L. Extension document informs establishment of new FTL/sandalwood smallholder and investor plantings - MAF, UWA, USC

4.2 Nursery research with MAF to develop quality seedling production systems for transfer to community-based nursery	An improved village-based nursery system for sandalwood seedlings Report available of robust method for producing seedlings of FTL, other hosts and sandalwood. Establishment of at least 2 village /smallholder nurseries to produce sandalwood and FTL seedlings	Information to guide and inform the design of the nursery trials Several villages producing quality seedlings
4.3 Establishment of sandalwood seed stand(s) representing the species geographical range (revised activity) Sandalwood rejuvenation for domestication & smallholder agroforestry:	Sandalwood seed lot comprised of a broad range of provenances. Ex-situ conservation stands established. Publications: Almeida et al. 2019 & Almeida et al. 2022 Manual produced of smallholder-appropriate methods to manage existing wild sandalwood trees. Report available of reproductive phenology of sandalwood in TL to plan seed collections.	
4.4 Evaluation of methods for communities to increase forage supply from FTLs and sandalwood production for short-term and long-term economic opportunities Survey of sandalwood producers and interviews with experts and key informants to understand key factors affecting the economic and financial viability of sandalwood investment. Development of cost-benefit models for decision-making Economic and financial analysis of sandalwood investment options.	Realistic assumptions for use in cost-benefit analysis Report and Microsoft Office Excel spreadsheet available of cost-benefit models for decision-making Timor Leste sandalwood policy review. Review report for stakeholder comment Report, policy briefs, and peer-reviewed papers available on sandalwood marketing (including harvest transport) for smallholder producers	Will guide user communities and NDAHE, development projects and NGOs

4.5 Establishment of critical sandalwood collection at Natabora. (*Extension*)	See Activity 4.3 above	
4.6 Identification of characteristics of successful nursery pot media (*Extension*)	See Activity 4.2 above	
4.7 Continue monitoring community and plantation sandalwood experiments		

7 Key results and discussion

7.1 Objective 1. Community decision-making for natural resources management (NRM)

Previously completed reports of surveys are available and have been covered in Annual Reports and publications (E.g. Baseline survey reports, animal control survey, and the business case for biochar). Results and Discussion of the more recent surveys on Fertiliser, Low labour mungbean system, Farmer perceptions of trees (specifically sandalwood), and the Bio-Char Plus Business Incubation report are integrated into the Key Results and Discussion within technical Objectives 2 through 4 (below). Here in the final report under Objective 1 we focus on two published studies of SoL3 data and our digital presence: One publication tracks the effect of the adoption of new maize varieties on market participation, while the other focuses on women's access to agricultural extension.

Technology adoption of high-yielding maize varieties increases smallholder farmers' market participation in rural Timor-Leste. A study was conducted of the role of high-yielding maize varieties as one of the key drivers of smallholder farmers' market participation in a highly subsistence rural economy in Timor-Leste (Akter et al. 2021). The analysis was based on SoL3 data from 700 households in rural Timor-Leste. The results revealed significant positive impacts of technology adoption on farmers' market participation. Households where women are relatively more active in agriculture than men are more likely to engage in agricultural commerce. The results also show a positive impact of technology adoption on maize productivity. These findings present the first empirical evidence of the causal link between technology adoption and market participation choices.

An agricultural program, such as SoL, which targeted engagement of women significantly improves women's access to extension. Agricultural development programs are increasingly aiming to boost women's engagement in agricultural extension in countries and regions where women are marginalized and their access to extension is constrained by socio-cultural and institutional barriers. Studies examining the impact of such programs on women's participation in extension and households' agricultural practices are limited. Using SoL3 data, our study identified a significant gender gap in access to extension in Timor-Leste (Akter et al. 2020). We found that an agricultural program with a conscious effort and clear target to engage women significantly improves women's access to extension. Additionally, our results revealed that women's access to extension changes households' cropping practice by increasing the cultivation of the number of major and minor crops and the number of plots. Interestingly, we found a significant negative correlation between women's access to extension and adoption of improved variety in the program villages. Learnings from AI-Com will be incorporated in the extension activities of the follow-up project AI-Com2.

Digital presence: During the AI-Com project we maintained the Seeds of Life (SoL) web page (http://seedsoflifetimor.org/) as a resource and updated the publication list. During SoL3 (2013-2016), the website attracted c. 25 users/day. Since the closure of SoL (2016), usage hovered around 21-23 users/d, indicating its potent heritage value. But from April 2020, when Timor-Leste closed its borders because of COVID-19, the number of SoL webpage users dropped dramatically to below 10 users per day as global attention to agriculture waned. In the last two years, the SoL web site serves 10 users per day.

Our AI-Com website (https://ai-com.tl/) allows AI-com publications to be available to a wider audience. The project also maintains its own English Facebook page which has attracted a consistent following. Follower number rose from launch in Dec 2017 to 12,212 by Dec 2019. It has remained static for the last 3 years as the number of posts reduced slightly following the departure of Sophie Rayner from AI-Com in December 2019. The most viewed post was about sampling sandalwood trees for oil content (50,000 views). Other topics, such as the use of biochar on vegetables in Viqueque and low-labour mungbeans, had 30,000 views.

7.2 Objectives 2. and 3. Intensive irrigated cropping systems for the South coast, and crop management packages for rainfed crops

Objectives 2 and 3 cover the cropping intensification research in the project. Rather than discussing piecemeal by Activity as in Section 6, they are discussed by sub-themes as follows:

- Biochar and soils
- Systems: Rice and crops after rice
- Systems: Biochar and soils
- Systems: New crops and old crops in new locations
- Aflatoxin

It should be noted that *Biochar and Soil* and *Systems* track directly onto new themes in the follow-up project AI-Com2.

Biochar and soils

Biochar almost universally increases crop yields in Timor soils.

In 2017, UNTL trials in the dry season at Vemasse showed major responses in yield to rice-husk biochar. This was confirmed on a range of horticultural and field crops at a wide range of other sites across the country. In 2021, to test the hypothesis that biochar (20 t/ha) increases plant growth and yield by increasing plant available P, Zn and possibly K, a set of pot trials with peanut were implemented around the country on 22 soils. Results for P, Zn and possibly K are discussed below. Peanut yield increased significantly with added biochar almost universally - in 20 of the 22 soils tested (91%). Of the soils that responded to added biochar, the average increase in peanut yield was 98%. The positive response of yield to applied biochar was consistent across all four parent material categories. Although alluvial soils had much lower yield (than other soil parent material) with no addition of biochar, the average response to added biochar was very similar.

Biochar can be combined with chemical fertilisers and cow manure to benefit from the additive effect, and sometimes the synergistic effect of the combination.

World Vision studied the impact of soil amendment with rice-husk biochar in combination with cow manure on orange-fleshed sweet potato in four municipalities with 23 locations in 2019 and again 40 sites in 2020. Each site was an unreplicated experiment with four treatments: 1) control, 2) 10 t/ha manure added, 3) 10 t/ha rice-husk biochar added and 4) both rice husk biochar and cow manure added, both at 10 t/ha. Across the 63 sites in both years the combination of rice-husk biochar and cow manure combined had a greater impact on yields than either alone. The average yield increase per added kg of manure and rice-husk biochar alone was 1.0 and 0.48 kg sweet potato respectively. However, the combination of manure and rice-husk biochar increased sweet potato yield by 1.8 kg per kg of added material. In terms of yield, the application of manure combined with manure increased yields from 10.3 t/ha to 45.5 t/ha across the 23 sites.

Biochar Residual Effect

The residual effect was followed up at most of the sites in 2021 and 2022. Over the three years of sweet potato production, control were 23 t/ha. With the application of rice-husk biochar and manure yields increased to 51 t/ha and 54 t/ha respectively. A combined application of cow manure plus rice-husk biochar recorded a yield of 106 t/ha over the three years. In all three years, the yield of the combination of biochar and cow manure was more than expected from the impact of the additions alone (Figure 2).

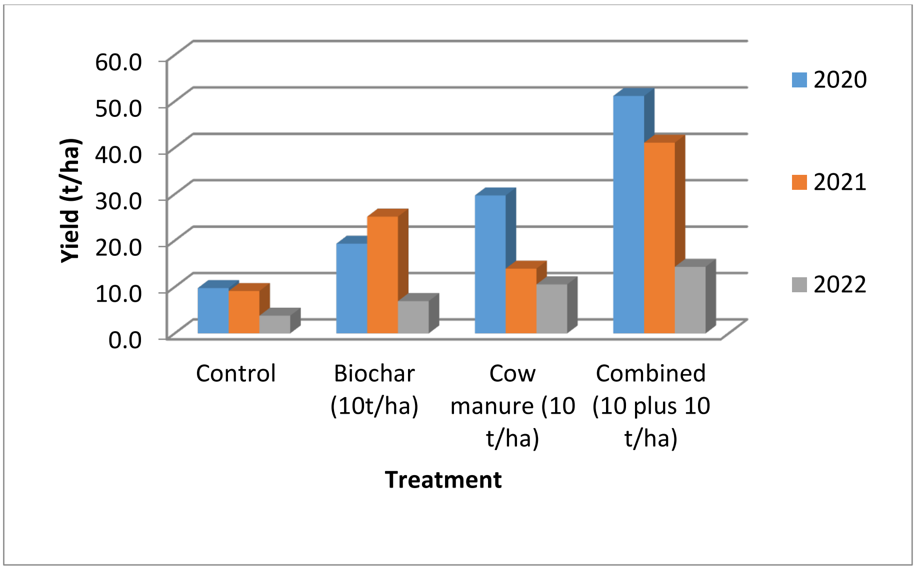

Figure 2. Impact of rice hull biochar (10 t/ha) and manure (10 t/ha) applied separately or in combination on sweet potato yields across 3 municipalities in Timor-Leste, on the year of application and the second and third years after application. (LSD $_{(P<0.05)}$ = 5.5)

Cost/benefit was calculated for the addition of manure and biochar to sweet potato. At a farmgate price of $0.80/kg for sweet potato, the addition of one kilo of manure increased the value of sweet potato by an average of $0.13 across both years. The addition of biochar gave a similar result, increasing the value of sweet potato production by $0.10/ kg of biochar. However due to the synergy of applying biochar and manure, when biochar and manure are added together, one kilo of combined biochar and manure produced $0.92 of extra sweet potato. The increased value of sweet potato per kilo of mixed biochar and manure was consistent across the years ($0.88 and $0.96, respectively).

Biochar is economic to make and be sold for horticulture production, and sweet potato production.

A Biochar Plus businesses in Maliana were incubated in 2021 to create a platform on which the market and adoption cycle for the product could begin. This followed up from the AI-Com business case study (Biochar Business Case - 2019 Ann. Report) for the production of Biochar and Biochar Plus (defined as Bio Char mixed with 2%N and 1%P_2O_5 added as Urea and Super Phosphate) and field trials indicating economic value addition of biochar was available for capture, for both the farmer and producer.

The business case showed that the volume of rice husk available does not warrant the capital investment and financial incentive that rice millers find appealing enough to undertake Biochar production. Therefore AI-Com supplied equipment to support the incubation of the business in Maliana. By so doing, and with business support, AI-Com was able to successfully incubate a business by adding a revenue stream to the existing rice milling business that will now begin a cycle of growth in agriculture in Maliana. Farmers now have access to a product that helps them improve their soil and yield. This allows for successive production cycle improvements enabled by the increased fertility of the soil, which in turn could increase future throughput at the rice mill and the ability to make more Biochar.

In 2021 at the conclusion of the short incubation period of the biochar manufacturer, one business (Vital) in Maliana had 690 kg of finished product in stock and approximately 2 t of Biochar at various stages of drying out before being mixed with Urea and SP-36 to create Biochar Plus.

Rice husk biochar rehabilitates acid weathered soils with a single application at 20 t/ha. The soils on the Baucau plateau have been identified as very infertile, sometimes with acid soil. But in 2018 a large response to soil amendment with rice-husk biochar was found on this plateau soil (An. Report 2019). The residual effect of this single application of soil amendment was then tracked from 2018 to 2022. The single application fertiliser treatments applied in 2018 were 1. Control, 2. Local fertiliser - cow manure at 1200 kg/ha, 3. Rice-husk biochar (30 t/ha), 4. Superphosphate (SP-36) at 80 kg/ha, and 5. Combination application - Biochar + SP-36. In 2022 the maize yield of the unfertilised control was 0.3 t/ha, whereas the plots fertilised once in 2018 with biochar yielded 3.7 t/ha and biochar + SP-36 gave 4.3 t/ha, indicating major residual effect in this soil of a single application in 2018 of soil amendment. In 2022 the pH_{H2O} of the control plot was 4.6, while the plots fertilised with biochar + SP-36 in 2018 the pH_{H2O} was significantly improved to 5.5. Maize was not grown continuously in the same plots over the five years. A rotation of the crop treatment within the design allowed maize to be rotated with legumes approximately every second year. AI-Com2 will continue to monitor the effect of biochar application on crop yield and selected soil properties at this field site.

Biochar, SP36 and Zn increases peanut yield in a diverse range of soils.

To test the hypothesis that biochar increases plant growth and yield by increasing plant available P, Zn and possibly K, a set of pot trials with peanut were implemented around the country on 22 soils. Peanut yield increased significantly with added biochar in 20 of the 22 soils tested (91%). Yield also increased in response to added SP36 and Zn sulphate in 15 and 10 soils, respectively (68 and 45% respectively). Most yield responses were additive to each other with very few significant interactions between added Biochar, SP36 and Zn sulphate on peanut yield among the 22 soils. Compared to the responses to added biochar (average increase in peanut yield 98%), the response to added SP36 was lower (46% yield increase and less again for the response to added Zn (31%). Soil parental material had an impact on the yield response to added SP36. Yield response to added SP36 was greatest on the northern Alluvial soils and on limestone derived soils, and zero on the southern alluvial soils. Although the plant response to added SP36 has been known in many soils in Timor-Leste, this is the first time a yield response to added Zinc has been measured. There was a significant correlation between soil pH, and the yield increase with added SP36 and Zinc. In general, soils that responded to SP36 application, also responded to added Zn application. The size of the response was negatively correlated with soil pH. Soils with pH 8.0 or higher showed very low response to added SP36 and Zn and as soil pH decreased, the yield response to SP36 and Zn increased.

The additive and combined effect of added SP36, Zn and Biochar on peanut yield across the 22 soils suggest that biochar is increasing yield in ways other than increasing soil availability Zn and P, thus disproving the hypothesis.

Although Mehlich 3 analysis could identify different levels of available nutrients between soils, the analysis was unable to identify any changes in available nutrients in response to added biochar. Additional targeted pot studies on mungbean, and for soil types whose response to biochar have not been investigated, will be conducted in AI-Com2.

Fortified biochar (Biochar Plus) increases the benefit of biochar in Timor-Leste.
Biochar Plus (combination of rice-husk biochar with low levels of N and P [2%N and 1%P_2O_5] was formulated and has now been tested on a range of crops under several field environments. To compare the impact of Biochar Plus (rates: 0, 1 and 3 t/ha) on horticultural yields, a field experiment was conducted over eight horticulture species in Maliana in 2021, as part of Acacio Guterres' PhD thesis. All species produced a significant

increase in yield with the application of 1 and 3 t/ha of Biochar Plus. Biochar Plus price was set as $0.50/kg and price of the vegetables were set at farm gate price in Maliana at the time of harvest. The increased yields in all species produced an attractive economic return for all species, producing an increase in return from $2 per kg Biochar Plus from capsicum to $44 per kg for watermelon.

To assess the optimal rates of Biochar Plus application, experiments was conducted by UNTL final year students on rock melon in Maliana in 2021 dry season. In all three experiments there was a positive and significant response in rock melon yield to the addition of Biochar Plus (rates 0, 1, 3 & 5 t/ha), and to a second factor (plant spacing, the use of different types of mulch, and the impact of terminal drought). There were no significant interactions between the application of biochar and the second factor in any of the trials. Overall, the average response was that one dollar of Biochar Plus produced $36 of rock melons. This was based on one kg of Biochar Plus producing 9 kg of rock melons.

Systems: Rice and crops after rice

Inputs for rice production

Average rice yields are low in Timor-Leste primarily because of the lack of inputs. Several years of experiments were undertaken by the project to quantify the effects of adding inorganic fertiliser (N, P & K) and rice-husk biochar to rice, including the comparison of red v. white varieties. A four-way factorial experiment showed that the application of N, P and biochar increased yields significantly, but the application of K did not reach significance. Application rates were N (100 kg N/ha), P (25 kg P/ha), K (45 kg K/ha) and biochar (10 t/ha) on rice. There were no significant interactions between any of the factors. The application of N produced the largest yield increase (3.7 t/ha); while P and biochar showed similar yield increases (0.7 and 1.1 t/ha, respectively), indicating the need to understand the dose response to fertiliser. To this end we used a multiple polynomial regression on the full data set - the combination of yield and treatment data from each experiment - comprising a total of 130 data points of different rates of N, P and biochar. Briefly, the yield of the varieties increased in a similar manner with the addition of N, P and biochar. Yield increase in response to added P and biochar application was linear, with non-significant polynomial terms in the regression, and only the application of N had a polynomial response. The effect of rice variety (Nakroma v. red rice) was non-significant in the model. The resulting regression accounted for 79% of the variation in rice yield with the root mean squared deviation (RMSD) between observed and predicted yield of 0.33 t/ha. The predicted responses of rice to added urea and SP-36 indicate that the MAF recommended rate is conservative and financially rewarding (Figure 3)

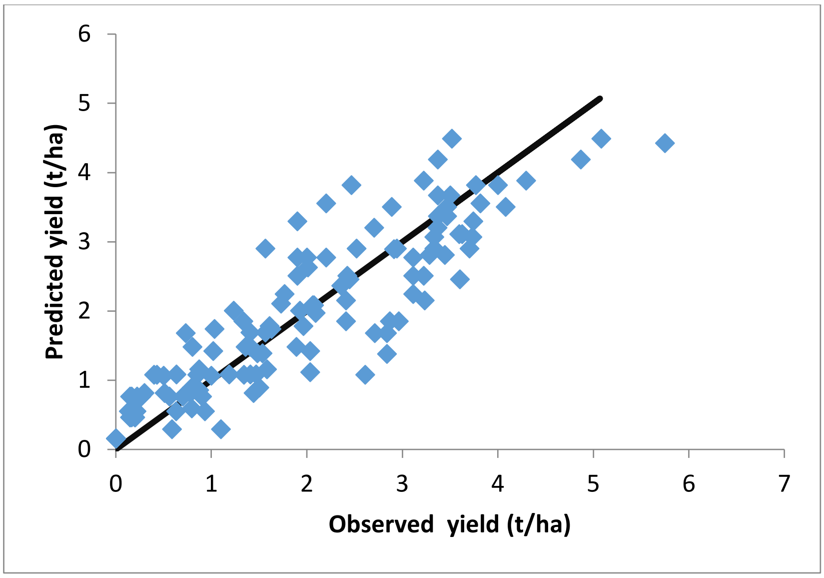

Figure 3. Observed versus predicted rice yield based on a linear regression using the rates of applied N, P and biochar.

Combined analysis over years and trials has shown that the MAF recommendation for rice inorganic fertiliser input is appropriate for both red and white rice varieties. The current MAF Good Agricultural Practices (GAP) for rice has a general application rate of 23 kg N (50 kg urea /ha) and 18 kg P /ha (50 kg TSP/ha). As this is a blanket rate for all rice areas, the rate needs to be conservative to ensure it has a maximum effect for increasing rice production. Based on AI-Com research this conservative rate is economic for all tested rice sites. At a relatively high yielding rice site, that has a control yield of 2.7 t/ha the recommendation of 50 kg urea and 50 kg SP36 would increase yield by 0.7 t/ha, returning an additional $280 for additional cost of $100. Lower yield sites have a higher and therefore greater economic return in the first year. In addition, AI-Com research has demonstrated the beneficial impact of urea and SP36 application in the second crop after application.

To measure the impact of biochar on the economics of rice production, a partial budget was used to define the economic return of biochar using the data from the MAF biochar rate trials over two years and four locations. The economic return is the extra value of rice produced per kg of biochar. On average, biochar produced $ 0.02-0.06 of value of rice per kg biochar applied over all years and test locations. Average returns were higher in Samalari ($ 0.08/kg) than in Laga ($ 0.038/kg) in 2019. In 2018 in Viqueque and Baucau, the economic return of biochar was $ 0.02-3/kg of biochar.

It is estimated that the cost of labour to produce husk biochar is approximately $ 0.05/kg of biochar. Then there are added costs of bagging, transport etc that could increase the cost of production and distribution to about $ 0.10/kg. The dollar return in the first season of applying rice husk on rice fields is probably less than the cost, and not advantageous to the rice farmer. There is a likelihood, however, that biochar will increase yields in the following years and would therefore give a benefit to the rice cropping system, but this remains to be tested. As a result biochar use on rice fields is not recommended to increase rice production.

Residual impact of inorganic fertiliser to rice is neutral or positive, NOT Negative.

AI-Com has demonstrated large economic yield increases in response to applied N as urea and P as superphosphate to rice. Although the resistance of farmers to chemical fertiliser has lessened, the residual impact of urea and superphosphate is often questioned. On-farm experiments were designed to investigate the residual impact of applied urea and superphosphate on the following rice crop in two subdistricts in Timor-Leste in 2019/20. At both Triloka and Laga application of the recommended fertiliser rate (50kg Urea + 50 kg/ha Superphosphate significantly increased yields in comparison to when no fertiliser was applied. In the following year, the residual impact was positive at both locations, but not significant at Laga.

Fertiliser survey: While fertiliser use (organic and inorganic) for cropping is low overall in Timor-Leste, barriers to increased use are surmountable.

AI-Com's agronomic trials showed major responses to fertiliser application in a range of crops. The adoption of inorganic fertilisers and new inputs, such as Biochar Plus, can increase domestic food production and conserve soils. However, Timorese farmers are known to use minimal inputs, including inorganic and organic fertilisers. The socioeconomic team conducted a survey in 2021 to explore farmer attitudes towards using organic and inorganic fertilisers and their application. The survey confirmed that Timorese farmers use minimal inorganic and organic fertilisers: From the farmers surveyed (N=157) only 50% had experience using inorganic fertilisers and 69% had experience with organic fertilisers. Over half of respondents (59%) expressed a favourable attitude towards using inorganic fertiliser into the future. All respondent groups, particularly non-users were positive about receiving training and participating in demonstration plots, indicating that they were open to gaining more knowledge on fertiliser application. Over half of respondents who intend to use inorganic fertilisers in the future suggested that the remaining respondents might be negatively influenced by their perceived concerns and barriers towards applying inorganic fertilisers. Compared to respondents' perceived physical and financial constraints to accessing inorganic fertilisers, almost all respondents reported having easy access to organic fertilisers (96%). Almost all former users and non-users strongly disagreed that they did not use inorganic fertilisers because of cultural taboos or that they were afraid people will mock them if they used inorganic fertilisers. In-depth interviews with key informants suggest that farmers' use of the phrase "fertilisers destroy land" is primarily rooted in their negative perception that they will become locked into a vicious cycle of dependency once they start using inorganic fertilisers, in particular, that the soil will become dense and unproductive if fertiliser use is discontinued. Considering respondents have very positive attitudes towards MAF extension workers, interventions such as training on proper fertiliser application and sustainable soil management through MAF extension services would likely be most relevant and effective.

As Timor-Leste develops legislations and policies on agrochemicals, including inorganic fertilisers, a testing and labelling model could be adopted by MAF to promote safe handling practices, correct application methods and reduce exposure of toxic chemicals for humans, animals and the environment. The importance of striking a balance between meeting the growing global demand on food production and food security with the need to minimise potential chemical toxicity on soil, animal and human health is increasingly recognised with the development of the International Code of Conduct for the Sustainable Use and Management of Fertilisers (FAO 2019). Considering inorganic fertiliser usage in Timor-Leste is currently low, and our survey findings suggest physical, financial and technical constraints to inorganic fertiliser adoption among the sampled farmers, this provides a timely opportunity for research and policy interventions to promote judicious fertiliser use that can lead to sustainable outcomes for the Timorese population and its environment.

Low labour mungbean system - Survey emphasised the value to households in increased income, decreased women's labour and increased soil fertility. In Timor-Leste mungbean is a minor crop usually sown after rice. The innovation of the low labour mungbean system entails changes in sowing method from dibble stick to broadcasting and in weed control from hand weeding to herbicide use with glyphosate before sowing. Both broadcasting and herbicide use for mung bean production are new to farmers. Herbicide use for maize production had been slowly increasing over the previous 3-5 years.

A socio-economic survey of low labour mungbean system was conducted and farmers who obtained a high production and income from mungbean were those who planted in the second rice planting season (between June-August). They had no problems with animal damage since rice farmers let their cattle graze on the uplands rather than on the cropped lowlands during this period.

Famers listed the main benefits of growing low labour mungbeans were the innovation provided a source of income (36%), mungbeans are high in nutritional value (18%) and growing mungbeans improved soil fertility (16%).

Men and women hold different roles in household agricultural production and taking a gender perspective can ensure pre-existing inequalities within households are not deepened, improve crop production and the long-term adoption of innovations. Most respondents indicated that both heads of households were jointly involved in deciding to implement the low labour mungbean system (77%). They responded similarly in terms of decision making on mungbean sale (65%) and the use of the derived income (68%). These findings, together with the gendered labour roles (e.g., men were responsible for herbicide application while women took charge of carrying, drying and threshing mungbean), suggest men and women are inter-dependent in implementing the low labour mungbean system. We found that men took charge of herbicide application because the sprayer tanks were considered too heavy by women, providing alternative, physically less demanding technologies for herbicide application can lessen the work burden for men and empower women who face labour concerns.

Most farmers wanted to continue applying the innovation in 2021, particularly since the price is higher for mungbean ($0.75-1.75/kg) than maize ($0.30/kg). Herbicide application helps farmers reduce time and labour spent on weed control. The gross margin analysis indicated that the gross income obtained from low labour mungbean system (no tillage) is higher ($509/ha) than with traditional method or tillage ($418/ha). The use of the system also increases the dollar return on labour from a range of $4 to 8/day to more than $8.00/day when planting using dibble stick to $15/day when broadcasting.

The technology for low labour mungbean was developed by farmers hybridising previous knowledge with new techniques to develop novel innovations (Williams et al. 2022). There are other such innovation developments in AI-Com/SoL3: variety selection and new varieties of sweet potato and the use of on-farm storage of maize in 44-gallon drums for the market. In all three cases the external technologies were introduced into the community for testing and extension combined with local knowledge and then developed into new innovations by local growers. Reflecting on the process after successful adoption, we realised that via on-farm testing (and demonstration), both the researcher with the farmers are co-developers of the novel innovations. The innovation or technology can be changed/modified/adapted by the family to best suit the family's needs. Recognising that farmers often add their knowledge to new techniques to produce novel innovations we have four recommendations for researchers working with farmers. These are 1) expect the farmers to adapt and change introduced techniques 2) allow farmers extra inputs and time to do their own experiments 3) visit the co-operating farmers after the testing/demonstration is finished to discuss and understand their response and changes and 4) recognise and promote the novel innovations as co-created.

Returning to mungbean, the crop is typically grown in the second wet season (June–October) in upland fields on the south coast. Following co-development with farmers, the researchers at Betano followed up low labour mungbean in the rice area of Akadiru in Betano in 2020. A total area of 6 ha had been sown with the two MAF-released varieties Lakateu and Kiukai in June and then harvested in October. The farmers in the demonstration were very pleased with the system of weed control using herbicide instead of cultivation. After they saw the establishment of mungbeans in the non-cultivated soil, they planted an extra 10 ha to mungbean using no-cultivation techniques. The reduced need for weeding and for irrigation were greatly appreciated by the farmers. Because they harvested during the COVID 19 emergency, the farm-gate price of mungbeans was $1.0 to $1.5/kg, while the normal on-farm price at harvest time is $0.75 /kg. By 2021 of the project more than 140 ha of low labour mungbeans were being grown along the south coast. In the final year of the project an additional 240 ha (estimated) of low labour mung beans was planted in Betano alone. Additional secure on-farm storage to prevent keep bruchid damage is becoming an issue, as buying demand has slowed down, and farmers cannot sell as quickly as in the last few years.

Increasing the access to information (and hence adoption) on the opportunities and limitations for expanding low-labour mungbean in the south coast region and inland irrigated zones will be a key objective of AI-Com2.

Systems: New crops and old crops in new locations

Evaluation of legume options: Promising common bean, cowpea and winged bean lines identified for varietal release

Against a backdrop of widespread low soil fertility nationally, with MAF we evaluated a range of introduced and local legume options. In common beans, we concluded three year's testing of 24 genotypes at three contrasting locations. As a result of consistent superior performance, three common beans (one local & two introduced) are to be presented to the national variety release committee. The local bean was sourced from Atsabe and is named "Lokal Atsabe". The introduced beans were sourced from CIAT and their CIAT accession names are GI0121 (ex-Netherlands) and G13898 from India.

Winged bean: The winged bean is a forgotten crop in Timor-Leste. In 2011-2013 the SoL3 program tested introduced winged bean genotypes on research stations, and three lines were selected for evaluation on-farm. MAF began to multiply seed of these three varieties to release them as varieties, but the seeds were admixed. AI-Com supported the seed increase of pure seed and confirmatory trials. Two winged beans are to be presented to the variety release committee. They were sourced from the Australian Tropical Germplasm Collection and designated as UPNG 10 and Thailand 6.

Short-season cowpea: The lines introduced from IITA were yield tested during the first two years and promising lines selected. From this initial evaluation clearly short season cowpea has considerable potential in Timor-Leste. But as seed stocks were lost, we need to revert to IITA for seed of the best lines.

Increasing the access to information (and hence adoption) on the opportunities and limitations for including additional legume options (common bean, short-season cowpeas and winged beans) in the south coast and north coast cropping regions will be a key objective of AI-Com2.

Red rice: One option for alternative crops to rice on spring-fed irrigated land is for farmers to grow red rice and to purchase imported lower-value white rice. For red rice there is both an internal and an international market. The lowest effort option for cropping choice to increase income in rice-based irrigated rice systems is to switch from white to red rice - as proposed in the MTR. For this comparison, Nakroma - released white rice cultivar - was tested against a MAF-tested red variety Goa 1 in many trials under Activity 2.1. For example, to improve rice productivity, the response of red and white rice varieties to inorganic fertiliser (N & P) was studied at three sites in Maliana in 2020 and to Biochar Plus in 2021 at five locations in Vemasse. A substantial response to soil fertilisation was exhibited. Because of the higher price of red rice ($0.6/kg paddy compared to $0.4/kg paddy for white rice), there was a greater dollar return for fertiliser applied to red than white rice. Averaged over sites, the economic return of Biochar Plus applied to red rice at the rate of 1 ton/ha is $0.99/kg, much more than the cost of production. In contrast the use of Biochar Plus on white rice as not an economic proposition.

Old crops in new areas

Common beans, onions and carrots are traditional crops in Timor-Leste and have always been grown in elevated areas, above 1000 m above sea level. However, during AI-Com evaluation, some species were tested outside their known range of adaptation. This testing has shown that crops like onion, carrots and common beans can be grown profitably in lowland areas, during the cooler dry season of April to October. Successful carrot crops were initially grown at Natabora ETA in 2019, much to the surprise of the staff at ETA. Again at 5 locations in the Natabora region in 2022, Luis Almeida's ARSF research grew profitable crops of onions and carrots in the Natarbora region, along the south coast. Common beans have been grown on the coast flat lands and on the Baucau plateau (400 m asl) to the surprise and profit of local farmers.

APSIM simulation helped researchers understand the cropping system

APSIM was used during AI-Com to simulate yields of maize and beans in complex multi-year experiments. These simulations built on climate change research using APSIM during Seeds of Life. Unlike Seeds of Life, these simulations were conducted by MAF researchers as part of a hands-on training exercise. This was a great learning opportunity for the researchers involved, as running the simulations tested their knowledge of the dry-land cropping system, and ability to analyse large output data sets.

Briefly, APSIM modelling was used to evaluate the impact of mulch, plant density and planting date of maize at Betano through simulating a complex virtual experiment (7 sowing windows, 5 plant densities, 13 years). In the following year, a similar simulation experiment on yield of mung beans and common beans was conducted to assess the impact of plant density (10-50 plants /m^2) and sowing date (same as maize) in Betano.

For maize, the plant density response was same for all sowing dates, suggesting on recommended sowing date is suitable for wet and dry season maize cropping. Consistent high yields were simulated for sowing dates from December to March, then dropped significantly in April to June. For the bean species maximum yield was obtained at 40 plants/m^2 at all sowing windows. As the sowing window is later than January, yields were from 900 kg/ha to 400 kg/ha in a May planting. In addition, the simulations suggested that optimum plant density for maize, mung and common beans are unlikely to change with sowing date, ranging from December to May. This adds to the evidence that the one recommendation is sufficient across these divers planting dates.

Aflatoxin

Aflatoxin was found in maize and peanut farm samples and in the blood of women and children, but the consumption of aflatoxin contaminated grain is not considered a causative factor in the current level of malnutrition and stunting affecting Timor-Leste children. Aflatoxins are toxic fungal metabolites produced by *Aspergillus* sp. with carcinogenic properties that are a common food contaminant of many crops including maize and peanuts. In Timor-Leste malnutrition and children's stunting are frequent and maize and peanuts are staple foods. We aimed to provide information on aflatoxin exposure nationally. The study measured levels of aflatoxin in locally-produced maize and peanuts (296 samples) and of aflatoxin-albumin conjugate in blood samples of women and young children (514 and 620 respectively) across all municipalities (de Almeida et al. 2019). Blood samples were collected within the Timor-Leste Food and Nutrition Survey in 2013. The average concentration of aflatoxin in the grain samples was lower than European Commission tolerated aflatoxin level in most maize (88%) and peanut (92%) samples. The pattern of extensive variation in aflatoxin between bags within farms necessitates testing every bag and precludes the introduction of a smart, reduced testing/sampling regime. Although aflatoxin–albumin conjugate was detected in more than 80% of blood samples, the average concentration in children and adults of 0.64 and 0.98 pg/ mg alb, respectively, is much lower than in other similar rural-based countries. Although low in concentration, blood aflatoxin levels and aflatoxin contamination levels in maize across municipalities were correlated significantly for mothers (R^2=37%, n=495) but not for children (R^2=10%). It is unlikely that the consumption of aflatoxin contaminated grain is a causative factor in the current level of malnutrition and stunting affecting Timor-Leste children.

7.3 Objective 4: Forage supply from forage tree legumes and sandalwood production

Survey of farmers' perceptions of trees (specifically sandalwood) found widespread interest to plant sandalwood primarily for income generation. Sandalwood (*S. album*) occurs naturally in the upland areas of the two AI-Com target zones of Natarbora and Maliana. There was consensus among respondents that wild sandalwood trees occurring on customary lands are owned by the customary groups (*uma lisan*) or individuals. Sandalwood planted on customary land or privately held land belong to the customary group and landowner, respectively. From 2018 to 2020 the AI-Com project engaged with 42 landowners to establish small sandalwood plantings of up to 20 seedlings each. All participating growers planted sandalwood on land over which they claim ownership. The General Regime of Forests (RDTL 2017a) supports landholder use of forest resources on customary land for commercial purposes. Nevertheless, harvesting sandalwood is prohibited due to its depleted state and associated concerns over sustainability (RDTL 2012). Commencing in 2012 this prohibition is effective for 25 years. AI-Com's participatory sandalwood plantings established with landowners from 2018 to 2020 will be unaffected by this ban, because the expected harvest age (least 20 years) will occur after the expiry of the moratorium. AI-Com2 will investigate the current scale of planted sandalwood in Timor-Leste that would contribute to a prospective legalised trade.

The National Policy on Forests of Timor Leste (RDTL 2017b) and the National Agricultural Policy and Strategic Framework (RDTL 2017c) both support sandalwood agroforestry for income generation. So, tree tenure of planted trees on one's own land is considered secure enough to facilitate smallholder investment in establishing woodlots.

There was some recognition among both men and women that women had the right to plant and own sandalwood trees. This view was held widely in Natarbora (Tetun-Terik ethnolinguistic group), but not in upland Maliana (Kemak ethnolinguistic group), where only 33-75% of men considered women could own sandalwood. The primary reason for this perception was that women migrate patrilocally following marriage. The right of married migrant women planting and owning sandalwood trees was not further clarified. Therefore, while women can own sandalwood in TL, there are cultural restrictions within particular areas or families that limit their rights to own sandalwood. In Natarbora, evidence of gendered labour divisions was found where men plant the sandalwood while women assist in weeding.

Interest in planting sandalwood was widespread among households with decisions regarding planting primarily made jointly by men and women heads of households, followed by the male head of the household. In only a small minority of households do women or other members of the family have the primary decision-making role regarding planting sandalwood. The reason for wanting to plant sandalwood was overwhelmingly for income generation to support family needs, send children to school, distribute equally among family members and for family cultural obligations.

Sandalwood mortality was recorded within the micro-woodlots established in 2019 and 2020, and attributed primarily to lack of water, and pest and livestock destruction. In addition to these factors, households listed fire, weeding and lack of market as a significant risk to and challenge for sandalwood production. Non-growers were also more likely to be not fully aware of the risks associated with sandalwood growing. Many of the risks respondents identified were production oriented, however lack of market is associated with the current prohibition of the sandalwood trade in TL. To mitigate the market risk there is a need for a review of current policy regarding the harvesting and marketing of planted sandalwood as being distinct from wild sandalwood.

The study found a need for improved sandalwood extension for and knowledge transfer within communities. FGD indicated that agricultural grower organisations operate in Maliana lowland and upland, and Natarbora lowland. But responses indicated little evidence for peer-based networks that facilitated transfer of agriculture or forestry knowledge in any of the target areas. Social innovation to facilitate information networks (formal/informal) could help to increase the penetration of extension interventions for both agriculture and forestry.

AI-Com2 will investigate how MAF training can be delivered to improve adoption of and scale-out smallholder sandalwood systems.

Site suitability & FTL/sandalwood agroforestry demonstrations

A field trial was established in Natarbora to examine the fresh forage production capacity of the FTLs and growth performance of sandalwood when grown in combination with *Leucaena* and *Sesbania* as within-row and *Casuarina* as between-row hosts. The research undertaken during Ai-Com has demonstrated that sandalwood can perform well in systems containing forage tree legume species *Leucaena* and *Sesbania*. Through observational research conducted at the Manduki sandalwood plantation, *Sesbania* has only a very short life (~2 years) when used as a sandalwood host in the tropics with an extended dry season (such as much of the north coast). The FTLs, particularly Leucaena, that are not well hedged can begin to dominate and 'over-top' the sandalwood causing a reduction in stem diameter growth in the latter. Sandalwood had no measured effects on the growth productivity of the two FTLs, however this is likely to change as the sandalwood mature and form a stronger association with its hosts. At 24 months no significant difference was found in forage productivity between *Sesbania* (1.57 $kg.tree^{-1}.month^{-1}$) and *Leucaena* (1.48 $kg.tree^{-1}.month^{-1}$). If we consider the mean monthly biomass production from the 14- and 24-month assessments as the mature production values, the range is between ~280 and 670kg $DW.ha^{-1}.month^{-1}$ which can conservatively support between one and three Bali cattle. The carrying capacity of this system is slightly less than the range in herd sizes (2.3 to 5.5 head) for cattle producing families in Timor-Leste. The maintenance of a 1 hectare agroforestry system is considered to be beyond the land available (0.5 to 0.7 ha) and management aspirations (0.08 ha to 0.21 ha) of prospective sandalwood growers in the AI-Com target areas of Natarbora and Maliana (de Almeida et al. 2022).

AI-Com2 will continue to monitor sandalwood growth and measure forage production in trial sites established during AI-Com1. This recognises the benefit of long-term longitudinal trials when studying perennial species, this project will build on the 5 years of previous work and obtain data otherwise not available.

Develop farm designs that incorporate crops animals and sandalwood for participatory testing to optimise sandalwood and fodder productivity.

Smallholder woodlots

Many farmers and neighbours were very keen to plant sandalwood, although some expressed concern about the long time required to harvest sandalwood. Community sandalwood planting was carried out over four years of the project with total of 189 sites established with twenty sandalwood seedlings provided to landholders for planting.

2018 Initiative

The sandalwood seedlings were planted into newly-established and protected *Leucaena* tree plantations. Four months following planting the tree survival rate was 79% with some saplings lost to heavy rainfall in February 2018. There was an indication that shading/competition from the host forage *Leucaena* trees improved sandalwood sapling growth. Three fertiliser treatments were applied to the sandalwood plantings at each site and together with a control were established in a randomised block design. The treatments were: 1. Control, 2. 200 g/tree NPK (15:15:15), 3. 5 kg/tree cow manure, and 4. NPK + cow manure. One year following planting the tree survival rate varied markedly across farmers/sites from 100 % survival with two farmers down to 20% at the poorest site. More competition at the tree base from the pot host increased sandalwood height growth. There was no fertiliser effect from the cow manure and a reduction in growth with NPK application. Good host and sandalwood management were clearly crucial to survival and early growth.

2020-2021

The 30 sites in Bobonaro were established in January 2021. After six months survival ranged from 0 to 90% with an average of 53% survival. This is a poor result with the most prominent cause of seedling mortality as uncontrolled animal grazing.

Seedling survival in the first six months was also found to be influenced by seedling height at planting. Survival was recorded six months after planting, with a positive correlation between mean height at planting and percentage survival across the sites explaining 20%

of the variation of survival between the 30 locations. While many local issues affect tree survival, the size of the seedling is an important manageable feature. This result confirms a similar finding for the provenance trials at Natarbora and Manduki (See Section 7:4.3b). Current recommendations are that trees 25-30 cm in height are ready for planting out. However, the average survival of trees of 28 cm height was 28%, whereas seedlings more than 45 cm when planted out had the increased survival rate of 56%. Regression analysis suggests that as seedling height increases, so does survival in the first 6 months.

Nursery research with MAF to develop quality seedling production systems for transfer to community-based nursery

A range of experiments were undertaken in relation to nursery production of sandalwood in Timor-Leste (Pereira, 2021 #223) on, for example, the effect of seed pre-treatments prior to sowing on germination, and of nursery potting media on seedling survival and growth.

Seed pre-treatment with Gibberellic acid (GA).

With and without GA3

The germination test on Suai & Soibada seedlots was the first successful demonstration of the benefits of GA3 use on sandalwood germination in Timor-Leste. This first trial showed the clear benefits of using GA3 to increase the percentage of seed germinating (53%) relative to the control (16.8%). There was also a small indication that longer soaking time increasing the speed and percentage of seed germinating. Thereafter trials to use local alternatives to GA3 such as crushed onion were less equivocal.

Concentration of GA3 and soaking time

Soaking seed in GA3 at 300 ppm for 16 to 24 h reduced the time to 30% germination down from 100 days (control) to 30 days. Additionally, total germination increased from 25 % to a maximum sandalwood germination of 67-78 % in response to GA3.

Commercial sources of GA3

All three tested forms of GA 3 showed approximately 40% germination after one month germination. GA3 sold in Dili with Indonesian packaging is suitable for promoting sandalwood germination. Two packets are required for one litre of soaking fluid that would cost $1 of GA3.

Potting media and irrigation

There were dramatic effects of potting mixture on survival with commercial potting medium (40% rice husks, 40% coconut peat 12% cow manure, 5% chicken manure and 3% ash) giving the lowest survival rate over time (Figure 4). Although losses were less than observed in the previous 2 years, over 50% mortality at 7 months is not a commercially attractive option.

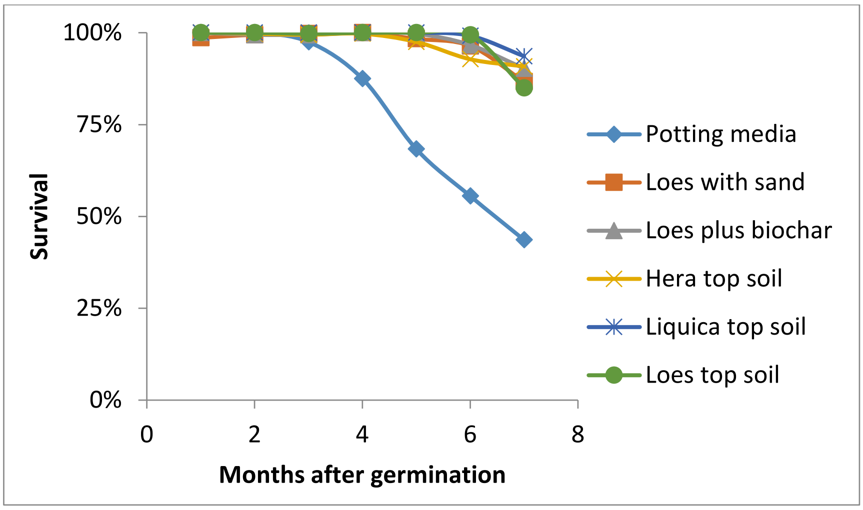

Figure 4. Sandalwood seedling survival (%) over time with different potting media.

Pest and disease characterisation & control

Nursery disease and potting media research: High mortality of young sandalwood seedlings under nursery conditions is widespread in Timor-Leste. The main cause for seedling mortality is a disease that causes symptoms of seedling wilt, damping off and dieback. In more extreme instances seedling mortality is very high with up to 80-90% succumbing. AI-Com engaged Australian plant pathologists (AQIS) who examined affected plant samples from the Natarbora nursery. Two species of *Fusarium* and another from the fungal family Ceratobasidiaceae, which includes the known pathogens *Ceratobasidium* spp. and *Rhizoctonia* spp. were identified. In another experiment in Timor-Leste, sandalwood seed collected in Liquiça was surface sterilised and grown under sterile laboratory conditions. Fungal hyphae that developed from within the seed were then further cultured for identification. One of the cultured fungi had a morphology like Fusarium but did not act as a pathogen under laboratory conditions. It is possible that a Fusarium-like endophyte could be borne within the seed and turn into a pathogen under stress conditions.

It appears that the fungal disease of seedlings in Timor Leste is caused by one or more fungal endophytes that can become pathogenic under wet and humid conditions. These pathogens are likely borne in the soil and/or seed. While Fusarium is a possible causal agent of the sandalwood seedling disease further work is required to confirm if other agents are also involved. Microscopic observations of roots revealed the presence of nematodes, which may promote fungal infection through the roots.

Sandalwood domestication & smallholder agroforestry:

Tree characterisation

An assessment of the wild populations of *S. album* was conducted in 2018 by sampling eleven wild populations across the environmental range of the species in Timor-Leste, targeting locations where there was a significant reported stand of older *S. album* trees. The aim was to build information on the species morphological, phytochemistry and genetic variation to inform a selection strategy. A technical note on the resource survey methodology was developed and tested with AI-Com and MAFF staff in April 2018 (Page and Almeida 2018). The research was presented and published as a conference proceedings paper (Almeida et al. 2021), which was further developed and submitted as a peer reviewed paper (Almeida et al. submitted).

Growth traits

The results represent a sample of trees with an estimated age of between 20 and 30 years attaining an average stem diameter of between 15 and 22 cm at 0.2 m AGL and stem growth rates of between 0.66 and 1.0 cm per year. The broad geology of the sites (limestone or sedimentary) had no detectable effect on the mean size (height, diameter or canopy area) of the trees.

Heartwood percentage

The sampled wild trees had low levels of heartwood (HW), particularly in sites like Atabae (4.0%), Balibo (6.9%) and Watulari (8.9%). The mean %HW across all sandalwood trees sampled in Timor-Leste was 11.8% with a mean stem diameter of 15.9 cm (under bark) and 18.9 cm (over bark) at 0.2 m AGL. In West Timor in a survey of wild trees of *S. album*, the mean stem diameter (DBH 22.5) and percentage (17–42% at 1.3 m) (Fox et al. 1994) was greater than in the present study. Percent heartwood was also lower in the TL wild samples (20 to 30 years) compared with 16-year-old cultivated *S. album* in Kununnura (Brand et al. 2012). While mean stem diameter was equivalent between TL (DUB at 0.2 m was 15.9 cm) and Kununnura samples (DUB at 0 m was 15.9 cm) the mean %HW was 11.8% and 19.2% at the respective locations. At the level of population, mean heartwood mass ranged between 1.4 and 3.8 kg for those trees that contained heartwood. This is substantially lower than the mean of 5.8 kg measured in 16-year-old trees grown in Kununnura. Viswanath et al. (2010) reported heartwood yield potentials of 3 to 4 kg at years 15 and 20 respectively, while Mishra et al. (2018) estimated 15 kg at 18 years for *S. album* grown in India.

The low proportion of heartwood relative to sapwood found in this study is important since it typically translates to high unit costs for removing sapwood prior to sale. The sapwood must be removed since it represents potential contaminant of the product by contributing undesired compounds (Hettiarachchi 2013). The low percentage heartwood in the samples of this study represents a current challenge for commercialisation, and therefore precocious initiation and rapid development of heartwood with high oil yield should be considered a priority for species domestication.

Heartwood composition

Heartwood oils accumulate in the heartwood over time (Burdock and Carabin 2008) and the concentration of heartwood oils is a key quality determinant. In the present study, there was no relationship between oil yield each with stem diameter, heartwood proportion or heartwood mass. Consistently high percentage compositions of santalol were found for most the samples with sufficient heartwood oils and the mean values across the nine of the eleven populations were within or above the limits for the international standards for *cis*-α- and *cis*-β- santalol (ISO 2002). Given the consistently high quality of the heartwood oil, this suggests that selection should focus on assessing stem growth rate, heartwood development and oil concentration.

AI-Com2 will investigate if there is variation in HW development in planted sandalwood systems and can heartwood development be improved through clonal selection

Genetic variation

Analysis of the SNP dataset revealed genetic diversity of the Timor-Leste population was moderate overall. Some provenances were found to lack diversity and contained only close relatives with significant levels of inbreeding (e.g., Com and Lore that are situated around 30 km apart comprised a cluster of close relatives), but other seed sources appeared to have predominantly outcrossed trees (e.g., Zumalai and Lalawa). The SNP data allowed a full pedigree matrix to be assembled which will facilitate management of relatedness among the sampled trees for the purposes of conservation, domestication and breeding. One of the first activities that could be guided by this new information is the thinning of the ETA-N conservation stand using the co-ancestry data to check that nearby trees are not close relatives. STRUCTURE analysis also allowed trees within seed sources of apparently mixed origins to be grouped together with populations that are their most likely origin.

Overall, the analysis revealed that while the Timor-Leste *S. album* population has been heavily harvested and has no doubt suffered from genetic depletion in some locations, there is still at-least moderate genetic diversity remaining. Careful selection of unrelated trees from within the existing conservation stand and wild or planted stands throughout Timor-Leste will result in a breeding population that is of sufficient size and diversity to be sustainable. This is good news, because it had been hypothesised that the remaining genetic base in Timor-Leste may be too narrow, requiring the importation of *S. album* accessions from elsewhere in the natural range. While this may not be necessary, it is argued that sampling from the West Timor population, which being based on the same land mass is likely to be an extension of the Timor-Leste population profiled here, would be of benefit for both conservation and domestication purposes. Further assessment of commercial traits, preferably in common-garden trials such as the ETA-N planting will also provide guidance on whether importation of germplasm from outside Timor-Leste is necessary and/or desirable.

Establish ex-situ conservation sandalwood trial based on seed collected from a broad geographic range for S. album.

Sandalwood provenance trials were established in Natarbora (south coast) and Manduki (north coast) during early 2020 using bulk seed collections from 11 different locations across 9 Administrative Posts in Timor-Leste.

Evidence suggests that sandalwood survival is influenced by the height of the seedlings at planting, with greater survival found for larger seedlings (See above Section 7.4.1b). Both at Natarbora and Manduki, dead seedlings recorded at 16 and 14 months respectively were significantly ($P<0.05$) shorter during the first measure (42.5 cm at 8-months for Natarbora and 45.8 cm at 3-months Manduki) compared with surviving seedlings (84.9 and 64.9 cm respectively). Mean seedling survival for the line-plots followed a similar pattern where the proportion of surviving seedlings was positively related to seedling height. Given this evidence is based on the first height measurements (8 and 3 months for Natarbora and Manduki respectively) it is therefore only indicative of initial planting height. The current AI-Com recommendation is that seedlings need to attain a height of 25-30 cm prior to planting, however higher survival might be expected with seedlings of around 60 cm. The doubling of the currently recommended height will impact nursery production regimes and therefore warrants further investigation.

While variation in mean height was recorded between provenances this was not statistically significant at either Natarbora (16 months) or Manduki (14 months). While significant variation in provenance-based tree height was recorded at earlier measures it was likely due to differences in seedling height at planting associated with seedlot management in the nursery (i.e. sowing times, nursery position, watering etc).

Greater tree height was recorded across all sandalwood provenances at Natarbora at 16 months (137.6 to 199.9 cm) compared with Manduki at 14 months (100.6 to 122.2 cm). This difference was influenced by the additional age at Natarbora at measurement, but also because Natarbora was planted 2 months earlier than Manduki during the wet season giving an early growth advantage. Mean monthly height growth at Natarbora was consistent at around 10 cm between 8 and 16 months. Monthly height growth in Manduki was less than Natarbora and varied from approximately 1 cm (3 and 8 months) to 9 cm (9 and 14 months).

A significant effect of host was found in the Natarbora provenance trial where those growing with mixed hosts (*Leucaena* and *Sesbania*) had a significantly greater height than those growing in association with just *Sesbania*, with *Leucaena* being intermediate. This result was in contrast with the sandalwood-FTL trial on the same site where height growth was significantly greater with those growing in association with *Sesbania*. While further measures of both height and diameter are needed to determine the longer-term influence of the host, it does indicate that both *Leucaena* and *Sesbania* are suitable as hosts for sandalwood production on the south coast of Timor-Leste.

At Manduki tree spacing (double vs single rows) was found to have a significant ($P<0.01$) effect on mean tree height at 14-months after planting, where trees were taller growing in double- (118.6 cm) compared with single-rows (106.1 cm). Further measurements and observations are required to determine if spacing continues to affect height and stem diameter growth in sandalwood.

The impact of sandalwood provenance on sandalwood performance in planted systems will continue to be assessed in AI-Com2.

Evaluation of methods for communities to increase forage supply from FTLs and sandalwood production for short-term and long-term economic opportunities

Woodlot survey of planted sandalwood

Based on data collected from the woodlot survey, we undertook tree selection based on standardised data for annual increment for heartwood weight and stem diameter at 0.2 m above ground level with the top 14 trees (~8% of sample) having a value of greater than 1.5 standard deviation above the mean. There is potential to include an additional 3 trees that have productivity just below 125 g/yr among those selected. All selected trees had a mean annual increment for heartwood above 125 g/year in the stem between 0.2 and 0.7m, which by 20 years represents a yield of 2.5 kg and above. Based on the work of Brand et al. (2012) with *S. album* growing in Australia at 16 years the stem between 0 and 1 m contains around 50% of total tree heartwood yield. Therefore, it is estimated that the selected trees from these woodlots will produce between 5.0 and 10.8 kg HW at harvest at 20 years. This can be compared with the above wild population data, wherein mean heartwood mass ranged between 1.4 and 3.8 kg for those trees that contained heartwood. Clearly, the selected material is promising for clonal propagation.

The proportion of heartwood (mass) in relation to the stem diameter (cm) was chosen because the age of the wild trees could not be accurately determined. Interestingly, there was no significant difference in heartwood mass relative to stem size (diameter) between planted and wild sampled trees (Figure 5). This suggests that selection for high growth and heartwood development is critical to the future commercial prospects of the species production in Timor-Leste.

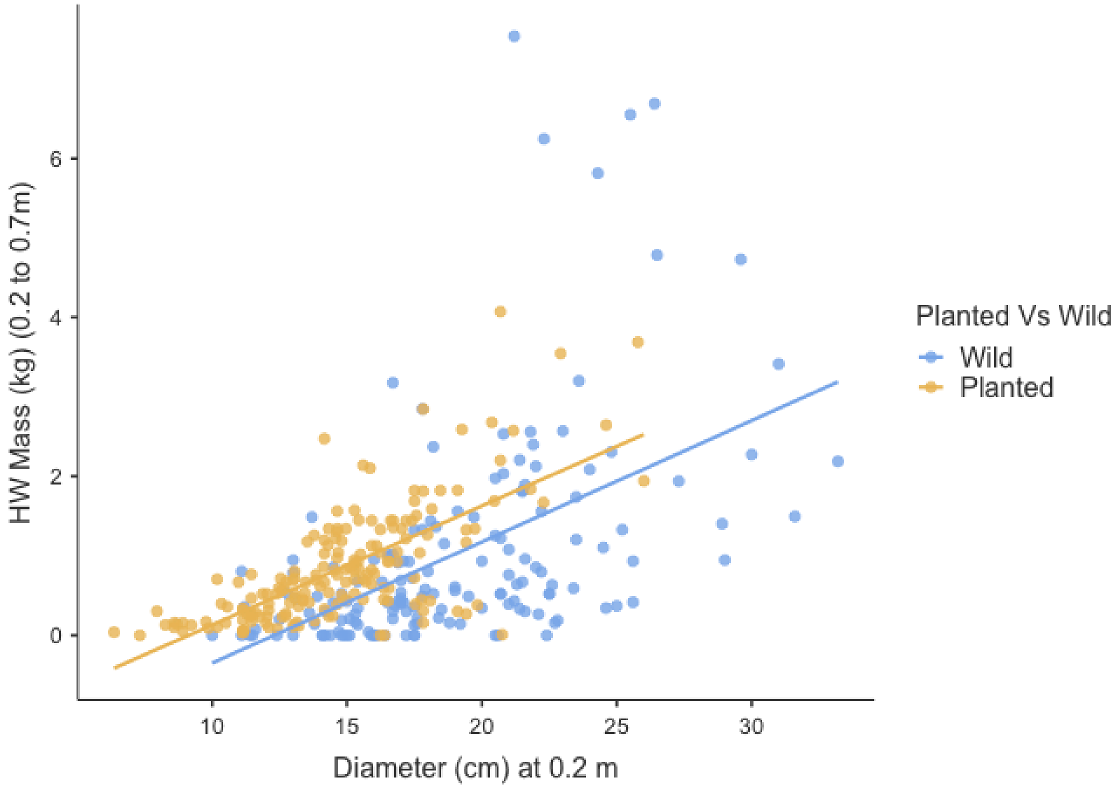

Figure 5 A scatterplot of heartwood mass (HW - between 0.2 and 0.7 m above ground level) against stem diameter at 0.2 m above ground level for both wild and planted trees. Planted trees ranged in age from 14 to 18 years, while the age of the wild trees was not accurately defined.

Survey of sandalwood producers and interviews with experts and key informants to understand key factors affecting the economic and financial viability of sandalwood investment.

A financial model was developed based on data sourced from a systematic literature review, which were validated and supplemented with information sourced from practitioners in Timor-Leste and Australia. Model assumptions are given in Section 5 Methodology. The financial model was used as the basis to investigate the performance of three different scenarios: (1) sandalwood combined with FTL and cattle production, (2) sandalwood production alone (at two different rotation lengths) and (3) FTL and cattle production alone. Results show that all modelled systems were financially viable at discount rates of 10 and 18%. Growing sandalwood combined with FTL and cattle production was profitable with a net present value (NPV) of USD 21,729 and land expectation value (LEV) of USD 23,928 at a discount rate of 10%. Growing sandalwood as an enrichment was profitable with an NPV of USD 9,718 and a LEV of 10,706 at a discount rate of 10%. Growing FTL and cattle production had a NPV of USD 10,326 and a LEV of 11,376 at a discount rate of 10%. These results reveal that combining sandalwood production with FTL and cattle production was the most profitable of the assessed smallholder investments.

The internal rate of return (IRR) calculated for the sandalwood FTL/cattle system in this study was 37%, which was substantially greater than the prevailing cost of capital (18-24%). However, the ADB (2019) suggests there are few viable microfinance institutions and credit unions and most have capacity constraints and limited product offerings. Therefore, while credit unions may provide agribusiness loans suitable for tree production, smallholders may only have limited access to such institutions and products. In Timor-Leste tree plantings are likely to be established using the owners own equity, particularly in the use of family labour. Stewart et al. (2021) reported that many smallholders do not factor in their own labour into their enterprises and that the cash outlays for establishing and maintaining tree plantings are significantly less than for those that use hired labour. It is possible that landowners in Timor Leste will use their own labour.

8 Impacts

8.1 Scientific impacts – now and in 5 years

Given AI-Com's *modus operandi* with UNTL, MAF and WV staff through specific sub-contract research by activity, AI-Com scientists have mentored national scientists to develop the necessary project proposals and the project's experimental program. Cooperating scientists then implemented the research and wrote first drafts of the reports which are summarized herein. Some specific issues were jointly written-up as international journal articles. This process of working together shoulder-to-shoulder has contributed to capacity building. Publications are listed in the Appendix spreadsheet and include international journal articles, conference papers, and an Extension Bulletin in Tetun. They also include international publications from the Seeds of Life project data.

Some project publications are now widely used. For example, the publication Williams et al. (2018) developing agricultural livelihood zones for Timor-Leste is commonly used in development and been formally cited 11 times. As mentioned above, the SoL website maintained by AI-Com with maps etc is still accessed 10 times daily.

AI-Com has delivered a body of evidence showing the low fertility status of many Timorese soils and a range of solutions to improve crop yields through organic and inorganic fertilisers. Zinc deficiency (as well as P deficiency) is now recognised in as a problem in many Timorese soils; and that rice husk biochar is able to increase level of available P and Zn in at least one deficient soil.

As an example of scientific impacts that relates to the following section on Capacity Building, the Timor-Leste Studies Association (TLSA) - an interdisciplinary research group on Timor-Leste - held a conference in Dili in June 2019 with the theme: "New Research on Timor-Leste". AI-Com researchers participated in the TLSA conference. Among the 41 published papers at the conference relating to agriculture, ten were presented by AI-Com funded researchers (Appendix). There were another four papers building on earlier Seeds of Life research (Appendix).

8.2 Capacity impacts – now and in 5 years

MAF research agronomists have shown significant capacity improvements in response to AI-Com project. Most of the MAF researchers were researchers for the previous Seeds of Life program. The style of research in SoL3 was variety evaluation of different varieties across locations and use. In AI-Com researchers learned to conduct soil research particularly identifying soil constraints. One of the larger joint experiments was testing the impact of zinc, phosphorus and biochar on 22 different soils. Each researcher was involved in a 4-way factorial experiment (i.e. three soil types, +/- Zinc, +/- super phosphate, and +/- biochar. This is the first time many of them had conducted an experiment with more than two factors. Analyzing the data of a multi-factorial experiment has been challenging but rewarding for all involved.

MAF researchers have also been crucial in scaling-up technologies from the project and have learned through the process. The identification of low-labour mungbeans was initially done on the South Coast in Natarbora, with the agriculture High School. However, most of the scaling-up has been around the Betano research station due to the active innovation research of MAF researchers. After attending field days in Natarbora, the researchers brought the technology back to Betano. And now hundreds of hectares of low labour among mungbeans are now planted in Betano. Many MAF researchers have now seen a successful scaling-up of their research. The researchers can now explain how the varieties they have tested, the velvet bean system they developed and now the low labour mungbean system were tested and developed within their research teams, and now expanded over Timor-Leste. These experiences given through ACIAR will be invaluable in their future research for development.

Many MAF researchers now have a track record of being part of successful research teams producing seeds and practices that are expanding to significant scale. When speaking at field days, or other opportunities, they now explain how the 1) varieties they have tested, 2) the velvet bean system they developed and now and 3) the low labour mungbean system were tested and developed within their research teams, and now expanded over Timor-Leste. These experiences given through ACIAR will be invaluable in their future research for development.

MAF and AI-Com social science staff were up-skilled to undertake their own gender research. During the program Joaquina and MAF staff were mentored in a range of social science skills including field work by Pyone Myat Thu. As a result, the team is now able to conduct gender research themselves. The AI-Com social research team recently designed, conducted and reported a gender analysis of two value chains for the TOMAK 2 project. The team worked on the objectives, methodology, preparing the excel sheets for efficient data collection through ODK, conducting the research, analysing and reporting back in a time efficient manner.

The overall gender-disaggregated data on capacity building is given in Table 1 focusing on MAF research staff and UNTL students. The percentage of female training days is 27.7%. During 2021 and 2022 group training in AI-Com was stopped due to COVID restrictions on gatherings and training restricted to one-on-one scientific exchange as restrictions allowed.

Year	Females	Males	Total
2017	22	62	84
2018	90	216	306
2019	74	185	259
2020	37	82	119
2021	3	2	5
2022	22	98	120
Total	248	645	893

Table 1. Gender-disaggregated capacity building (training days) in the project by year.

Cooperation with UNTL has linked project agronomic implementation to student capacity building (and additional to the above data), AI--Com has guided and funded the final year research of 65 UNTL students over the course of the project. Sixty (44M 16 F) were agronomy students and 5 (1M 4F) were from the department of social economy. After graduation, some UNTL students have continued to work in agriculture, spreading new technology to farms and new locations. One story is Mr Aroya, who was a final year student in 2020. Aroy was supported by AI-Com to conduct his fourth-year research project at Vemasse in 2019. He was one of 12 students who grew a wide range of horticulture crops during the dry season and discovered the large yield responses to biochar and other soil amendments.

As this field work was being conducted, photos of the crops were presented on the AI-Com Facebook page. In response to the photos of the UNTL experiments, a landowner from Natabora contacted the students and asked Aroy to work with him on unused land in Natabora. In the 2020 dry season, Aroy was employed as an agronomist in Natabora to manage and grow 1 hectare of water and rock melons. Aroy with support from other UNTL colleagues grew these crops with the knowledge and experience they learnt during the AI-

Com supported research the previous year. This is one of the few occasions that an agronomist has been employed to manage an intensive farm.

UNTL social economics students have learned new skills, especially gross margin analysis. Final year projects by UNTL socioeconomics students were based on the gross margin analysis and return on labour of various agronomic trials. Some have also participated in AI-Com surveys after graduating.

Mr Acacio Guterres left UNTL to join Charles Darwin University in late 2019 to study for a doctorate. His thesis topic is Impact of Rice Husk Biochar and Inorganic Fertiliser on Sustainable Food Production and Income Generation in a Vegetable-Rice Cropping Sequence in Timor-Leste. The thesis research was conducted in Maliana and is co-supervised by Rob Williams with partial AI-Com operational funding.

More recently MAF directorate of agro-commerce has established a 100-ha site with new graduates, and alumni from Israeli training. Their vegetable production system incorporates the use of rice husk biochar. This technology was taken there by UNTL students who had conducted final year research with AI-Com.

World Vision staff conducted approximately 40 on-farm trials using biochar in each of the last 4 years. Although very competent in conducting field trials, AI-Com was able to give them good training on working with national data set across locations. WV staff also received training on the economic value of biochar, cow manure or both on sweet potatoes.

8.3 Community impacts – now and in 5 years

Source of Innovation

AI-Com has continued the ACIAR and Seeds of Life tradition of being a source of innovation for the wider community working in Agriculture in Timor-Leste. In 2021 MAF (with technical support from FAO) published “Compendium of Adapted Technologies and Practices for Climate Resilient Agriculture”. The compendium describes 43 innovations and practices proved in Timor-Leste. Some 55% of practices were tested and proven as part of Australian funded projects, with 43% directly from ACIAR-funded activities. Even though AI-Com was only three years old, the project contributed three innovations to the compendium. More broadly, ACIAR innovations and AI-Com innovations are being used by other partners. The development of value chains for TOMAK has relied heavily on Seeds of Life and AI-Com innovations, tested and proven within Timor-Leste. As TOMAK scales up these innovations to rural communities in three districts the impact of Seed of Life and AI-Com program will only expand. TOMAK is likely to scale-up the innovations of SoL common bean, sweet potato and winged bean varieties, as well as biochar and low labour mung beans to rural communities in their three target districts. As TOMAK phase 2 rolls out, the impact of Seed of Life and Ai-Com program will only expand.

Changing attitudes and practices to fertiliser use

Agronomic research by MAF, and UNTL (supported by AI-Com) regularly showed the large positive response of fertiliser (Urea and SP36) on rice. The trials on rice farms also confirmed the government recommendation for Urea and SP36 of 50kg/ha each year. However only at the end of AI-Com phase 1, can we detect changes in behaviour and attitude towards fertiliser use.

During the lifetime of AI-Com, there has been a large change in acceptance of artificial fertiliser among some Timorese communities. When AI-Com supported UNTL funded research in the Buluto irrigation areas (Vemasse and Leleia) farmers did not want to be involved in using fertiliser in the following years. This is even though the rice yield increased from 1.5 to more than five t/ha. When initial experiments were done in 2018 by the JICA project, that was working in the same area, they planted demonstration plots, but never included fertiliser. JICA is now promoting fertiliser amongst rice farmers in the

Buluto irrigation area and about 75% of farmers are using it in their fields. A higher adoption is seen in Maliana, near the border with West Timor. Virtually all 144 rice farmers in the Maliana One irrigation area have used a purchase scheme with their rice association to purchase fertiliser. Average application rate was 2.3 50-kg sacks per farmer. In the fertiliser survey, over half of respondents (59%) expressed a favourable attitude towards using inorganic fertiliser in the future. All respondent groups, particularly non-users were positive about receiving training and participating in demonstration plots, indicating that they were open to gaining more knowledge on fertiliser application. The UNTL / AI-Com research, which has continued to show the large positive response of fertiliser on rice has provided the basic data to support the efficient use of small rates of urea and super phosphate on rice fields Ongoing research on the second season impact of fertilisers on rice fields has also giving confidence to farmers that they are not destroying their field with the application of inorganic fertiliser.

The change of attitude was also picked up in the AI-Com fertiliser survey conducted in 2020. In the survey, over half of respondents (59%) expressed a favourable attitude towards using inorganic fertiliser in the future. All respondent groups, particularly non-users were positive about receiving training and participating in demonstration plots, indicating that they were open to gaining more knowledge on fertiliser application.

Low-labour mungbean

There have been considerable impacts on developing and scaling up low labour mungbeans. Low labour mungbean was a system developed between researchers and the farming community in a way to grow mungbeans profitably after a rice crop. The system was beautifully spelled out by a rice farmer on the south coast named Juliana at a field day of a replicated trial on her land. She described the best way to grow mungbeans after rice was 1) harvest the rice, 2) spray round-up to kill the weeds and the rice, 3) irrigate the field, and broadcast mungbeans as it drains, 4) have a holiday in Dili and 5) go back and harvest mungbean. The mention of the holiday in Dili was because she knew there was no need for in-season weeding.

Since that time, there have been hundreds of hectares of low-labour mungbeans sown. The economic benefit is quite dramatic. One hectare of mungbeans is producing a gross margin (without labour) just over $500 per hectare. As low labour mungbeans require the input of 50 labour days the dollar return per day is more than $10 a day. Most of the labour saving is women’s work of planting and weeding.

The second benefit is that the low labour mungbeans are being grown on land that didn’t grow beans in the past, and on abandoned rice bays. In the irrigation areas around Betano there is significant unused rice bays because people don’t have the labour and or judge the return from rice is too low. In the last rice season, much of this abandoned rice area was converted to low labour mungbean production. The result was lower labour input, higher dollar return per labour day and the gross margin per hectare was similar, if not higher, under the mungbean system compared to a rice crop.

The third impact of low labour mungbeans is the impact of the residual nitrogen on the following crop. A well grown mungbean crop that yields 700 to 1,000 kg per hectare and the residual plant matter adds approximately 20 kg of N into the soil, available for the following crop. If the following crop is rice, that 20 kilograms of N would increase yield approximately half a ton to hectare This yield increase has been noticed by farmers who have grown rice after low labour mungbeans, and they have been very surprised that their rice yields are better after growing a mungbean crop.

A fourth impact is that low-labour mungbeans has started the discussion of herbicide use in Timorese agriculture. Low labour mungbeans depend on a herbicide (normally glyphosate) to kill weeds prior to planting. The vast majority of MAF staff have limited experience or training on the use of herbicides, so find it difficult to evaluate novel options that include herbicide. Farmers have no such fears, and after trying herbicides for weed control are convinced of their benefits. At an AI-Com field day on herbicides, farmers explained “We know the benefits of herbicide, but what is the real downside?” During a discussion with women from farming families familiar with pre-plant herbicide application, they expressed concern over what men spend money on, but on herbicides the comment was “When our husbands spend money on herbicide, we never get angry, because it saves us a lot of work”.

Almost all development agencies have excluded herbicide use from their range of topics they will work with. This has been very frustrating to several MAF district-based directors who know that their farmers are using herbicides, but feel they need assistance to help farmers to use herbicides safely and efficiently. In the Municipality of Manufahi FAO has and is promoting conservation agriculture using the velvet bean system. A high percentage of farmers have modified the system and incorporate a herbicide where the velvet bean has not fully smothered the weeds. AI-Com was the first agency to work with farmers and MAF Manufahi to help farmers use herbicides safely and efficiently. (It should be noted that the USAID-funded AVANCA has worked on safe pesticide guidelines in Timor-Leste, but not in Manufahi.)

8.3.1 Economic impacts

Making biochar a business

The discovery and use of biochar as a fertiliser and soil ameliorant has been an unexpected outcome of this project. The initial project design made no mention of biochar but did refer to unspecified methods of increasing rice production. Biochar was initially used as a locally available treatment, acceptable to farmers. It was initially used in the first phase of UNTL experiments in Vemasse, a rice growing area. At that time, there was no experience in Timor of people using and producing biochar. The method to burn it was introduced to AI-Com project through one of the lectures at UNTL Dr. Antonio da Costa. He was aware of the chimney method and showed that to the students so they could make char for the small trials in Vemasse.

Since then, the information of biochar and its benefits has grown significantly each year.

In the first year, biochar was tested at one location on a range of crops. The remarkable result was that 10 or 20 ton per hectare of biochar was able to double the yield of many crops. This research was replicated in different locations and the conclusion was that a wide range of soils, with different soil pH respond very positively to applying biochar.

Impact 1: Rice husks now have a value. Prior to the discovery that rice husk biochar has a positive influence on crop yield, rice husks were a waste-product burned at rice mills. People could turn up to the rice mill and take rice husks away, because the option was just to burn it where it where it lay. Now that rice husk biochar has shown to have a value, husks are now sold at a price. One farmer in Balibo who was sourcing rice husks from out of the village, pleaded with us not to tell the rice mill down the road that he was making biochar and earning an income from the rice husk rice husk he was collecting free.

Impact 2: Producing an income for rice millers. Burning and producing biochar adds an income stream to rice mills in the country. One private owned mill in Maliana now sells biochar and Biochar Plus to farmers locally. In other locations, the rice millers do not yet produce biochar, but some rice husks are being sold.

Impact 3: Increasing yields on farm. Research has shown that almost all soils in Timor respond to Rice Husk biochar. In pot trials using peanuts as a test species, 22 of the 23 soils had an increased yield in response to biochar application. On average, the yields increased by 96% in the pot trial. World Vision using multi-location demonstrations showed a doubling of sweet potato yield across 40 sites in four districts of East Timor.

The mechanism for this is unknown. But is likely to involve improvements in the physical, chemical and biological properties of the soil though we have in-sufficient data to support this. We do have data from one site, which shows soil amendment with biochar increases the level of plant available potassium, phosphorus and zinc in the soil.

Impact 4. Identification of soil, chemical constraints. In attempting to diagnose the mechanism by which biochar increases rice yields, we have uncovered significant zinc deficiency in Timorese soils. A review of SoL soil data analysis revealed low levels of zinc availability as a problem in about a third of these samples. A recent pot trial has not just assessed soil chemistry but also looked at plant response. In almost all 23 soils peanut yield responded positively to added superphosphate. In addition, in about a third of those soils, there was a large increase in yield due to added Zinc. Zinc and P nutrition should be a focus of future soil research within East Timor.

Impact 5. Acid soils on the Baucau plateau are now being rehabilitated. Many soils on the Baucau plateau are quite acid, low in phosphorous and produce very poor yields. The research site given by farmers to the MAF at Darasula includes this soil. During SoL3, a range of experiments, using lime, superphosphate and nitrogen, was attempted to improve the maize yield from zero at this site. The soil is quite acid and very low in phosphorus, but whatever the treatment there was no response to the maize crop. The AI-Com project using biochar has been able to rehabilitate soil very similar to the Darasula site by using rice-husk biochar. An application rate of 20 t/ha did not significantly increase soil pH_{H2O}, however, there was a significant response on maize growth. After five years of just one single application, maize yields in that site went from under 1 t/ha to 4 t/ha hectare in replicated experiments. Although there was no improvement in the first year, as the long-term residual experiment continued, maize yields have only increased. The yield increases are combination of the one application biochar and rotating with legumes every second year.

Impact 6. Identification of fortified biochar. One significant limitation of biochar is that there is insufficient rice husk available in the country to rehabilitate significant areas and to have a national impact on the soils. We have tried to resolve this by introducing fortified biochar. Fortified biochar is rice husk biochar with an added 1% P_2O_5 and 2% nitrogen as urea. Recent research has shown massive improvements in yields in the use of fortified biochar. Fortified biochar is locally sold as Biochar Plus.

Impact 7. Fortified biochar production. A Biochar Plus business case was developed for producing biochar and fortified biochar (Biochar Plus). After the study, a commercial opportunity was developed with a private rice miller in Maliana. In response to the report, AI-Com worked with a rice miller (Vital) in Maliana to estimate costs and benefits of producing biochar. In summary, the desktop research show that biochar was a small, but profitable sideline for the rice milling company. It has identified that two products were possible. One was pure biochar, and the second was a fortified biochar with urea and Super Phosphate. The rice miller now sells biochar and Biochar Plus making them available in Maliana. Other groups are also burning biochar and selling it as a commercial operation. A youth group at Balibo/Maliana buys rice husks in Maliana, carries them to Balibo and produces biochar. They sell it locally and in Dili for $0.40 a kilo. There are small number of people in Dili who also burn and produce biochar, mainly as a pot plant media. There are likely the other sites where people have taken the technology and learned how to make biochar. One Timorese youtuber has made videos on burning rice husks and loaded them on the net:
https://www.youtube.com/watch?v=q2JI9qPSGR4&t=1011s and
https://www.youtube.com/watch?v=QsbiGLDLuY8.

Millenium Green Agro company produced 30,000 sandalwood seedlings

The use of GA3 is now widespread in sandalwood nurseries throughout the country. With its use a large number of extra sandalwood seedlings were produced in-country. But, for example, an outstanding feature was that the company Millennium Green Agro had planted out 28,000 seedlings and was only able to sell 2,000 due to severe disease in the nursery. The problem was identified by AI-Com in 2020, and a solution found using loam top-soil as the potting media. In 2021 Millennium Green Agro successfully produced and sold 30,000 seedlings (Jan 2021) and has continued to plant 30,000 seedlings this year for sale in 2022. GIZ Partnership for Sustainable Agroforestry Project in Timor-Leste (EU funded Programme) undertook in 2019 "a Promotion for Sandalwood Propagation in Timor-Leste" effort in which they consulted and used many resources from the AI-Com project.

Sandalwood knowledge platform for future improvement in Timor-Leste

The project has developed a solid knowledge platform for sandalwood improvement in Timor-Leste primarily through a survey of wild sandalwood trees. The survey not only covered silvicultural aspects, but also pests and disease incidence, oil quality and genetic analysis. A socio-economic survey revealed widespread interest among householders to plant sandalwood.

The wild sandalwood survey showed that the remaining wild trees in TL had a generally low heart wood content which leads to an opportunity to select and reproduce elite mother trees. High heartwood content trees are relatively rare in the wild populations tested so far, but a few trees have high levels of heartwood. It is unknown if the trees with high heartwood are genetically superior or grew in an environment conducive to high oil content. To the extent that the differences are genetic, progeny of these trees will also have high oil content.

Heartwood oils accumulate in the heartwood and their concentration is a key quality factor. We found a consistently high percentage composition of santalol for most the samples with sufficient heartwood oils, suggesting that selection should focus on assessing stem growth rate, heartwood development and oil concentration.

An analysis of genetic variation (SNP dataset) among wild sandalwood samples revealed the genetic diversity of the Timor-Leste population as moderate overall. While the TL *S. album* population has been heavily harvested and suffered from genetic depletion in some locations, there is still at-least moderate genetic diversity remaining. Careful selection of unrelated trees from within the existing conservation stand and wild or planted stands throughout the country will result in a breeding population that is of sufficient size and diversity to be sustainable.

8.3.2 Social impacts

8.3.3 Environmental impacts

COVID Impacts: Despite COVID restrictions in 2020/21, most (90%) of the scientific program was implemented as planned, as many Timorese scientists were regionally based close to trial sites. The international travel restrictions, however, precluded international monitoring; the fluctuating local travel restrictions also reduced monitoring and the regular shoulder-to-shoulder exchange at trials. This had knock-on effects on the maintenance of scientific quality as data interpretation from trials not visited by lead researchers may be problematic.

8.4 Communication and dissemination activities

Many of the above impact stories contain elements of communication and dissemination. Other aspects are given here.

Digital presence: During the AI-Com project we maintained the Seeds of Life (SoL) web page (http://seedsoflifetimor.org/) as a resource and updated the publication list. During SoL3 (2013-2016), the website attracted c. 25 users/day. Since the closure of SoL (2016), usage hovered around 21-23 users/d, indicating its potent heritage value. But from April 2020, when Timor-Leste closed its borders because of COVID-19, the number of SoL webpage users dropped dramatically to below 10 users per day as global attention to agriculture waned. In the last two years, the SoL web site serves 10 users per day.

Our AI-Com website (https://ai-com.tl/) allows AI-com publications to be available to a wider audience. The project also maintains its own English Facebook page which has attracted a consistent following. Follower number rose from launch in Dec 2017 to 12,212 by Dec 2019. It has remained static for the last 3 years as the number of posts reduced slightly following the departure of Sophie Rayner from AI-Com in December 2019. The most viewed post was about sampling sandalwood trees for oil content (50,000 views). Other topics, such as the use of biochar on vegetables in Viqueque and low-labour mungbeans, had 30,000 views. The 'Aroya' Impact story under Section 8.2 Capacity Building Impacts has a Facebook dimension.

Extension materials: The technical document on sandalwood hosts (Page et al. 2018) was launched by S. E. Engr. Estanislau Aleixo da Silva, Minister of Agriculture & Fisheries on April 3, 2018 at the onset of the AI-Com Annual Reporting and Planning meeting. A total of 1500 copies of the Tetun-language document were printed and distributed.

The 'Pacific Sandalwood Growers Manual' represents an important achievement and is published in ACIARs monograph series (Page et al. 2022). This document has been printed by ACIAR with 50 hard copies in English distributed to AI-Com. ACIAR publishing has plans for the translation of the document into Tetun, with a more significant printing and distribution in Timor-Leste.

Many of the extension materials need to be re-printed for extension purposes.

9 Conclusions and recommendations

9.1 Conclusions

The AI-Com project which ran from 2016 to 2022, addressed two broad avenues of agricultural research in Timor-Leste: Firstly, cropping intensification to produce legumes and grain for an emerging stock and food processing industry and secondly the production of selected non-timber tree products (tree legume fodder and their companion sandalwood) to diversify farm incomes. We also researched the social context upon which the uptake of such innovations depends.

While fertiliser use (organic and inorganic) for cropping is low overall in Timor-Leste, a fertiliser survey found that barriers to increased use are surmountable. The residual impact of inorganic fertiliser to rice was found neutral or positive, NOT Negative.

Rice-husk biochar almost universally increased crop yields in Timor soils. Biochar can be combined with chemical fertilisers and cow manure to benefit from the additive effect, and sometimes the synergistic effect of the combination. Biochar is economic to make and be sold for horticulture production, and sweet potato production. A diverse range of soils exhibited a positive response to biochar, SP36 and Zn in peanut yield. Fortified biochar (Biochar Plus) increases the benefit of biochar in Timor-Leste.

Regarding the low-labour mungbean cropping system, a survey emphasised the value to households in increased income, decreased women’s labour and increased soil fertility.

In an evaluation of legume options, promising lines of common bean, cowpea and winged bean were identified for varietal release that require seed multiplication.

Red rice was identified as an alternative crop to white rice to grow on spring-fed irrigated land while farmers purchase imported lower-value white rice.

Common beans, onions and carrots are traditionally grown in the highlands (areas above 1000 m above sea level) in Timor-Leste. With AI-Com, it was shown that these crops can be grown profitably in the lowlands during the cooler dry season of April to October.

Aflatoxin was found in maize and peanut farm samples and in the blood of women and children, but the consumption of aflatoxin contaminated grain is not considered a causative factor in the current level of malnutrition and stunting affecting Timor-Leste children.

Insights from the project that are likely to lead to substantial benefits are: 1. No negative effects of fertiliser were observed and farmer are willing to use fertiliser if they are confident of benefit; 2. Biochar input increases productivity in horticulture and its manufacture is a good basis for economic activity; 3. Many soils seem responsive to addition of P and Zn; 4. Low labour mungbean saves time and increases profit; 5. Common bean and winged bean lines have been identified for varietal release for crop intensification; 6. Use of quality topsoil and GA3 improves sandalwood seedling performance; 7. Sandalwood in conjunction with fodder tree legumes is a viable option for farmers.

Improved scientific capacity was a major output from the project.

9.2 Recommendations

Researchable issues stemming from the project

- The project has highlighted the benefits available from research in Timor Leste on soil fertility and conservation agriculture. But further research investment is strongly warranted.
- As some of the insights from the project are relatively preliminary, they will need further research to be impactful, such as responses to Zn and P, and attitudes to inorganic fertiliser.
- The long-term effect of biochar application on crop yield and selected soil properties needs to continue to be monitored.
- Additional pot studies on mungbean, and for soil types whose response to biochar have not been investigated need to be conducted.
- AI-Com2 will continue to monitor sandalwood growth and measure forage production in trial sites established during AI-Com1. This recognises the benefit of long-term longitudinal trials when studying perennial species, the AI-Com2 project will build on the 5 years of previous work and obtain data otherwise not available.
- To enable long-term sandalwood improvement through domestication, judicious consideration of genetic relationships among selected individuals is needed. The source of genetically distinct and improved selections can be the conservation stand in Natarbora, planted woodlots and wild populations. Further assessment of commercial traits, preferably in common-garden trials such as the Natarbora planting will also provide guidance on whether importation of germplasm from outside Timor-Leste is necessary and/or desirable.

Capacity building needs identified by the project

- Best practices for use of agrichemicals for safety and resistance management.
- The study found a need for improved sandalwood extension for and knowledge transfer within communities. AI-Com2 will investigate how MAF training can be delivered to improve adoption of and scale-out smallholder sandalwood systems.
- The robust financial performance of sandalwood and FTL systems used in a cut and carry system for cattle production suggests great potential for this agroforestry system. Prospective growers and investors need ready access to this information, which can be achieved by summarising key management assumptions and financial indicators.

Institutional suggestions

- Need to link farm-ready research “products” to the extension system(s) such as low-labour mungbean in the south coast region and inland irrigated zones.
- Need for seed multiplication by MAF and increasing the access to information (and hence adoption) on the opportunities and limitations for including additional legume options (such as common bean, short-season cowpeas and winged beans) in the both the south and north coast cropping regions.
- With assistance from the ACIAR Dili office, meet with DFAT Development leadership and TOMAK to ensure their development efforts follow Australian-led innovation.

Others

- Digital heritage: Support the current project’s web page maintenance and evolution. As there are few ACIAR agriculture projects in TL, there is a chance to have a catch-most web resource that includes Seeds of Life and AI-Com products.
- Reprint many of the extension materials for extension purposes.

- Take steps to ensure that the Agricultural Technical School of Natarbora planting of sandalwood is protected from theft from future claims into the future by clear ownership.
- Publication of research results from AI-Com in the international literature.

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