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Contents

List of abbreviations and definition of terms

AAR	Average annual rainfall
ACIAR	Australian Centre for International Agricultural Research
AEN	Agronomic efficiency of the applied nitrogen fertiliser
Al	Aluminium
BBSDLP	Balai Besar Sumber Daya Lahan Pertanian (Collaborating Indonesian organisation)
BD	Bulk density (Mg/m^3 or g/cm^3)
BPTP	Balai Pengkajian Teknologi Pertanian or Assessment Institute for Agricultural Technology - (Project coordinator Indonesia)
BS	Base saturation
C	Carbon
Ca	Calcium
CEC	Cation exchange capacity
DPI	Department of Primary Industries
EM38	Electromagnetic induction equipment model EM38
HCl	Hydrogen chloride
K	Potassium
KCl	Potassium chloride
KWT	Kelompok wanita tani (Women farmer group)
m a.s.l.	Meters above sea level
Mg	Magnesium
Na	Sodium
NSW	New South Wales
P	Phosphorus
PPA	Pressure plate apparatus
PPL	Penyuluh Pertanian Lapangan (Agricultural Extension Officers)
TAI	Tamworth Agricultural Institute
UNSYIAH	The University of Syiah Kuala, Banda Aceh

The term ‘dryland’ (rainfed) in the context of this project is an area where crops grown are 100% reliant on seasonal rainfall or where there is no irrigation infrastructure available.

The term “dry season” is used when crop growing is conducted during the dry season after the wet season rice is harvested. This is normally between April and August.

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2 Executive summary

The income of dryland farmers in both Aceh, Indonesia and New South Wales (NSW), Australia is affected by low soil productivity associated with soil fertility decline and drought. In Aceh, the low income of farmers is compounded by small farm size, lack of capital and market price fluctuations. This project operated between February 2015 and June 2019 and aimed to improve the income of smallholder farmers in dryland systems of Aceh by increasing crop yield. The project objectives were to: (1) characterise current practices and systems in dryland areas of Aceh Besar, Bireuen, Pidie and Aceh Barat districts in order to identify constraints and opportunities to improve crop yield; (2) to evaluate and demonstrate promising technologies to increase production; and (3) to increase capacity of the extension services to support farmers and women farmers. In Australia, the project evaluated soil and land use management to improve soil and water productivity and sustainability under objective 2.

Surveys (Objective 1) found that Aceh's dryland farmers only grow one rice crop per year during the wet season (September–March). They are reluctant to crop during the dry season (April–August) because of the risk of low yields or crop failure due to low soil moisture availability. This risk was increased by low soil fertility associated with low soil nitrogen, carbon and other nutrients, and additional risk factors including lack of agronomic knowledge, extension advice, and finance. To generate income, most male farmers migrated to the city to seek employment during the dry season.

Technologies evaluated (Objective 2) include the incorporation of dry season crops such as mungbean, soybean, peanut, and maize into the rotation, and improved fertiliser management and use of soil amendments such as compost, manure and biochar. The inclusion of dry season crops in the rotation increased crop frequency from one to two crops per year. This could generate an additional farm gross margin of A$159 to A$2,584/ha/year depending on the crop grown. Improved fertiliser management increased crop yields. The increased income from growing dry season crops resulted in improved living conditions for participating farmers and reduced urban migration for employment during the dry season. However, using soil amendments to improve yields gave inconsistent results that were not reproducible.

The capacity building and extension program (Objective 3) directly reached 725 women farmers, 16 food crop farmers, 44 local field extension officers (also known as PPL), 51 university students and 10 project staff in Aceh, and indirectly over 100 local farmers. The PPL, whose role is traditionally to support only wet season rice farmers, were identified as a key resource to achieve practice change and invited to be project partners. The PPL, participating farmers and students were trained to produce and use compost, liquid fertiliser, and biochar and to use improved fertiliser management. Communication activities were conducted to facilitate the sharing and exchange of information between project participants. The 725 women farmers were supported to grow vegetables in groups (KWT), in their backyard. University students were involved in research, demonstration and communication activities which built future agricultural research capacity in Aceh.

A significant outcome for women farmers was the ability to generate an additional income of A$402–A$2,000 per year for each family by growing backyard vegetables. This facilitated women farmers to shift from financial dependency to becoming self-reliant and in some cases entrepreneurs. Building the capacity of women farmers had social benefits which included the positive impact from empowering women, improved food security and family health and wellbeing.

This research was the first and only study that attempted to evaluate dryland agricultural systems in Aceh and one of the very few comprehensive dryland studies in Indonesia. The scientific knowledge generated about Aceh's dryland soils will inform future agriculture research and development to support the Indonesian food security program.

The two dryland research components in NSW were: (1) an evaluation of soil and pasture responses to soil amended with poultry litter biochar and (2) an evaluation of carbon changes under annual cropping, planted agroforestry and natural grassland. The biochar increased the nitrogen use efficiency of applied fertiliser leading to a 19% increase in herbage mass of digit pasture. The biochar also increased soil carbon for at least six years. The evaluation of the effect of landuse on

soil carbon showed that cropping reduced soil carbon by 1% over five years while under trees and natural grassland soil carbon increased by 7% and 25%,respectively, for the same period. This suggests that the loss of soil carbon due to annual cropping activities may be offset by replanting trees or maintaining natural grassland in farming systems. Alternatively, a carbon-rich material such as biochar could be applied to soil as an amendment.

The project's findings have been communicated in scientific forums (including the Australian National Soils Conference and an invitation to publish in a special edition of the journal Soil Research), popular mediums (including ABC Landline and associated online platforms), the ACIAR website, national and international seminars in Indonesia, and multiple project forums in Aceh.

This project recommends:

1. For ACIAR: to use the women farmer group (KWT) program in Aceh as a model for soil management and food security projects in developing countries.
2. For farmers and project partners in Aceh:
    a. farmers in Aceh to continue to grow crops during the dry season with support from BPTP Aceh and PPL
    b. women farmer groups continue to be encouraged to grow vegetables in their backyards with support from BPTP Aceh and PPL
    c. BPTP Aceh to encourage local government to provide supplementary irrigation infrastructure (i.e groundwater pumps) for dry season crops
    d. BPTP Aceh to promote the benefits of growing vegetables by women to local government and encourage them to provide water storage options and enable women farmers to hand-water their vegetable gardens
    e. BPTP Aceh and UNSYIAH to work collaboratively on the long-term assessment of compost, biochar and manure and quantify their economic benefits
    f. ongoing commitment from UNSYIAH and BPTP Aceh to maintain and increase research, reporting, and scientific writing capabilities.
3. For NSW DPI:
    a. further investigate and develop biochar practices in NSW to allow further quantification of the benefits from reduced nitrogen fertiliser requirements and increased soil carbon
    b. consider mechanisms to support developing a biochar industry in NSW
    c. continue to encourage the maintenance of perennial vegetation in farming systems to offset the loss of soil carbon under intensive cropping.

3 Background

3.1 Key issues in Aceh

The poverty level in rural Aceh (19%) is doubled that in the urban area (BPS 2019; World Bank 2008). The high rural poverty level is linked to low income from small farm size of 0.25–0.5 ha per family (BPS 2012), low crop yields (BPS 2013), low level of land ownership, sensitivity to market price fluctuations, and limited access to finance. Low dry season crop yields (Table 1) are associated with low soil fertility (Mulyani and Hidayat 2009), low soil water holding capacity and low dry season rainfall (McLeod et al. 2010), and limited access to good quality seed (Nugraha 2013). As a result, most farmers seek off-farm work in the dry season in preference to growing crops.

Table 1. The average dryland crop yields in Indonesia and Aceh (details in Appendix 1, D01).

Dryland crops	Average Indonesian yield (t/ha)	Potential Indonesian yield (t/ha)	Aceh's average yield (t/ha)
Corn	4.8	11.6*	3.7
Dryland (gogo) rice	3.3	4.7	2.9
Soybean	1.4	3.0	1.3
Peanut	1.3	2.5	1.2
Mungbean	1.2	2.2	1.1

*(Agustiani et al. 2018)

This project targeted smallholder farmers in dryland agriculture systems across Aceh Besar, Pidie, Aceh Barat and Bireuen districts to increase cropping frequency by incorporating dry season crops (such as those listed in Table 1) and vegetables, in addition to their usual wet season rice. This could increase their household income. For this to be viable, dry season crop yields would need to improve.

Indonesian farming systems consist of wet season (September–March) and dry season (April–August). Subsistence farming dominates, with rice as the main crop grown during the wet season in flooded bunded fields. During the dry season, farmers grow 'palawija' (dry season crops) such as maize, mungbean, soybean or peanut which are sold to provide a cash income (Adisarwanto et al. 2001). Typically the palawija crops are not fertilised as farmers assume water and nutrients left after a wet season rice will be sufficient for dry season crops. Not applying fertiliser may contribute to the low crop yield (Table 1; McLeod et al. 2013). The government of Indonesia subsidises fertiliser for rice (Warr and Yusuf 2014), but there is no fertiliser subsidy for other crops. Farmers tend to over fertilise their rice crops.

Some areas are well supported by a network of irrigation infrastructure and in these areas farmers grow irrigated rice, referred to as lowland rice-based systems. These systems can produce up to three or even four rice crops per year. In the rainfed systems (referred to as dryland) the rice-growing period is limited to the wet season (Adisarwanto et al. 2001).

In Aceh, farmers in the lowland systems follow the Indonesian cropping pattern of growing rice in the wet season and palawija crops in the dry season. However, in dryland systems, Aceh's farmers do not grow a crop during the dry season because of the risk of low yield.

Gender inequality is a major issue in Aceh. Rural women have limited employment opportunities and their contribution in assisting with growing rice crops is not equally acknowledged. This project helped women farmers to earn income by supporting them to grow backyard vegetables.

3.2 Dryland farming systems

The major constraints for dryland farming systems in Aceh (Indonesia) and NSW (Australia) and include low soil fertility and low soil water availability (Mulyani and Hidayat 2009; Carberry et al. 2010). Removal of nutrients via harvested materials, soil erosion, loss of soil carbon, and soil structure decline exacerbate these constraints.

In Aceh the major risks for crop production are the high-intensity and amount of rainfall during the wet season depleting the soil of nutrients and the lack of rainfall during the dry season. The majority of the 1,400–2,200 mm annual rainfall occurs during the wet season (September–March), leaving insufficient soil moisture to support crops during the dry season (April–August) (McLeod et al. 2010). However, recently Aceh's rainfall pattern has become increasingly unpredictable with crop damage by flood reported during dry seasons and crop failure due to drought during wet seasons.

In the context of this project, dryland areas in Aceh are categorised as either dryland upland or dryland lowland. The dryland upland are areas where there are no bunded rice fields, and rice is grown under aerobic conditions also known as 'padi gogo'. Dryland lowland refers to areas with bunded paddy fields but without irrigation infrastructure, where rice is grown during the wet seasons, also known as 'padi sawah'.

The small farm size and subsistence nature of rice farming in Aceh means that dry season crops present an opportunity for most farmers to source extra income (McLeod et al. 2013). However, the risks associated with low crop yields are a major barrier. A potential solution to increase crop yields is to improve fertiliser use and soil fertility. In addition, improving the local government understanding about dry season crops could facilitate policy development for the provision of supplementary irrigation water to dryland farmers either from groundwater pumping or rainwater harvesting program. It could also increase engagement of the private sector and community investment in dryland farming (Lakitan and Ghofar 2013).

In addition, there is a lack of institutional support for dryland and dry season farmers originates from the prolonged conflict that saw Aceh closed to the rest of Indonesia for over three decades (Schulze 2004). The dryland areas were considered unsafe as it was mostly under the control of the rebels. Therefore PPL was not sent to the dryland systems. The conflict has also prevented the flow of agricultural information in and out of most of the dryland areas. It was only after the peace agreement in 2005 that it was considered safe to visit the dryland areas.

The safety issues associated with prolonged historical conflicts have resulted in a lack of information about dryland systems in Aceh. This includes a lack of information about its dryland soils (McLeod et al. 2013). Previous soil studies conducted by the local university are mainly based on pot trials, and uncoordinated and disjointed. Most of the reports and publications on this research were damaged during the Indian Ocean Tsunami in 2004.

In the northwest slopes and plains of NSW, Australia, the average annual rainfall of 650 mm and atmospheric evaporative demand of >1,000 mm render water as the most limiting production factor for dryland crop production. Farms sizes are much larger (>100 ha) than in Aceh. The farming systems include both irrigation and dryland production, with cotton dominating the irrigated system on Vertosol soils of the plains. Dryland systems include winter and summer crops and pasture on both Vertosol and Chromosol soils on the ranges and plains.

The dryland farming systems in the region consist of summer or winter crop rotations with pasture that incorporates short or long fallow of up to 18 months. The winter crops (wheat, pulses and canola) are usually grown on stored soil moisture from the previous summer fallow. The common summer crops are sorghum, maize, sunflower and dryland or irrigated cotton. Crop rotation with pasture is also used for the management of disease and soil compaction.

Similar to farmers in Aceh, farmers in Australia are also facing increasingly unpredictable rainfall patterns and increased climate extremes resulting in severe drought, heat, fire and flood.

Dryland farmers in NSW seek agronomic support from commercial advisers or agronomists. Under exceptional circumstances (i.e. severe drought or flood) they are also able to seek assistance from the government.

3.3 Project justification and benefits

This project supports the ACIAR medium-term strategy for Indonesia (ACIAR 2012), the Indonesian National Agriculture Strategy for Sustainable Self-sufficiency for Food Crops (Deptan 2011), adaptation to rainfall variability and climate change, increased diversification and value-adding of food crops and improving farmers' welfare. It also supports the NSW DPI's Strategy for sustainable management of natural resources, which aligns with the NSW 2021 State Plan to protect the natural environment (NSW DPI 2012).

This project evolved from five former ACIAR projects following the 2004 Indian Ocean tsunami: C2004/121, SMCN 2005/004, SMCN 2005/075, SMCN 2005/118 and SMCN 2007/040. Project SMCN/2007/040 recommended developing technologies to:

1. improve soil fertility and increase productivity and profitability of farming systems through research to improve dryland farming production
2. strengthen partnerships with UNSYIAH
3. develop UNSYIAH agriculture research skills and staff capacity to train and mentor future agriculture scientists in Aceh
4. expand the development of the women farmer group program to assist women to achieve financial independence
5. assess long-term benefits of soil amendment
6. provide ongoing support for local field extension officers to help the women farmer group program.

The potential use of dryland areas in Indonesia to help meet food security is high (Abdurachman et al. 2008; Mulyani and Hidayat 2009), yet actual use is low. Moves to close the yield gap (Table 1) in the 1,154,445 ha of dryland areas in Aceh are expected to significantly improve the incomes of 400,000 farmers and contribute to the national food security program.

Since 2005, five ACIAR projects in the coastal and lowland rice-growing areas of Aceh have provided a good understanding of the lowland farming systems. There is still little knowledge about Aceh’s dryland (rainfed) systems. Up-to-date information about soil quality and fertility status of dryland farming systems in Aceh is non-existent. The existing fertiliser recommendations at the village or subdistrict level are developed from outdated, small-scale soil and topographic maps, without support from site-specific soil data. This knowledge gap, confounded by the traditional view that dryland crops are not important, results in poorly managed dryland crops.

This project included a specific target to build the capacity of women farmers in dryland systems of Aceh to earn an income and to empower towards closing the gender gap (Meinzen-Dick and Quisumbing 2012). Experience from ACIAR project SMCN 2007/040 showed that in the lowland system, encouraging women farmers to grow backyard vegetables in groups provided a means to earn an income (Table 2) and it empowered them. The support of the PPL was critical to this success. The model of growing vegetables by women farmers in the lowland system was applied in this dryland project.

Table 2. Monthly gross margins for women farmer groups in the lowland system of Aceh Besar (McLeod et al. 2013).

Group	**Land area**	**Production cost**	**Income**	**Gross margin**	**Home consumption[1]**	**Net benefit**	
	(m²)	(Rp)	(Rp)	group (Rp)	member (Rp)	member (Rp)/month	Total (Rp)/month
Tani Sejahtera	900	389,000	3,560,000	3,171,000	161,000		
Sejahtera	500	97,000	1,620,000	1,523,000	109,000		
Maju Beusare	1,000	606,000	4,080,000	3,474,000	168,000		
Average	–	364,000	3,087,000	2,722,667	146,000	150,000[1]	296,000

[1] average value of home consumption from group plots (Rp.5,000 /day) - (A$1=Rp.9,000 (2012).

In NSW Australia, this project (1) evaluated the long-term benefits of poultry litter biochar on soil fertility, nutrient use efficiency and pasture productivity when grown on a degraded Red Vertosol in Tamworth and (2) compared potential recharge, water productivity and soil fertility dynamics of undisturbed grassland, planted agroforestry and dryland crops in a Black Vertosol in the Liverpool Plains.

The beneficiaries of the project in Aceh include smallholder farmers, agricultural research and extension providers, and agricultural research academic staff and students in the University of Syiah Kuala (UNSYIAH), Banda Aceh. The biochar evaluation in Tamworth will add to the understanding of the interaction of biochar and fertiliser on organic matter in the soil. The soil water study in the Liverpool Plains will add to the understanding of the hydrologic and soil responses to various land-uses in the Liverpool Plains.

4 Objectives

The project aims to identify cost-effective management practices that increase the productivity and profitability of selected crops of economic importance to dryland cropping systems of Aceh.

The research questions addressed in this project are:

1. What are the challenges and opportunities for soil and water management to increase cost-effective production of economically important food crops under dryland conditions in Aceh?
2. What are the possibilities for improving crop rotations best suited to local conditions?
3. What are the appropriate soil and water management practices for the improved crop rotations?
4. What are the most effective dissemination strategies for the promising technologies identified by the project?

The specific objectives and associated activities are:

Objective 1. To examine current practices in dryland cropping systems in the selected districts and identify agronomic constraints for increasing productivity considering the local agro-ecological and socio-economic conditions (surveys)

Activity 1.1. Identify representative sites and crops important for dryland cropping systems through a synthesis of existing information and field surveys (socio-economic survey).

Activity 1.2. Determine important soil physical and chemical characteristics and availability of water at selected sites and identify the key soil and water constraints to increasing production (soil survey).

Objective 2. To develop integrated soil, water and crop management practices for increasing the cost-effective production of key dryland crops in rotations

Activity 2.1. Conduct field experiments to identify potential management practices at contrasting sites relevant to dryland cropping systems.

Activity 2.2. Evaluate promising technologies selected from Activity 2.1 in farmer participatory trials at selected sites.

Activity 2.3. Conduct experiments in NSW to evaluate management practices that improve soil nutrient and water availability in dryland farming systems.

Objective 3. To develop strategies for dissemination of promising technologies to extension services and smallholders

Activity 3.1. Conduct training programs for at least 40 district extension staff for efficient dissemination of promising management practices to smallholders.

Activity 3.2. Support the adoption of promising crop rotation practices and identify opportunities for improvement.

Activity 3.3. Establish sites for demonstrating promising technologies to farmers.

Activity 3.4. Analyse, report and communicate key project results to research and extension staff, farmers and local government in the target districts.

Expected project outputs:

1. Best management practices developed to increase the cost-effectiveness of dryland cropping systems in four districts of Aceh.
2. Farmer participatory trials conducted to field test the promising technologies.
3. Training activities conducted for extension staff, students and farmers.
4. Promising management practices demonstrated through field demonstrations, extension leaflets, reports and publications.
5. Project forums, networks and case studies conducted to strengthen the activities of 30 new women farmer groups.

Expected project impacts:

To have the farmers adopt the promising technologies developed from this project has the potential to increase yields of soybean by about 30%, peanut by 40% and dryland rice by 20%. The annual income of dryland farmers is estimated to increase by an average A$300/ha from yield improvements and increased production from dry season crops. Benefits from growing vegetables by the women's farming groups are estimated to reach A$260/year/household. This is expected to result in a collective improvement in income of about A$3 million per year for 4,000 dryland farmers and 7,000 households in the four target districts within five years of the completion of the project.

Anticipated social impacts include improved family health and nutrition due to increased knowledge and wellbeing of women farmers, as well as increased and more diverse vegetable consumption. A positive environmental impact is expected through improved management of soil and farm inputs. Scientific communities will have a better understanding of soil, water and crop constraints in dryland cropping systems and technologies to address these constraints. The community impact will be achieved through the increased collaboration and collective capacity of BPTP Aceh, agriculture extension staff and the local university (UNSYIAH) to influence local government decision-making processes about issues affecting smallholder farmers in Aceh.

5 Methodology

The implementation plan for this project was agreed in February 2015 with an initial plan to finalise the soil and socio-economic survey and reporting during the remainder of 2015. The research, demonstration, communication and development activities were conducted from 2016 to early 2019.

5.1 Location

This project focuses on dryland systems of Aceh Besar, Pidie, Aceh Barat and Bireuen districts (Table 3). These were selected based on the significance and the potential of key dryland crops (soybean, peanut, dryland rice, maize and vegetables) in these districts. In the context of this project, the term dryland is defined as those areas that are 100% reliant on rainfall for cropping.

Table 3. The significance of key dryland crops in the four selected districts of Aceh based on an assessment conducted by BPTP Aceh in 2014.

District	**Dryland crop**				
	Soybean	Peanut	Dryland rice	Maize	Vegetables
Aceh Besar	**			**	***
Aceh Barat		***	***	**	**
Bireuen	***			**	***
Pidie	***	***	***	**	

** Moderately significant crop in the local economy of this district.
*** Highly significant crop in the local economy of this district.

5.2 Climate

Aceh has a humid to dry tropical climate (Schmidt and Ferguson, 1951). The rainfall distribution is bi-modal (Figure 1), with a distinctive wet season (September–January) and dry season (February–August). Aceh Besar and Pidie districts have average annual rainfall (AAR) of 1,200–1,450 mm (BMKG Blang Bintang 2017) while Aceh Barat district is wetter with 2,250–3,500 mm AAR.

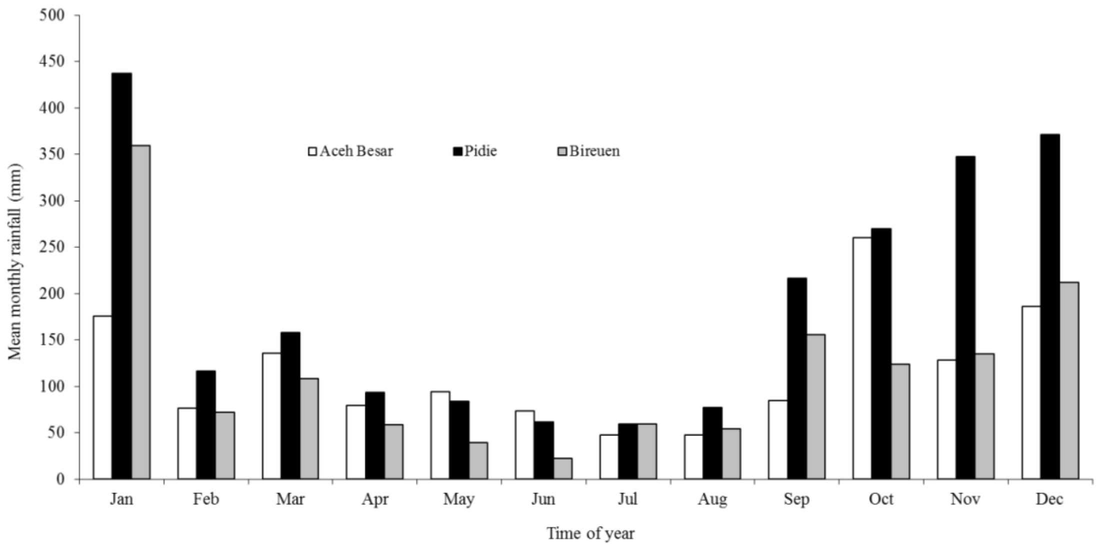


Figure 1. Monthly rainfall distribution for Aceh Besar, Pidie and Bireuen (McLeod et al. 2010).

The annual cropping patterns in the dryland farming systems are dictated by the availability of water (rainfall; Table 4).

Table 4. Common cropping patterns in Aceh's mainstream agricultural systems

Dryland upland annual cropping pattern											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Soybean/maize/ horticulture/padi gogo			Vegetable/food crops						Soybean/maize/horticulture/padi gogo		
Dryland lowland annual cropping pattern											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wet season flooded rice (padi sawah)			Palawija crops or vegetables						Wet season flooded rice (padi sawah)		

5.3 Objective 1: To examine current practices in dryland cropping systems in the selected districts and identify agronomic constraints for increasing productivity considering the local agro-ecological and socio-economic conditions

The activities undertaken to achieve Objective 1 included socio-economic and soil surveys to characterise the dryland systems and the current farming practices. The results were intended to guide the research activities, and the results of the research to guide demonstration activities. Both the soil and socio-economic surveys were planned to be conducted in shared locations. However, differing priorities and work schedules of the partner organisations meant both were conducted independently and sites were not shared. The soil survey results were also delayed by more than six months because of local 'red tape' in chemical procurement at UNSYIAH, resulting in delayed research activities. This meant a significant delay (more than 12 months) for the demonstration activities. To prevent further delays, the demonstration activities were conducted concurrently with the research activities, which resulted in a weaker link than intended between research and development activities. This is an acknowledged weakness of the project.

5.3.1 Activity 1.1. Identify representative sites and crops important for dryland cropping systems through the synthesis of existing information and field surveys (socio-economic survey in Aceh)

BPTP Aceh conducted a desktop study of socio-economic data from the local agricultural agency and bureau of statistic publications to obtain an overview of dryland farming systems in Aceh. This was supplemented by a field survey to confirm key results from the desktop study. The field survey was conducted in one dryland lowland rice site and one dryland upland site (also identified by BPTP Aceh as non-rice dryland) for each district (Table 5). The dryland lowland has bunded paddy fields but no irrigation infrastructure, so rice crops are grown during the wet seasons in flooded rice fields. In the dryland upland (non-rice dryland) there are no bunded rice fields and rice is not the main crop. When farmers in the dryland do grow rice during the wet season, they grow the upland rice variety (not flooded).

The selection of these sites was guided by the local government or field extension staff and was based on accessibility and the presence of dryland areas. A combination of an interview with individual farmers and focus group discussion (FGD) was used. The FGD consisted of farmers, local field extension officers and a village leader. There were 15 farmers interviewed per village resulting in a total of 120 surveys completed.

Table 5. Location of the socio-economic survey by BPTP Aceh.

District	Subdistrict	Village	Agro-ecosystem
Aceh Besar	Darul Kamal	Lambaro Biluy	Rainfed low land
	Lhoong	Jantang	Non-rice dry land
Pidie	Padang Tiji	Kupula Tanjung	Rainfed low land

District	Subdistrict	Village	Agro-ecosystem
	Simpang Tiga	Pante	Rainfed low land
Bireuen	Jeumpa	Paloh Panyang	Rainfed low land
	Peudada	Jaba	Non-rice dry land
Aceh Barat	Samatiga	Suak Timah	Rainfed low land/dry land
	Meurebo	Ujung Tanjong	Non-rice dry land

Data collected in these surveys included demographics, landholding, income source and distribution, labour source and allocation, irrigation and drainage infrastructure, extension support, input/output, market prices and existing farmer practices (crop rotation, crop selection, farm inputs and cultivation) – see Appendix1, D4.

5.3.2 Activity 1.2. Determine important soil physical and chemical characteristics and availability of water at selected sites and identify the key soil and water constraints to increasing production (soil survey in Aceh)

The objective of the soil survey was to identify specific production constraints of dryland systems in Aceh and to guide management practices to improve crop yields. Over 500 soil samples were collected from the representative dryland sites across Aceh Besar, Pidie, Bireuen and Aceh Barat districts (Figure 2) covering 30 subdistricts (Table 6). There were 126 locations sampled at depths of 0–20 cm and 20–40 cm, representing a range of soil types and land uses. The samples were analysed (Table 7) to determine soil fertility status. The interpretation of the soil chemical properties and the determination of soil fertility status was based on criteria from Balai Penelitian Tanah (2005). Soil types were identified using the Indonesian classification system (Subardja et al. 2014) and USDA Soil Taxonomy (2014).

Table 6. Location summary of soil surveys and the number of soil samples collected.

District	Subdistrict	Number of samples		
		0-20 cm	20-40 cm	Horizon
Aceh Besar	Jantho, Seulimum, Kuta Cot Glie, Lembah Seulawah, Mesjid Raya, dan Darussalam	36	36	41
Pidie	Padang Tiji, Batee, Muara Tiga, dan Laweung	25	25	26
Bireuen	Jeumpa, Juli, Peusangan, Peusangan Siblah Krueng, dan Krueng Manee	30	30	31
Aceh Barat	Meureubo, Samatiga, Bubon, Kawai 16, Woyla, Kawai XVI, Woyla Barat, dan Pante Cermin	25	25	48
Ie Seuum, Krueng Raya, Aceh Besar		28	28	5
Experimental site of Campus Darussalam, Syiah Kuala		20	20	6
Experimental site of Pidie, Muara Tiga, Pidie		3	3	5
Experimental site of Jantho, Aceh Besar		5	5	6

Table 7. Methods of soil analysis.

Parameters	Methods
soil pH and EC (dS/m)	suspension of (1:2.5) soil to H_2O and 1N KCl ratio
organic C (g/kg)	Walkley and Black
total N (g/kg)	Kjeldhal digestion
P_2O_5 (mg/kg)	HCl extract (25%)
K_2O (mg/kg)	HCl extract (25%)
available P (mg/kg)	Bray 1 solution, then spectrometer
exchangeable cations Ca, Mg, K and Na (cmol(+)/kg)	1N NH_4OAc pH 7 extract
exchangeable Al and H (cmol(+)/kg)	1 M HCl extract (McLean method)
cation exchange capacity (CEC) cmol(+)/kg	1N NH_4OAc pH 7
base saturation (%)	calculated: (sum of base cations/CEC) x 100
particle size analysis	pipette method
bulk density(Mg/m^3)	standard bulk density ring
soil water content at sampling	gravimetric

Parameters	Methods
soil water content at pF 4.2 and 2.5	pressure plate apparatus and gravimetric
soil water holding capacity	calculated
soil permeability (cm/hr)	constant head permeameter
soil porosity (%)	calculated from bulk density
aggregate stability index	dry and wet sieving

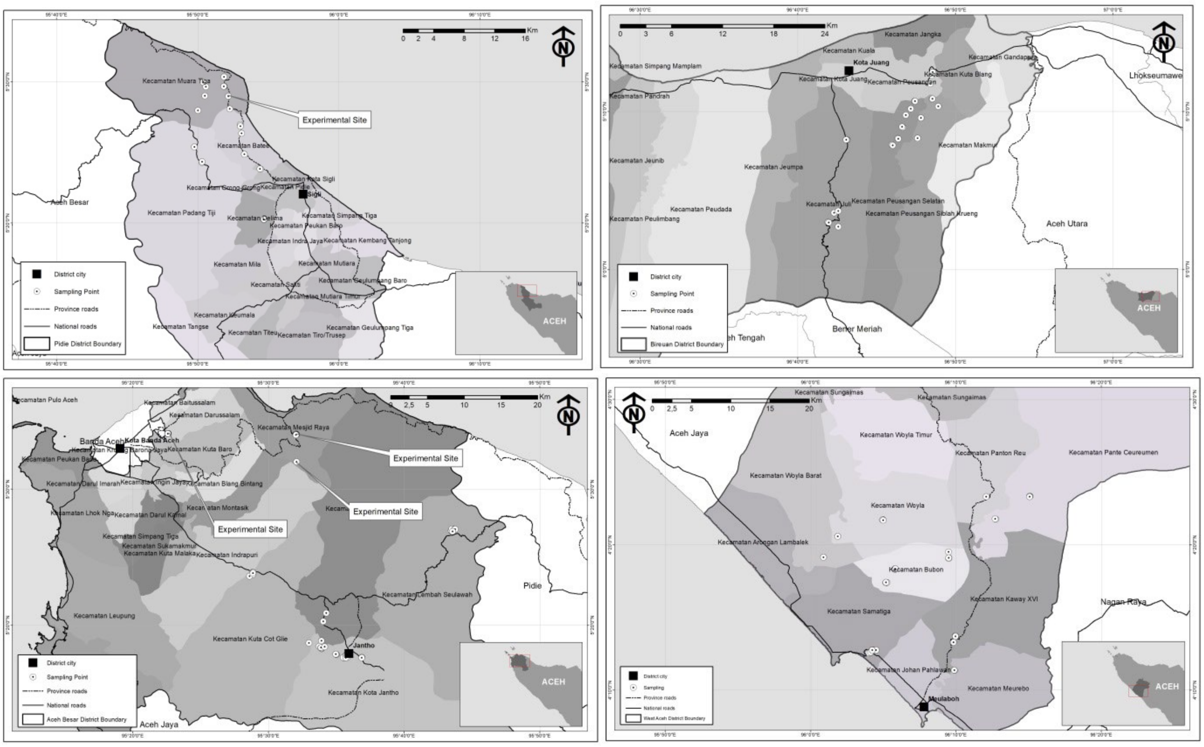


Figure 2. Location of soil survey and experimental sites across Pidie (top left), Bireuen (top right), Aceh Besar (bottom left) and Aceh Barat (bottom right) districts.

5.4 Objective 2: To develop integrated soil, water and crop management practices for increasing the cost-effective production of key dryland crops in rotations

5.4.1 Activity 2.1. Conduct field experiments to identify potential management practices at contrasting sites relevant to dryland cropping systems (Aceh and NSW Australia)

Location of the experiments in Aceh

The evaluation of soil and crop responses to the amendments were conducted by the UNSYIAH team and students at locations described below. Soils in all of these locations have low C and N contents and or low soil water holding capacity. Therefore the application of soil amendment is expected to improve soil fertility.

Jantho, Aceh Besar (05˚17'05.2"N and 95˚28'13.1"E, 100 m a.s.l., 3–25% slope)

The Jantho site is sloping and dominated by acidic Podzolic soils with a low fertility status that is typical of dryland soil in Aceh. The soil has medium texture, moderate to heavy bulk density, low water holding capacity (9.6–23.4%), good permeability and soil porosity (36.5–41.8%) but is limited by an unstable aggregate. The soil is low in total C, N, P and K contents and low in exchangeable base cations and base saturation, but it has moderate to high potential CEC and no threat of aluminium (Al) toxicity (Table 8). This site was terminated after the first dry season crop due to security reasons.

Muara Tiga Pidie, Pidie (05°28'13.1"N – 95°50'09.6"E, 31 m a.s.l., 0–3% slope)

The Muara Tiga site is flat, dominated by a neutral to slightly alkaline Cambisol/Inceptisol with low to moderate soil fertility, medium texture, bulk density >1.25 Mg/m^3, good structure and higher soil water holding capacity and permeability. The C and total N contents, total P, total K, and potential CEC are higher than the soil in Jantho, but of the base saturation is low (Table 8). The soil fertility constraints are low organic C, low base cations and low base saturation. This site was terminated after the second dry season crop due to security reasons.

Darussalam, Aceh Besar (05°17'05.2"N and 95°28'13.1"E, 3 m a.s.l., 0–2 % slope)

The Darussalam site was established as a replacement for both the Jantho and Muara Tiga sites. The land is owned by UNSYIAH and is located within the University precinct which made it easier to manage and monitor. The Darussalam site is flat and dominated by Entisol (Alluvial Eutric or Entisol) that has medium texture (sandy clay), bulk density of 1.06–1.24 Mg/m^3, low to moderate water holding capacity, good permeability, but low porosity and is dispersive. The soil is slightly alkaline, has low organic C and total N contents but high P, available P and K contents. The total exchange base cations and the base saturation are high but with a low of potential CEC (<16 cmol(+)/ kg) because of the high sand content (Table 8). The main fertility constraints are associated with low C and N contents.

Ie Seuum, Aceh Besar (05°34'01" N and 95°32'027" E, 10-50 m a.s.l., 3–60% slope)

Ie Seuum is located in the District of Mesjid Raya Aceh Besar. Soil at Ie Seuum has a low to moderate soil fertility status, is slightly acidic to neutral with low C and N contents, medium to high P and K contents, low to high exchangeable cations (Ca, Mg, K and Na), low to moderate base saturation, and moderate to high potential CEC.

Table 8. Characteristics of each experimental site.

District	Aceh Besar (Teureubeh Jantho)	Pidie (Paud, Muara Tiga)	Aceh Besar (UNSYIAH, Darussalam)	Aceh Besar (Ie Seuum)
Climate (Schmidt-Ferguson 1951)	C (1,734 mm AAR)	B (1,400–2,200 mm AAR)	B (2,500 mm AAR)	C (2,019 mm AAR)
Soil (Soil Survey Staff 2014)	Podzolic (Typic Hapludult)	Cambisol (Vertic Eutrudept)	Alluvial Eutric (Typic Udifluvent)	Dystric Cambisol or Inceptisol order (Typic Dystrudepts)
Bulk density (Mg/m^3)	0.97 – 1.24	1.12	1.06 – 1.24	1.23 – 1.27
Water holding capacity (%)	9.60 – 23.40	NA	12.83 – 16.72	11.90 – 14.40%
Permeability (cm/hr)	24.00 – 41.40	36.98 – 60.65	14.47 – 29.55	12.20 – 28.90
Porosity (%)	36.50 – 41.80	41.08 – 46.57	39.62 – 45.23	39.70– 47.20
Agregate stability index (%)	34.10 – 36.70	46.98 – 50.95	37.41 – 45.21	35.40 – 47.80
Soil texture class	clay, silty loam	clay, silt	sandy loam	silty loam
pH (H_2O) 1:2.5	6.02 – 6.60	7.33 – 7.75	7.20 – 8.60	6.24 – 6.94
C-organic (%)	0.32 – 1.79	0.75 – 2.07	0.74 – 1.54	0.49 – 1.67
Total N (%)	0.11 – 0.20	0.22 – 0.34	0.05 – 0.11	0.11 – 0.21
Total P (mg/kg)[1]	60 – 100	240 – 880	490 – 1220	25 – 707
Total K (mg/kg)[1]	30 – 40	280 – 810	490 – 420	72 – 234
Available P (mg/kg)[2]	0.90 – 2.80	10.00 – 87.90	28.00 – 85.00	4.30– 104.50
Ca-exch (cmol(+)/kg)	1.54 – 4.75	5.32 – 6.24	5.33 – 15.97	6.50 – 14.90
Mg-exch (cmol(+)/kg)	0.67 – 0.81	0.42 – 0.56	3.51 – 6.27	0.21 – 1.90
K-exch (cmol(+)/kg)	0.10 – 0.20	0.19 – 0.20	0.12 – 0.39	0.45 – 1.04

District	Aceh Besar (Teureubeh Jantho)	Pidie (Paud, Muara Tiga)	Aceh Besar (UNSYIAH, Darussalam)	Aceh Besar (Ie Seuum)
Na-exch (cmol(+)/kg)	0.75 – 0.85	0.25 – 0.60	0.08 – 1.60	0.32 – 0.82
Sums of cation (cmol(+)/kg)	3.13 – 6.59	6.65 – 7.10	10.77 – 19.75	3.13 – 6.59
CEC (cmol(+)/kg)	20.00 – 26.00	40.80 – 49.20	9.42 – 14.57	23.20 – 40.40
Al-exch, H-exch (cmol(+)/kg)	BDL	BDL	BDL	BDL
Base saturation (%)	12.00 – 33.00	13.60 – 16.30	>100.00	31.50 – 46.00
Cultivation system	mixed farming, shrubs	shrubs, mixed farming, chilli	experimental farm	horticulture, agroforestry
Soil fertility status	low	medium	medium	Low–medium

[1]extracted with 25% HCl; [2]Bray II extract; BDL = Below detection limit; EC on all sites was <0.5 dS/m.

Experimental design

The focus of the research was to evaluate the role of soil amendment and fertiliser management to improve crop yield. The soil amendment options selected were those easily accessible to farmers such as rice husk and cow manure. These can be applied to the soil in their raw state, composted or converted to biochar.

Biochar is a carbon-rich material produced from organic material by thermal decomposition in the absence, or under limited supply of oxygen, known as pyrolysis (Lehmann and Joseph 2009). Biochar has been used to increase soil fertility (Chan et al. 2007) while sequestering carbon. The application of biochar as a soil amendment can improve yield (Chan et al. 2008) via its high nutrient content, the liming potential (Van Zwietten et al. 2010), and improved fertiliser use efficiency.

In the Jantho and Muara Tiga sites, two experiments were established in 2016 (Figure 3 A, B and C) and were intended to run for three dry seasons to evaluate soil and dryland crop responses to soil amendments and fertiliser and the carryover on crops. However, after the first dry season crop, both sites were terminated due to security. The treatments applied (presented in Table 9) were combined with three planting configurations of soybean monoculture, sweetcorn monoculture and, mixed crop planting of soybean and sweetcorn (Table 10). Each treatment combination had three replicates resulting in 45 plots of 3.5 × 2.1 m each.

The variables measured included:

- Soil pH, organic C, total N, available P and exchangeable K (at 45 and 95 DAP)
- Soybean: the weight of 100 soybean seeds, number of imperfect soybean seeds per plant and estimated soybean yield (t/ha) from each plot
- Sweet corn: the fresh weight of corn seed per cob, fresh weight of cob with and without husk, marketable cob per plot, and numbers of seed per cob.

The soil and crop data were analysed using analysis of variance and continued with LSD 5% if there was a significant difference between treatments.

Table 9. Soil amendment treatments applied in both Jantho and Muara Tiga sites for experiments A and B (Figure 3).

Treatment	Rate	pH	Organic C	Total N	Avail P
A0: NPK (15:15:15) (the control)	400 kg/ha	-	-	-	-
A1: Rice husk biochar	10 t/ha	7.50	35.00	0.53	0.02
A2: Cow manure	10 t/ha	9.40	28.50	2.80	2.60
A3: Rice husk biochar + NPK (15:15:15)	10 t/ha + 400 kg/ha	-	-	-	-
A4: Cow manure + NPK (15:15:15)	10 t/ha + 400 kg/ha	-	-	-	-

Table 10. Planting configurations of soybean and maize used in both Jantho and Muara Tiga sites for experiments A and B (Figure 3).

Ref	Crop planted	Planting spacing	Plant Population (per 3.5 × 2.1 m plot)
S1	Soybean monoculture	30 x 30 cm	84
S2	Sweet corn* monoculture	70 x 30 cm	35

S3	Mixed crop (alternate rows of sweetcorn* and soybeans)	–	Soybeans 28 Sweet corn 35

* Sweet corn was planted 21 days post soybean.

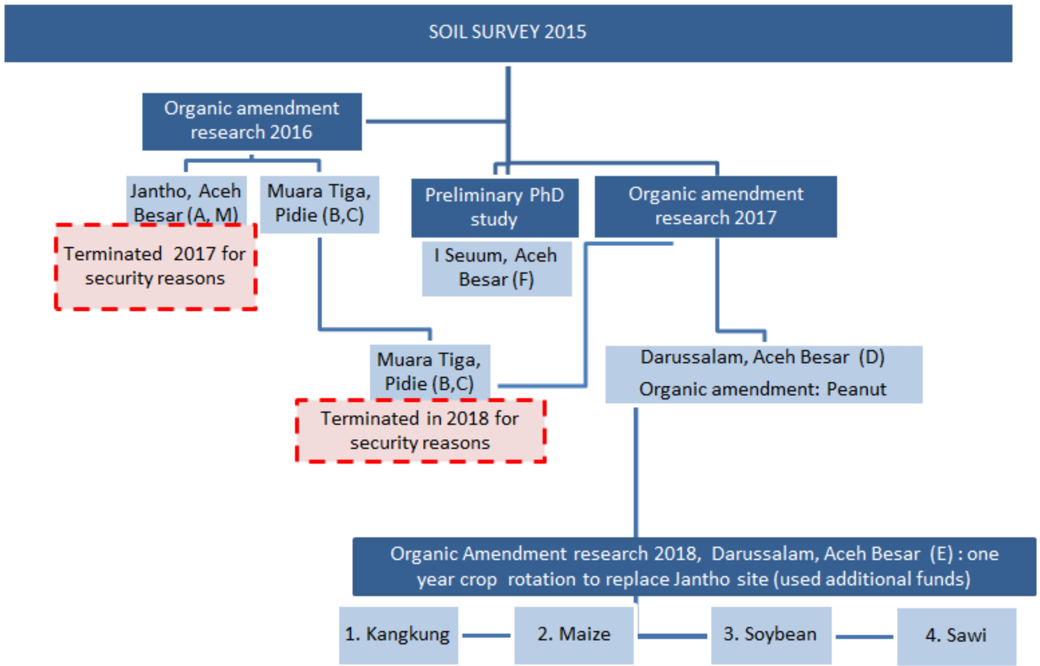


Figure 3. Overview of research activities in Aceh.

From the planting configuration experiment, the land equivalent ratio (LER) was calculated as the ratio of the area under sole cropping to the area under intercropping needed to give equal amounts of yield at the same management level. LER is used to compare yield advantage from mixed-cropping and monoculture (Mead and Willey 1980), and is calculated using the following equation:

$\mathrm{LER} = \frac{Yjk}{Yjj} + \frac{Ykj}{Ykk}$, where,

Yjk = yield of sweetcorn in intercropping, Ykj = yield of soybean in intercropping, Yjj = yield of sweetcorn monoculture and Ykk = yield of soybean monoculture.

LER > 1 indicates yield advantage for mixed-cropping

LER = 0 indicates no difference in yield between monoculture and mixed-cropping

LER < 1 indicates yield advantage for monoculture.

In the Jantho site, an additional experiment (Figure 3, experiment M) was conducted to evaluate the role of mulch in soil properties and yields of dry season crops of maize, peanut and soybean. The treatments applied were:

- M0 = control (without mulch)
- M1 = without mulch + NPK 400 kg/ha
- M2 = maize mulch 5 t/ha + NPK 400 kg/ha
- M3 = maize mulch 10 t/ha + NPK 400 kg/ha

The soil parameters assessed include soil chemical (pH, total N, organic C, available P and exchangeable K) and soil physical properties (bulk density, porosity, water holding capacity and aggregate stability).

In the Muara Tiga site an additional experiment (Figure 3 experiment C) was conducted to evaluate soil and peanut crop responses to compost and manure as detailed below:

- S0 = control (without soil amendment)
- S1 = cow manure 10 t/ha
- S2 = compost 10 t/ha

- S3 = manure 10 t/ha + compost 10 t/ha

Four varieties of peanut (Tuban, Hypoma2, Bima, Kelinci and Gajah) were planted into each of the triplicate treatment plots. Agronomic and nutritional parameters measured include plant heights at 15 and 30 DAS, dry matter weight, nutrient (N, P and K) uptake and use efficiency and yield.

Soil physical parameters measured before sowing and the day before harvest include soil water content at pF2.54 (to determine water content at permanent wilting point) and pF4.2 (to determine water content at field capacity), soil porosity (calculated from bulk density and particle density), permeability (constant head method) and aggregate stability of soil (wet and dry sievings).

In the Darussalam site, two consecutive peanut crops (Figure 3, experiment D) were conducted in the dry seasons of 2017 and 2018 to investigate soil and peanut yield responses to cow manure and biochar made from rice husk or coco-peat. The first peanut crop did not respond to the low organic amendment rate, therefore the application rates were increased during the second peanut crop (Table 11). The low rate was applied in the first crop to make it more realistic for farmers to adopt.

Table 11. Organic amendment used for the peanut trial at Darussalam site.

Symbol	1st Peanut crop (June-September 2017)	2nd Peanut crop (April-July 2018)
RHB0	Rice husk biochar 0 t/ha	Rice husk biochar 0 t/ha
RHB10	Rice husk biochar 2.5 t/ha	The residue of rice husk biochar 2.5 t/ha + rice husk biochar 10 t/ha
RHB5	Rice husk biochar 5 t/ha	The residue of rice husk biochar 5 t/ha
CPB0	Cocopeat biochar 0 t/ha	Cocopeat biochar 0 t/ha
CPB10	Cocopeat biochar 2.5 t/ha	Residue of cocopeat biochar 2.5 t/ha + cocopeat biochar 10 t/ha
CPB5	Cocopeat biochar 5 t/ha	The residue of cocopeat biochar 5 t/ha
CM0	Cow manure 0 t/ha	Cow manure 0 t/ha
CM10	Cow manure 2.5 t/ha	Residue of cow manure 2.5 t/ha + cow manure 10 t/ha
CM20	Cow manure 5 t/ha	Residue of cow manure 5 t/ha + cow manure 20 t/ha

The Jantho and Muara Tiga sites were replaced by establishing the second experimental plot in the Darussalam site in 2018. A one-year of crop rotation trial was established (Figure 3, experiment E) to evaluate soil and crop responses to soil amendment. The crop rotation experiment had to be conducted within the one year to fit in with the remaining time for the project. Soil amendments used included a combination of NPK fertiliser with rice husk, rice husk biochar and cow manure (Table 12). The crops grown in the rotation were kangkung (*Ipomoea aquatic*), maize (*Zea mays*) and soybean and sawi/choy sum (*Brassica chinensis*). Kangkung and choy sum are short term vegetable crops that can be harvested within one month. This allowed maize to be grown during the dry season of 2018, but unfortunately, soybean a dry season crop had to be grown during the wet season of 2018 to allow the completion before the project ended.

Table 12. Treatments evaluated for the rotation experiment at the Darussalam site.

No	Symbols	Treatments season 1 (Kangkung)	Treatments seasons 2, 3 and 4 (maize, soybean, mustard green)
1	R1	control (NPK 0% or no NPK)	control (NPK 0% or no NPK)
2	R2	control (N and K fertiliser)	control (N and K fertiliser)
3	R3	control (NPK 50% recommendation)*	control (NPK 50% recommendation)
4	R4	rice husk 2.5 t/ha + NPK 0% or no NPK	residue rice husk 2.5 t/ha + rice husk 10 t/ha + NPK 0% or no NPK
5	R5	rice husk 2.5 t/ha + N and K fertiliser	residue rice husk 2.5 t/ha + rice husk 10 t/ha + N and K fertiliser
6	R6	rice husk 2.5 t/ha + NPK 50% recommendation	residue rice husk 2.5 t/ha + rice husk 10 t/ha + NPK 50% recommendation
7	R7	rice husk 5 t/ha + NPK 0% or no NPK	rice husk 5 t/ha + NPK 0% or no NPK
8	R8	rice husk 5 t/ha + N and K fertiliser	rice husk 5 t/ha + N and K fertiliser
9	R9	rice husk 5 t/ha + NPK 50% recommendation	rice husk 5 t/ha + NPK 50% recommendation

10	R10	rice husk biochar 2.5 t/ha + NPK 0% or no NPK	residue rice husk biochar 2.5 t/ha + rice husk biochar 10 t/ha + NPK 0% or no NPK
11	R11	rice husk biochar 2.5 t/ha + N and K fertiliser	residue rice husk biochar 2.5 t/ha + rice husk biochar 10 t/ha + N and K fertiliser
12	R12	rice husk biochar 2.5 t/ha + NPK 50% recommendation	residue rice husk biochar 2.5 t/ha + rice husk biochar 10 t/ha + NPK 50% recommendation
13	R13	rice husk biochar 5 t/ha + NPK 0% or no NPK	rice husk biochar 5 t/ha + NPK 0% or no NPK
14	R14	rice husk biochar 5 t/ha + N and K fertiliser	rice husk biochar 5 t/ha + N and K fertiliser
15	R15	rice husk biochar 5 t/ha + NPK 50% recommendation	rice husk biochar 5 t/ha + NPK 50% recommendation
16	R16	cow manure 2.5 t/ha + NPK 0% or no NPK	residue cow manure 2.5 t/ha + cow manure 10 t/ha + NPK 0% or no NPK
17	R17	cow manure 2.5 t/ha + N and K fertiliser	residue cow manure 2.5 t/ha + cow manure 10 t/ha + N and K fertiliser
18	R18	cow manure 2.5 t/ha + NPK 50% recommendation	residue cow manure 2.5 t/ha + cow manure 10 t/ha + NPK 50% recommendation
19	R19	cow manure 5 t/ha + NPK 0% or no NPK	residue cow manure 5 t/ha + cow manure 20 t/ha + NPK 0% or no NPK
20	R20	cow manure 5 t/ha + N and K fertiliser	residue cow manure 5 t/ha + cow manure 20 t/ha + N and K fertiliser
21	R21	cow manure 5 t/ha + NPK 50% recommendation	residue cow manure 5 t/ha + cow manure 20 t/ha + NPK 50% recommendation

The 50% fertiliser rate in Table 12 was determined based on the soil analysis and plant requirements (Table 13).

Table 13. Fertiliser recommendation (100% rate) for different season and crop in the crop rotation experiment.

Season/Crop	100% NPK (15-15-15) recommended dose (per ha)	N and K recommended dose (per ha)
1 Kangkung	322 kg	169 kg urea and 52 kg KCl
2 Maize	750 kg	420 kg urea and 300 kg KCl
3 Soybean	100 kg	25 kg urea and 50 kg KCl
4 Choy sum	No fertiliser applied (relied on residue from previous crop)	No fertiliser applied (relied on residue from previous crop)

The Ie Seuum site was used as a source of soil for a pot experiment (Figure 3, experiment F) to evaluate the influence of native arbuscular mycorrhizae fungi (AMF) and cellulotic fungi (CF) in drought management of maize. This was a preliminary study for PhD research at UNSYIAH. The proline content of the plant was used as an indicator of drought tolerance with higher proline content indicating more severe water stress. It was hypothesised that AMF, CF and their interaction, could improve the growth and yield of maize as indicated by lower proline content. Three dominant species of AMF (Glomus sp. 4, *Acaulospora tuberculata*, and *Gigaspora cf gigantea*) spores were evaluated for their potency at various levels of soil water content (25, 50, 75 and 100% FC) on maize growth and nutrient uptake.

This experiment used a 3 × 3 factorial randomised block design with three replications. The first factor was the inoculation of native AMF inoculant (no AMF inoculation, *Acaulospora tuberculate*, and *Gigaspora cf gigantean*). The second factor was inoculation of native CF inoculant (no CF inoculation, Isolate A 3.1and Isolate L 5.1).

Soil was inoculated with AMF and CF at sowing and watered to field capacity (FC) before drought stress treatment (50% FC) was applied at 30 days after sowing (DAS). Water was applied using the methods used in Meddich et al. (2015) and Zarik et al. (2016). Fertilisers were applied at an equivalent rate of 250 kg/ha urea, 75 kg/ha TSP and 100 kg/ha KCl. This is about 75% of the recommended doses for this soil type. At 45 days after sowing, the proline content of the leaf tissue was measured using HPLC and the AMF colonisation of maize roots was analysed.

5.4.2 Activity 2.2. Evaluate promising technologies in farmer participatory trial sites (farm demonstrations)

BPTP Aceh is responsible for conducting activity 2.2, with the objective to increase cropping frequency by introducing dry season crops to farmers that are normally only growing one rice crop per year during the wet season.

There were four demonstration sites used (Figure 4). Two sites used for food crop (rice and palawija) farm demonstrations were Lambaro Biluy village in Aceh Besar district and Blang Keutumba village in Bireuen district (Figure 4). The other two demonstration sites used for vegetable growing by the women farmers were the Beuraden village in Aceh Besar district and the Blangbladeh village in the Bireuen district.

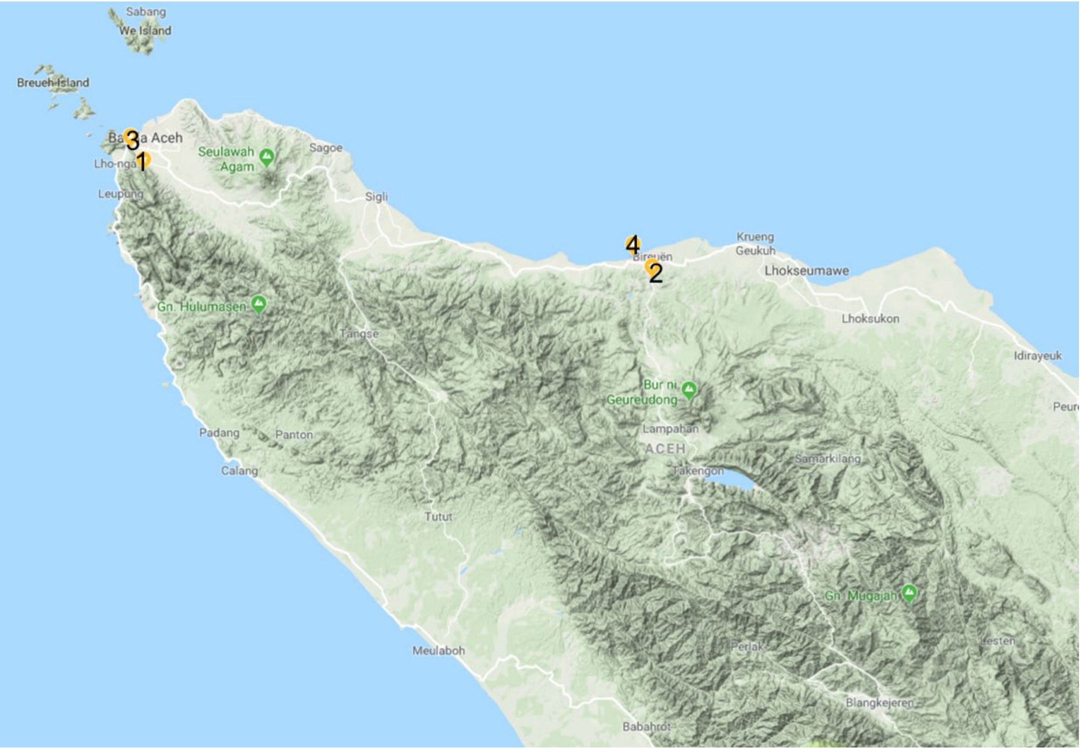


Figure 4. Location of the demonstration sites (1–4); 1 = Lambaro Billuy, 2 = Blang Keutumba, 3 = Beuraden, and 4 = Blang Badeh.

1. Lambaro Biluy Village is located in the Darul Kamal subdistrict, in Aceh Besar (05°27’58”N 95°20’21”E) with an altitude of 19 m a.s.l. It has a flat terrain with annual average rainfall between 1,250 and 1,700 mm. The village has 59 ha of rice fields and 41 ha of dryland used for housing, gardening and forestry (Appendix 3, D14–18). The soil on the site is a low fertility (Table 15), loamy clay, has pH > 7, high organic carbon, medium level nitrogen (N) and low available potassium (K) and phosphorus (P).

The village has a population of 351 people (112 families), of which 62 families are farmers. The majority of farmers in Lambaro Biluy (82%) have small farms (< 2,500 m^2). Most farmers do not own the land. Rice is the main crop and is only grown once a year during the wet season (Table 14) using traditional methods where seedlings are transplanted using a 20 × 20 cm spacing (jajar tandur), fertilised 15–20 days after planting and without integrated pest management. Farmers use the recommended blanket fertiliser rate of 200 kg/ha NPK fertiliser (15:15:15) + 200 kg/ha urea. Rice crops are hand-harvested and often left piled in the field for a long period, which can compromise the grain quality. The long-term average rice yield in the village is between 3 to 4 t/ha and it is mainly used for family consumption.

Most farms are traditionally left fallow during the dry season because there is not enough rainfall to support crop production. There is water available from the mountain that could be used to irrigate dry season crops, but the local farmers do not have the skills nor the capital to manage this water and have not previously experimented with growing dry season crops. These are the main production constraints for dry season cropping in the area. The farmers (husbands) normally seek off-farm employment during the dry season in the nearby quarry or as a labourer in Banda Aceh city, earning an average of Rp.700,000 IDR or A$70 per month, totalling about A$500 income outside the rice-growing season.

Traditionally, most rice stubble is burnt or left in the field for the livestock to graze or to decompose until the next rice season. The local farmers do not normally assess the value or quality of their land and typically rely on field extension officers (PPL) or leading farmers for fertiliser management and application advice for their rice crop. A few farmers make and use compost using traditional methods (without fermentation) from rice stubble, manure and semi-decomposed leftover livestock feed. The manure is sourced from 3–5 animals (usually cows) that are cared for and shared with wealthier livestock owners in the village or smaller animals (goats or poultry) they may have.

Table 14. Existing cropping pattern in Lambaro Biluy village.

<table>
<tr><th colspan="12">Lambaro Biluy Village – Existing cropping pattern</th></tr>
<tr><td>Apr</td><td>May</td><td>Jun</td><td>Jul</td><td>Aug</td><td>Sep</td><td>Oct</td><td>Nov</td><td>Dec</td><td>Jan</td><td>Feb</td><td>Mar</td></tr>
<tr><td colspan="7">Bare</td><td colspan="5">Wet season rice (Padi sawah)</td></tr>
</table>

Table 15. Constraints and opportunities identified for the Lambaro Biluy demonstration site.

Constraints	Opportunities
Insufficient rainfall during the dry season	To manage and use the available mountain water for dry season crops
Low level of technology/practices	Introduce appropriate dryland soil and crop management (sowing rates, timing, fertiliser) adapted from the existing crop management package for Aceh
Low soil fertility	Improved soil and fertiliser management
Lack of experience with dry season crops	Possible new rotation: wet season rice followed by dry season crops (rice or palawija crops)

Table 16. Cropping sequence used in the demonstration site at Lambaro Biluy, Aceh Besar.

<table>
<tr><th>Year</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sept</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td>2016</td><td colspan="3">No crop</td><td colspan="6">Dryland rice
(Situ Bagendit and Batutegi)
1.5 ton/ha cow manure, recommended NPK (15:15:15) of 250 kg/ha, ZA (22% N) 200 kg/ha, SP-36 (36%P205) 50 kg/ha. A new planting configuration of skip-row 2 : 1 (10 : 20 : 40 cm) were used)</td><td colspan="3">Wet season Rice
(Situ bagendit and Inpari 32)</td></tr>
<tr><td rowspan="5">2017</td><td colspan="3" rowspan="5">Wet season Rice (continued). ZA 125 kg/ha, Urea 125 kg/ha, NPK 300 kg/ha, compost 1500 kg/ha (Application anorganic fertiliser 50, 75 and 100 % dosage of liquid organic fertiliser)</td><td colspan="2">Dryland Rice (Batutegi)</td><td colspan="2">Peanut (Kelinci)</td><td>red chili (Lado)</td><td>red onion (BimaBrebes)</td><td rowspan="5">No Crop</td><td colspan="2" rowspan="5">Wet season rice (Inpari 30)</td></tr>
<tr><td colspan="2">Urea (100)</td><td colspan="2">Urea (-)</td><td>Urea (50)</td><td>Urea (25)</td></tr>
<tr><td colspan="2">SP36 (-)</td><td colspan="2">SP36 (100)</td><td>SP36 (150)</td><td>SP36 (150)</td></tr>
<tr><td colspan="2">ZA (100)</td><td colspan="2">ZA (-)</td><td>ZA (50)</td><td>ZA (25)</td></tr>
<tr><td colspan="6">All with compost 2.0 t/ha, NPK 250 kg/ha, and</td></tr>
<tr><td rowspan="3">2018</td><td colspan="3" rowspan="3">Wet season Rice (continued).
NPK 350 kg/ha
ZA 250 kg/ha
Petroganic 500 kg/ha</td><td colspan="6">One crop from previous dry season crops (peanut)</td><td colspan="3">Wet season Rice</td></tr>
<tr><td colspan="2">Treat. A</td><td>Treat.B</td><td>Treat.C</td><td colspan="2">Farmer practice</td><td colspan="3">Variety : Inpago 8
Soil Treatment and Seed</td></tr>
<tr><td colspan="2">Compost 1.500 kg/ ha +NPK 200 kg/ ha +KCl 75</td><td>Compost 1.500 kg/ ha +NPK 200 kg/ ha+ZA</td><td>Compost 1000 kg/ ha +ZA 125 kg/ ha+SP36 100+KCl</td><td colspan="2">NPK 200</td><td colspan="3">Petroganic 500 kg/ha NPK 350 kg/ha Urea 250 kg/ha</td></tr>
</table>

Of the 62 farmers in the village, 11 were participating in the Lambaro Biluy demonstration site. They all shared two hectares of contiguous land owned by three participating farmers (Muksin, Arifin and Tgk Sanusi). The remaining participants are renting from these landowners and they are called 'penggarap'. All of the participating farmers care for 3–5 cows but only the three farmers who owned the land (Muksin, Arifin and Tgk Sanusi) own their cows, the rest are in a shared arrangement with cow owners in the village or from the surrounding villages. The shared arrangement is under the traditional law called 'mawah', a verbal agreement that has been practiced for centuries. Under this specific mawah agreement, the owner and the carer of the animals will share 50% of the calf produced during the agreement. Therefore, eventually the carer could become a cow owner.

The lack of history and experience for dry season crops in the village presented a challenge to the farmers and PPL when planning for crop rotations that included a dry season crop. In the wet season, the choice was clear, rice! In the dry season of 2016 (April) dryland rice or 'padi gogo' was introduced as the first dry season crop in the village. The crop choice for the subsequent year was based on the crop that returned the highest profit or yield in the previous season (Table 16). It was a learning process for both farmers and advisers.

From the first cropping season, farmers were trained to make and use compost from rice stubble and cow manure using the improved method with a fermenting agent. The compost making is costing approximately Rp.600/kg (approximately A$60/tonne).

Demonstration activities in Lambaro Biluy were supported by the local PPL Devi and Ramlan from BPTP Aceh.

2. The Blang Keutumba village is located in the Juli subdistrict, Bireuen District (5˚09'00.4"N, 96°43'40.1"E, (Figure 4) at an elevation of 150 m a.s.l. Blang Keutumba has a population of 2,470 people (565 families) of which 148 families are farmers. There are 135 hectares of arable land in the village; eighty hectares are dryland farms, 30 hectares are rainfed sawah and 25 hectares are backyard gardens (Appendix 3, D14–18). Farmers in Blang Keutumba are 100% reliant on rainfall; there is no other source of water. Farming activity is focused on wet season dryland rice (padi gogo) grown in unbounded fields, but many farmers also grow pasture grass (elephant grass) to sell to a nearby livestock company. However, there is no record provided of any income farmers obtained from growing this pasture. Few local farmers that grow occasional dryland crops use traditional practices that include irregular plant spacing with broadcast fertiliser application limited by affordability. Most farmers follow annual cropping patterns similar to those in Lambaro Billuy village (Table 4). The current yield of dryland rice (padi gogo) grown during the wet season is about 2.5 t/ha due to lack of rainfall, low soil fertility and poor farming practices.

The area selected for the demonstration site was two hectares of contiguous land shared by five participant farmers. Three of the farmers owned a total of 12,500 m^2 land and the other two participants are renting the rest. The soil at the demonstration site is classified as clay, with pH 7.5, low total carbon and nitrogen, available oxygen and medium cation exchange capacity.

The first season in 2016 was used to introduce soybean, maize and mungbean to the farmers, so there was no comparison of technologies evaluated. These crops were grown using the standard management practices for each crop obtained from the province. In the subsequent seasons, compost, new fertilisers, fertiliser application methods and crop management practices were introduced. The new technologies were compared to traditional farming practices (irregular planting space, broadcast and non-split fertiliser application and no compost) and new crop varieties were introduced. Unlike farmers in the Lambaro Biluy site, the group decided to purchase the compost for about Rp.1,000/kg (A$100/tonne).

Similar to Lambaro Biluy, crop profitability in the previous season determined the crop choice the following season (Table 17), again reflecting that it was a learning process for both farmers and advisers.

The site in Blang Keutumba was supported by the local PPL Feri Fadli and Irhas from BPTP Aceh.

Table 17. The new crop sequence used in Blang Keutumba, Bireuen District demonstration site.

<table>
<tr><th>Year</th><th>Time</th><th colspan="12">Commodity</th></tr>
<tr><td rowspan="3">2016</td><td>Jul-Oct 2016</td><td colspan="4">Mungbean</td><td colspan="2">Soybean</td><td colspan="6">Corn</td></tr>
<tr><td rowspan="2">Nov 2016-Mar 2017</td><td colspan="4" rowspan="2">Dryland rice (DR), Farmer Practice</td><td colspan="2" rowspan="2">Dryland rice, Farmer Practic</td><td colspan="3">Dryland rice OM 2 t/h</td><td colspan="3">Dryland rice OM 5 t/h</td></tr>
<tr><td>Inpago 8</td><td>Batutegi</td><td>Inpari 41</td><td>Inpago 8</td><td>Batutegi</td><td>Inpari 41</td></tr>
<tr><td rowspan="4">2017</td><td rowspan="2">Apr 2017-Aug 2017</td><td colspan="4">Mungbean</td><td colspan="2" rowspan="2">MB, FP</td><td colspan="3">2 t/h compost</td><td colspan="3">5 t/h compost</td></tr>
<tr><td>Nil</td><td>2 t/h compost + 300 kg NPK</td><td>300 kg/h NPK</td><td>FP</td><td>Bima 15</td><td>Sukmaraga</td><td>Bisi-18</td><td>Bima 15</td><td>Sukmaraga</td><td>Bisi-18</td></tr>
<tr><td rowspan="2">Nov 2017-Mar 2018</td><td colspan="4">Dryland Rice (Inpago 9)</td><td colspan="2" rowspan="2">Dryland Rice Inpago 8, FP</td><td colspan="3" rowspan="2">Dryland Rice Inpago 10, FP</td><td colspan="3" rowspan="2">Dryland Rice Inpago 10, FP</td></tr>
<tr><td>Nil</td><td>2 t/h + 300 kg NPK</td><td>300 kg/h NPK</td><td>FP</td></tr>
<tr><td rowspan="4">2018</td><td rowspan="2">Apr 2018-Aug 2018</td><td colspan="4">Mung Bean</td><td rowspan="2">MB, FP</td><td rowspan="2">Corn, Var. Bisi 18, FP</td><td colspan="3" rowspan="2">Corn, Bisi 18, 2 t/h compost</td><td colspan="3" rowspan="2">Corn, Bisi 18 5 t/h compost</td></tr>
<tr><td>Nil</td><td>2 t/h + 300 kg NPK</td><td>300 kg/h NPK</td><td>FP</td></tr>
<tr><td rowspan="2">Oct 2018-Mar 2019</td><td colspan="4">DR</td><td colspan="2" rowspan="2">Dryland Rice Inpago 8, FP</td><td colspan="3" rowspan="2">Dryland Rice Inpago 8, FP</td><td colspan="3" rowspan="2">Dryland Rice Inpago 8, FP</td></tr>
<tr><td>Nil</td><td>2 t/h + 300 kg NPK</td><td>300 kg/h NPK</td><td>FP</td></tr>
</table>

3 and 4. Demonstration sites 3 and 4 were the locations for the women farmer groups (Kelompok Wanita Tani or KWT) demonstration sites. They were KWT Jeumpa Puteh in the Beuraden village (site 3, Figure 4) Aceh Besar and KWT Kasih Ibu, in the Blangbladeh village (site 4, Figure 4), Bireuen. Both sites were used as meeting places for all other KWT group members for project communication and extension activities such as KWT forums, farmers-to-farmer visits, and the regular ACIAR project team visits. Both demonstration sites had a focus on producing and applying liquid organic fertiliser and compost and were in central locations for the respective districts of Banda Aceh and Bireuen. As a result of their involvement in the ACIAR project, KWT Jeumpa Puteh was a recipient of the local government funding to conduct extra activities in developing a red onion industry from growing to postharvest and was often invited by the local government guests to showcase their activities.

Both Jeumpa Puteh and Kasih Ibu sites were selected because:

- there was an active local field extension officer supporting the group activities
- the KWT had a high level of member engagement
- there was strong interest by members to innovate and learn new farming methods/techniques
- the site was strategically located (ease of access and dissemination)
- the local village leaders supported the group.

There are 725 women farmers (32 KWTs) supported by this project to grow vegetables in vacant village land or backyards. The project provided initial inputs, agronomic advice and introduced new technologies to the group via their PPL. Their main purpose to grow vegetables was to meet family need for fresh vegetables, but all groups also gained extra income by selling excess produce. Each KWT consists of 15–30 women farmers aged between 20–65 years. Each KWT has a leader, who was also the group treasurer. The members control the running of the KWT, giving them the opportunity to develop skills in leadership, management and networking. Each KWT was supported by a local field extension officer known as Penyuluh Pertanian Lapangan (PPL), who provide advice on soil management, agronomic issues and guide the marketing strategy for the excess produce.

5.4.3 Activity 2.3. Conduct experiments in NSW to evaluate management practices that improve soil nutrient and water availability in dryland farming systems (NSW, conducted by NSW DPI)

The objectives of the research in NSW were to (1) evaluate long-term benefits of poultry litter application to a degraded Red Vertosol, and (2) compare the water productivity and soil carbon dynamics in an undisturbed natural grassland, planted agroforestry and dryland crops in a Black Vertosol. The Red Vertosol site is located at Tamworth Agricultural Institute (TAI) Paddock 26 (430 m a.s.l., 31.09°S 150.85°E) and the Black Vertosol site is located at the Breeza Field Station, BFS (Paddock 1, 12 and 13), in the Liverpool Plains (280 m a.s.l., 31°10' 37.96” S, 150°25' 17.28” E) (Figure 5). Both sites (Figure 5) are representative of dryland systems in the region.

Figure 5. Location of the Breeza field station (BFS) and the Tamworth Agricultural Research Institute (TAI) in NSW, Australia.

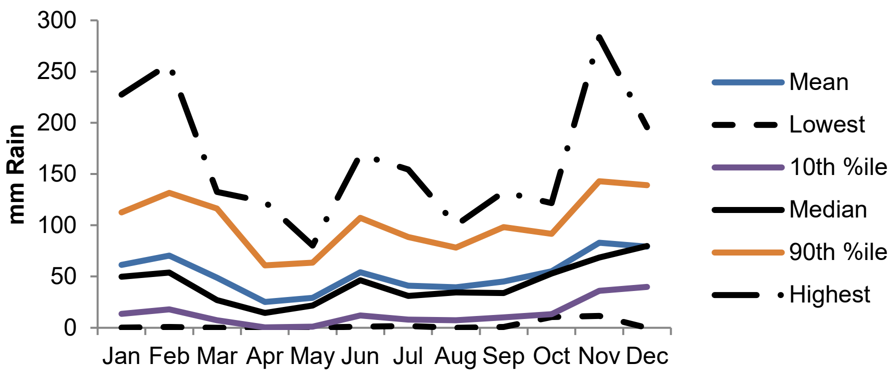


Figure 6. Monthly rainfall distribution at Tamworth (BOM online 2018) which is similar to Breeza.

The region has a temperate climate with temperatures ranging from -6°C in winter to >35°C in summer. The annual rainfall is 650 mm, which mainly falls during summer (Figure 6). The annual evaporation demand of around 1,500 mm far exceeds the annual rainfall but the episodic summer storms often cause runoff and soil erosion. Summer fallows to conserve moisture are common practice after winter crops. The mismatch between rainfall distribution and crop water demand presents the risk of deep drainage leading to the rise of groundwater and dryland salinity. The low soil carbon levels (Young et al. 2008) further inhibit water availability and is one of the major production constraints in the region.

Paddock 26 at the TAI has a slope of approximately 3% and was a productive cropping soil until the early 1980s when yield decline was associated with severe topsoil erosion. This paddock was sown to pasture species in the early 1990s and has remained under volunteer pasture since. The soil is a degraded Red Vertosol with approximately 40% clay content, has low fertility, total N content of 0.14%, total C content of 1.5%, available P (Colwell) of 22 mg/kg, and soil pH_{CaCl2} of around 5.7. The soil was compacted with a bulk density of 1.55 Mg/m^3.

In 2010, two biochar experiments were established on the site to (1) evaluate nitrogen fertiliser use efficiency of a digit pasture (*Digitaria eriantha* cv. Premier) grown in soil amended with poultry litter biochar (PLB), and (2) to evaluate the effect of PLB on soil fertility when applied in combination with manure and maize stubble. This project continues the measurement of these experiments to assess the longevity of the effects of PLB on pasture productivity, fertiliser use efficiency and nutrient availability on this soil.

The BFS site is flat and has a deep cracking clay alluvial soil (solum > 6 m depth). The soil is fertile and extensively used for summer and winter cropping research by NSW DPI.

*A long-term evaluation of nitrogen fertiliser use efficiency and yield of a tropical pasture (***Digitaria eriantha** *cv. Premier) in soil amended with poultry litter biochar*

The first experiment at TAI included three nitrogen (N) fertiliser rates (0, 50 and 100 kg N/ha), with and without biochar. The biochar was produced from wood-based poultry litter at 550 °C by Pacific Pyrolysis and contained 1.7% total nitrogen, 40% total carbon, and 2,900 mg Colwell P/kg. In December 2009, the biochar was incorporated into the top 10 cm of soil prior to sowing a tropical digit grass (*Digitaria eriantha* cv. Premier) in January 2010. At the end of the establishment period in May 2010, the total soil N was similar for all plots (~ 0.11–0.12%) and the available soil P in the biochar plots was ~ 50 mg/kg compared to ~ 32 mg/kg in the non-biochar plots.

All plots were fertilised annually in September with 200 kg of single superphosphate (18 kg P/ha) and in October with half of the N (25 and 50 kg N/ha) as urea. The remaining half of the urea was applied between December and January with rainfall. Pasture herbage mass (HM, kg DM/ha) was assessed monthly during the growing season (September to May), along with N and P content of the plant dry matter. These assessments were used to calculate seasonal nutrient uptake and the agronomic efficiency of applied N (AEN).

Evaluation of available nitrogen

An evaluation of nitrogen availability from applied fertiliser in soil amended with poultry litter biochar was conducted in the laboratory using small pots, to help explain the nitrogen uptake by pasture in the field experiment described above.

An equivalent of 0, 5 and 10 t/ha of poultry litter biochar was applied with 0, 100 and 400 kg/ha nitrogen to 715 grams of soil (oven dry basis) in each small pot. Each treatment had four replicates, resulting in a total of 36 pots. The soil used was obtained from 0–10 cm from the field pasture study, crushed to pass a 2 mm sieve and packed into a pot (8 cm diameter, 12 cm height) at the field bulk density of 1.42 Mg/m^3. Prior to adding the fertiliser, each pot was saturated by adding 250 mL deionised (DI) water. A filter paper was placed on top of the soil surface to protect it from the force of water during the application. The pot was covered with a plastic cap to prevent evaporation while the soil was allowed to drain into a plastic container. The leachate was reused twice to re-irrigate the same pot to ensure soil in the pot was uniformly saturated. The pots were then allowed to drain under gravity to field capacity (until no more water flowed out from the base). Each item used was weighed and the pot with soil was again reweighed after the field capacity was reached. The urea granulates were weighed and dissolved in 100 mL of DI water for the initial application and the leachate was collected after two days. In the subsequent leaching, 50–75 mL of DI water was applied to produce around 50 mL leachate. The leachate was collected at 2, 5, 9, 19, 23, 29, 37, 44, 51, 58, 65, 72 and 126 days after fertiliser application and analysed for EC, pH, NO_2, and NOx in the soil laboratory at TAI. NO_3 was calculated as (NOx - NO_2). At the end of the experiment, soil from each pot was analysed for Colwell P, nitrate N, EC, pH, total C and N, cations, CEC and total P.

The long-term effect of poultry litter biochar on soil fertility when biochar is applied individually or in a mixture with either cow manure or maize stubble

In 2010, 240 inert mesh bags (< 1 mm mesh size) containing six mixtures of degraded Red Vertosol with various amendments were buried at 10 cm depth in Paddock 26 at TAI, on a strip of land above the tropical pasture experiment. This was conducted to evaluate the long-term changes in soil carbon and nitrogen and soil fertility of these mixtures over time. The six mixtures, (Table 18) each with five replicates, were made of 200 g soil only as the control (C), soil + 10 g cow manure (M), and soil + 10 g maize stubble (S), each with and without 10 g of poultry litter biochar (PLB). All amendment materials had a high carbon content of > 37% (Table 19). The nitrogen content of the manure and the biochar were higher than the stubble. Six months after the burial, 60 bags were recovered and analysed for total carbon, nitrogen, other chemical properties and soil respiration. After another six months, and annually thereafter, 30 bags were recovered for the same analyses. All bags were recovered from the burial site after 72 months.

Table 18. Mixtures of soil amendment used in the study.

Label	Treatment	Description
C	Control	Soil only
C+	Control + poultry litter biochar	Soil + 10 g PLB*
M	Cow manure	Soil + 10 g cow manure
M+	Cow manure + poultry litter biochar	Soil + 10 g cow manure + 10 g PLB
S	Stubble	Soil + 10 g maize stubble
S+	Stubble + poultry litter biochar	Soil + 10 g maize stubble + 10 g PLB

* PLB = Poultry litter biochar, produced by Pacific Pyrolysis at 550°C.

Table 19. Carbon and nitrogen contents of soil and amendments.

	Total carbon (%)	Total nitrogen (%)	C:N
Soil	1.5	0.1	15
Cow manure	37.5	1.6	23
Maize stubble	42.5	0.4	106
Poultry litter biochar	37.0	1.7	22

Soil water, water productivity and soil carbon dynamics under undisturbed grassland, cropping and agroforestry on a Black Vertosol soil in the Liverpool Plains of NSW

At the BFS, soil water monitoring was started in 2012 to evaluate the interaction between agricultural water and the local shallow groundwater in collaboration with the National Centre for Groundwater Research and Training. Twenty-one neutron probe access tubes were installed to a depth of 6 m in three paddocks of about 5 ha each. Six tubes were installed on undisturbed grassland (Paddock 13), six tubes on cropping paddock (Paddock 12) and nine tubes on planted trees (Paddock 1), three tubes on each *Eucalyptus agrophloia, Casuarina cunninghamiana and Eucalyptus mollucanna*.

Both the cropping and agroforestry paddocks were first cropped in the 1940s. The undisturbed grassland has never been cropped and it is protected under the Native Vegetation Conservation Act NSW. The trees were planted by a Greening Australia tree planting program into the cropping Paddock 1 in 2002, with 4 × 3 m spacing (833 trees/ha). There were more than seven tree species planted but we only selected three species with the highest surviving rates (above). Therefore, at the start of the study in 2012, the cropping paddock had been cropped for 72 years. The trees were about 10 years old and were planted in a paddock that has been cropped for 60 years.

The growing of dryland crops and fallow management in paddock 12 was done by the station manager using standard cropping practices. The cropping paddock was fallow in 2013, sown to wheat in 2014, faba bean in 2015 and wheat in 2016. It was again fallow from 2017 to 2018 due to drought. Crop yield (t/ha grain) was either provided by the station manager or estimated from a 1 m sampling square. The total biomass was calculated based on a known harvest index or estimated from the sampling square.

The grass biomass was initially sampled at six-monthly intervals but this was increased to monthly for better prediction of growth. Tree growth was initially measured at six-monthly intervals using the trigonometric approach but was changed to annually or bi-annually depending on visual observation of growth.

Soil water in the 0–580 cm soil depth zone was measured monthly at 20 cm depth intervals using the neutron moisture meter from the 21 tubes. This was used to calculate annual (calendar year) soil water balance and water productivity. The majority of water measurements coincided with the biomass measurements. However, if this was not possible, the closest water measurement was used in the calculation of crop water use.

Deep soil corings (to 580 cm) were conducted in 2012 and 2017 and samples collected were analysed for total soil C and N contents, soil pH and EC, available P and P buffering index (PBI), chloride concentration and nitrate. The differences in chloride profiles between land use over time were used as an indicator of historic deep drainage for the BFS.

In addition to measuring soil water with the neutron moisture meter (NMM), we also tested electromagnetic induction technology (EM38) to predict soil water. The current measurement method for soil water with the neutron moisture meter is the most robust method. However, it is cumbersome, time-consuming, presents radiation hazards, and is expensive. Therefore, there is a need to shift from the current NMM method to a faster, cheaper and safer method. Previous ACIAR projects in Aceh supplied three EM38 units. The method developed in NSW to use EM38 to measure soil water is transferrable to Aceh and the project team in Aceh have been trained for this purpose for their future dryland research.

The ACIAR funds which supported this research allowed changes in soil water, carbon, nitrogen and chloride profile from 2015 to 2017 to be monitored and added to the existing data (already collected since 2012), allowing a longer-term assessment of how land use affects soil water dynamics and water productivity in this system. The calibration of the EM38 to measure soil water established for this site is a valuable dataset that can support future water research in the farming system using the same equipment at the BFS.

5.5 Objective 3. To develop strategies for dissemination of promising technologies to extension services and smallholders

5.5.1 Activity 3.1. Conduct training programs for at least 40 district extension staff (PPL) for efficient dissemination of promising management practices to smallholders

This training activity was conducted by BPTP Aceh staff in two stages. The first stage was conducted in two zones: (1) West coast zone for Aceh Barat and Aceh Besar, conducted in Banda Aceh on 26 December 2016; (2) East coast zone for PPL from Bireuen and Pidie districts conducted in Bireuen on 27 December 2016.

The training topics for stage 1 included basic soil knowledge and the use of soil test kits for dryland cropping, soil amendment using biochar, organic fertiliser and the use of rhizobium, integrated pest management, soil management, and proposal and report writing.

Forty-four PPL were trained in stage 1, comprised of 27 PPL who support the women farmer groups, 2 PPL who support the two demonstrations sites, and an additional 15 other PPL from the study districts as part of the capacity building.

Following the training, PPL was expected to apply their new knowledge by conducting 30 small demonstration activities in growing vegetables with KWT (Activity 3.3) and 12 demonstration activities in growing dry season crops by 12 other PPL outside KWT (Activity 3.2). This will include the ability to select a relevant topic to the group/project, the ability to write a proposal for the activity, conduct the activity and write a report of their respective activity. The 30 PPL supporting KWT were given a topic around soil and fertiliser management for growing vegetables in their group. The other PPL were required to submit a proposal relevant to dryland or dry season crops. The guidelines for the proposal and demonstration activity were provided to each PPL. The trained PPL were required to submit their interest and report to BPTP Aceh. However, most PPL found that this was an extremely difficult task and no proposal was submitted by the due date. Some of the PPL who conducted a small demonstration with their groups were not able to record data or write the report.

The main reasons for this were lack of time and lack of habit for record-keeping and writing of report.

To help with the writing and reporting issue, the training for stage 2 was focused on a proposal and report writing. The stage 2 training was conducted in Aceh Besar (24 April 2018); Aceh Barat (3 May 2028) and Bireuen (07 May 2018) attended by the same participants as those in stage 1 training.

Training materials for stage 2 included writing proposals, designing and reporting of demonstration activities. Training reports and materials submitted by BPTP Aceh are presented in Appendix 5, D26-30.

5.5.2 Activity 3.2. Support the adoption of promising crop rotation practices and identify opportunities for improvement

This was planned to be conducted via 12 small-scale demonstration activities by PPL trained under Activity 3.1. After the completion of the stage 1 training, the PPL were required to submit a proposal to BPTP Aceh for a small crop demonstration (not vegetables) to apply the knowledge they gained during the stage 1 training. The crop choice for the demonstration was limited to a food crop (e.g. rice, maize, soybean, mungbean or peanut). This was part of the capacity building activity for the PPL and was funded by the project for A$1,000 for each PPL demonstration. This is the only and first project that required the PPL to plan, design, conduct and report a demonstration activity. However, most PPL were not able to meet the requirement to prepare and plan for a demonstration until late into the project timeline. Eight proposals submitted were either impractical or outside the scope of the project. The PPL also found difficulty in writing a report and eventually only two out of 12 PPL demonstrations were completed and reported on (Report in D32, Appendix6).

The inability of BPTP Aceh and PPL involved meeting this specific milestone was reported and discussed during the mid-term review in 2017. The mid-term reviewers suggested to drop the requirement for 12 small demonstration activities as it is a small part of the project but presented a great challenge for BPTP Aceh. The project leader suggested replacing the 12 demonstration activities planned with 3–4 simpler demonstrations such as using the new integrated crop management initiative for dryland that was promoted by the Indonesian government. The ACIAR Program Manager supported this idea and this was documented in the mid-term review report and travel report (February 2017), agreed to by all project partners. However, BPTP Aceh insisted to keep to the original plan for 12 small demonstration activities (i.e. saving face) but failed to deliver.

5.5.3 Activity 3.3. Establish sites for the demonstration of promising technologies to farmers

The aim of activity 3.3 is to support women farmer groups (KWT) by establishing two demonstration sites in Beuraden, Aceh Besar and Blang Badeh, Bireuen (Figure 5), where women farmers are working in groups to grow and market vegetables using organic fertiliser or biochar they produced.

The formation of 30 KWTs was preceded and guided by the results of an impact analysis of women farmer groups in the lowland areas from project SMCN/2007/040 (Deliverable report 34, Appendix 6). However, during the period between the planning and the start of this project, the government of Indonesia rolled out a national backyard vegetable growing program (KRPL) with a much greater budget allocation per KRPL group. The relatively small amount of funds allocated for KWT in this ACIAR project did not compete with the funding from the KRPL program, resulting in difficulties for BPTP Aceh to form new KWT groups. The alternative strategy was used, which was to support existing but inactive KWTs that missed out on KRPL funds.

There were 27 field extension officers (PPL) supporting all KWT groups because some PPL supported more than one KWT. Each of the group's PPL was allocated A$1,000/group over three years to conduct small demonstration activities to apply the knowledge they gained during their training (described in Activity 3.1). This is part of the capacity building activity for the PPL and at the same time, they can transfer the new knowledge to the KWT members. There were 30 vegetable growing demonstrations expected from PPL that were working with KWT. This is different from the 12 PPL demonstrations previously outlined.

5.5.4 Activity 3.4. Analyse, report and communicate key project results to research and extension staff, farmers and local government in the target districts

The communication activities were conducted in the form of:

1. Annual workshop on data analysis and interpretation before and after the experimentation season as an internal project activity conducted by UNSYIAH academic staff and students
2. Annual presentation at local and international scientific forums including at the UNSYIAH annual forum and the Australian soil conference. The project also organised one national workshop on dryland agriculture systems held in Aceh, involving contributions from invited speakers from universities outside Aceh (Proceeding is presented in Appendix 8, D40)
3. Two extension forums to facilitate information exchange and networking, coordinated by BPTP Aceh, for women farmers across the four districts and at a provincial level. At these forums, relevant external speakers from the local government areas were invited to contribute or to inform women farmers and their PPL supporters about local and national opportunities
4. Three farmer-to-farmer visits to enhance peer-to-peer learning involving women farmers and food crop farmer demonstration sites coordinated by BPTP Aceh
5. Case study booklet produced from KWT demonstration activities, compiled by BPTP Aceh towards the end of the project.

Other training activities for advisory (PPL), students and project staff

The project provided in-class training on data analysis and interpretation for the project staff and students involved in research and demonstration activities, as well as field training in the EM38 and its use for measuring soil water.

In addition to the planned training for farmers by their PPL, they also provided training in postharvest processing to maximise their opportunity to earn extra income. This training was conducted by experts from the Legume and Tuber Research Institute from Malang (East Java) (see report in Appendix 5, folder Post harvest training report.zip).

5.6 Partnerships

The project was built on established collaboration with local and national partners, and networks with agricultural agencies, which included:

1. NSW Department of Primary Industries, Australia was responsible for the overall management and support for the project activities, for the research component in NSW Australia and project reporting to ACIAR
2. Assessment Institute for Agricultural Technology Aceh (BPTP Aceh) was responsible for conducting the demonstration, capacity building and communication activities, and reporting of demonstration and capacity building activities to NSW DPI for compilation for ACIAR
3. Balai Besar Sumber Daya Lahan Pertanian (BBSDLP) – Bogor, supporting BPTP Aceh and UNSYIAH on technical and capacity building aspects on soil and climate required for demonstration and research
4. Pusat Penelitian dan Pengembangan Tanaman Pangan (Puslitbangtan) – Bogor, supporting BPTP Aceh and UNSYIAH on technical and capacity building aspects on cropping required for the demonstration and research
5. University Syiah Kuala (UNSYIAH) – Banda Aceh was responsible for conducting a body of research involving the university students, capacity building and communication activities, and reporting of research and capacity building activities to NSW DPI for compilation for ACIAR.

To ensure the relevance of the project to meet farmers' needs, over 40 local field extension officers were involved in gathering information and providing support in the field demonstration and training activities for the farmer demonstrations and the women farmer groups.

The project also directly involved:

1. Sixteen food crop farmers at two demonstration sites (Aceh Besar and Bireuen)
2. Forty-eight university students enrolled at the University of Syiah Kuala
3. Seven hundred and twenty-five women farmers from across Aceh Besar, Aceh Barat, Bireuan and Pidie districts.

Indirectly, the project maintained links and communicated with local government, village, subdistrict, district, and provincial levels in Aceh. Local government representatives were invited, where relevant, to the project's forums and seminars.

6 Achievements against activities and outputs/milestones

The progress towards achieving the three project objectives was measured by 39 milestones produced from nine activities. Each milestone was delivered in one or more deliverable reports resulting in 43 deliverable reports (D1–D42). Deliverable report D32 was removed during the mid-term review because it was no longer relevant to the project.

Objective 1: To examine current practices in dryland cropping systems in the selected districts and identify agronomic constraints for increasing productivity considering the local agro-ecological and socio-economic conditions

Activity	Outputs/ milestones	Completed (Y/N)	Application	Other realised or potential applications/impacts
1.1 Identify representative sites and crops important for dryland cropping systems through a synthesis of existing information and field surveys.	Results from previous surveys collated and synthesised and possible crops and sites identified (PC: BPTP Aceh)	Y D1-D2	Used as a broad guide for field demonstration locations and activities	Contribution to database for dryland system in Aceh
	Document outlining project roles and responsibilities for each partner organisation confirmed at project inception meeting (PC, A)	Y D3	Each project partner and team member within the partner's organisation understand their roles and responsibilities	Clear tasks and roles for each partner of the project help project implementation
	Field survey report completed (PC:BPTP Aceh) *	N* D4	To guide research and demonstration topics	Demonstration activities were not well guided
1.2 Determine important soil physical and chemical characteristics and availability of water at selected sites and identify the key soil and water constraints to increasing production (PC, UNSYIAH).	More than 400 soil samples from representative sites from four target districts collected, processed and analysed	Y D5	Used to derive information to determine production constraints and management options	First set of soil information on Aceh's dryland systems produced that will provide confidence in informing the scientific community and guide management options Broaden UNSYIAH research capabilities
	Document characterising soils at project sites completed	Y D6	Capacity building	
	Document identifying soil constraints at each project sites completed	Y D7	Guided research program (topics – UNSYIAH)	

PC = partner country, A = Australia

*INCOMPLETE

- All possible options have been used since 2015 to obtain the report from BPTP Aceh, started with a direct request by Gavin Tinning/ Malem McLeod to Ir. Ferizal. Gavin Tinning started a draft for Ir. Ferizal to complete, and Ir. Ferizal made multiple written promises and timelines to complete it (email records available), but he had not met any of his own deadlines. The persistence of the issue has been discussed with ACIAR Country Manager and ACIAR Program Manager who helped multiple times (email records available), but also failed to get BPTP Aceh to commit to writing this report. The Indonesian country manager notified the IAARD office in Indonesia and the Secretary (Dr. Prama Yufdy) intervened by sending Dr. Edi Husen to BPTP Aceh to assist, who also failed. Again both the mid-term reviewer (2017) and the final reviewer (December 2018) recommended that BPTP Aceh complete the survey report. Both were ignored. After the final review. Ir. Ferizal (BPTP Aceh) promised two due dates to complete the reports (January 7th and February 21st 2019), but neither was met. The reviewer (Prof. Hasil Sembiring) notified the national head of BPTP (Dr. Harris) who contacted BPTP Aceh, but still no report was submitted. Finally, in March 2019, ACIAR Indonesian Country Manager reported the issue to the new DG of IAARD who indicated that they would not like any incomplete report against their name (email/WhatsApp record available). To date, this specific report has not been completed by BPTP Aceh.

Objective 2: To develop integrated soil, water and crop management practices for increasing the cost-effective production of key dryland crops in rotations.

Activity	Outputs/ milestones	Completed (Y/N)	Application	Other realised or potential applications/impacts
2.1. Conduct field experiments to identify potential management practices at contrasting sites relevant to dryland cropping systems (PC: UNSYIAH)	Research topics covering crop rotations, nutrient management, soil and water management are finalised for experiments	Y D8	The experiments are conducted in the selected three sites	Increased capacity in UNSYIAH to develop integrated research with multiple components and partners. UNSYIAH will use this project as a model for the future research program
	Two sites established	Y D9	Research activities conducted	
	Postgraduate student program commences	Y D10-11	14 (1 PhD, 13 Masters)	New agriculture scientists for Aceh are produced
	Undergraduate students identified (5/yr)	Y	23 undergraduate students over 4 years	From 2005 to 2019, 51 UNSYIAH students were supported by this project
	Trial results compiled, analysed and documented annually**	Y – In progress D12-13	Promote research improvement	Increase students' capacity to write scientific reports
2.2. Evaluate promising technologies selected from 2.1 in farmer participatory trials at selected sites (PC: BPTP Aceh)	Two participatory sites identified and selected	Y D14	Lambaro Biluy and Blang Keutumba	Participatory demonstration activities conducted
	The two sites established, agreement established with farmer groups, and crop planning protocols determined for the project period	Y D15	The participatory demonstration trials conducted	Cultural and practice changes into crops/year
	At least two crop rotation packages prepared for demonstration	Y D16-17		Several options of crop rotation are available (peanuts, chilli, onion)
	Crop growth, yield and soil data collected for each crop	Y D18	Soil and crop data set can be used to select promising technology	Help farmers to decide on new cropping rotations
	Economic analysis (Benefit/cost analysis) completed for each crop	Y D18	BPTP Aceh has comparative data to develop cropping system analysis	Practice changes: 1. Dry season crop is economically beneficial if the water is not severely limited 2. Farmers now produce good compost and reduce input costs 3. Additional 84 farmers will grow dry season crops to 59 ha (from 2 ha) 4. Two farmers want to be peanut seed growers
2.3. Conduct experiments in NSW to evaluate management practices that improve soil nutrient and water availability in dryland farming systems (NSW, Australia)	Yearly sample collection and analysis for the long term biochar experiment from SMCN 2007/040 – Tamworth: 108 soil samples and 120 plant samples/year	Y D19	Increase dataset on biochar application in dryland agriculture	Increase the scientific understanding about the role of poultry litter biochar on crop yield, nutrient use efficiency, and nutrient dynamics over six year period
	Conduct soil column/leaching experiment –Tamworth	Y D20		

	Process and analyse existing soil samples (288 samples) collected in 2012 from Breeza, Liverpool Plains	Y		
	Collect 288 soil samples and analyse for soil fertility including soil carbon for (0–30 cm) and soil chloride for 0-600 cm from Breeza	Y D21		
	Measure seasonal plant growth and yield for native pasture (undisturbed grassland) and crops, annual for trees-Breeza	Y D22		
	Collect soil water measurements from Tamworth and Breeza	**Y** D23-24		
	Process and analyse data generated from Tamworth and Breeza	**Y** D23-24		
	Publish results for organic amendment, pasture yields and leaching experiments Liverpool Plains study	Y D25	Two papers presented at the 2018 National soil conference. One journal paper is being drafted	A new understanding of long-term benefits of poultry litter biochar in maintaining soil carbon and soil fertility

PC = partner country, A = Australia; **reports from the final research (2018-2019) are not yet completed. The quality of the reporting by UNSYIAH staff in the absence of DPI support is inadequate. Results are poorly presented, and the report is poorly written, despite the capacity building activities provided in data analysis, reporting and writing. The lack of interest in report writing is an ongoing and known issue for Aceh and this is well documented in every travel report submitted to ACIAR in addition to the verbal and email communication with ACIAR Program Manager. Those who do write do not write clearly and mostly in Bahasa Indonesia. This is exhausting for the Australian team. In the past, there are many members of the Australian team that can focus on assisting with writing reports from Aceh. The people who were assigned this task in this project resigned because of this challenge. Therefore future projects in Aceh should include partner members who can write and are dedicated to writing reports.

Objective 3. To develop strategies for dissemination of promising technologies to extension services and smallholders

Activity	Outputs/ milestones	Completed (Y/N)	Application	Other realised or potential applications/impacts
3.1. Conduct training programs for at least 40 district extension staff for efficient dissemination of promising management practices to smallholders (PC: BPTP Aceh)	Training program finalised – including crop nutrition, fertiliser management, application of soil test kits for dryland, soil fertility and water management	Y D26	43 PPLs from 4 districts were trained	Trained PPL were able to help farmers in managing dryland farming Increased capacity to support farmers Based on survey results the training topic was narrowed down to focus on soil and crop management for dryland systems
	Stage 1 training delivered	Y D27-28		
	Review of training program conducted	Y D29	Training stages 1 and 2 were combined	
	Stage 2 training components delivered	Y D30		
3.2. Support the adoption of promising crop rotation practices	~~Assessment of relevance for farmers of crop calendars for food production and crop decisions in target districts~~	NA	NA: milestone (D31) was removed during mid-term review (2017)	NA

Activity	Outputs/ milestones	Completed (Y/N)	Application	Other realised or potential applications/impacts
and identify opportunities for improvement (PC: BPTP Aceh)	12 small projects/demonstration activities established for extension staff to apply promising crop rotation technologies in dryland cropping	N D32	There were 8 proposals submitted, 6 were successful and 2 failed. 4 proposals were eligible for funding but only 2 reports were completed**	PPL learn how to conduct the experiment but there is an urgent need for further training and practice on writing up the report Training needs identified
3.3. Establish sites for the demonstration of promising technologies to farmers (PC: BPTP Aceh, all about women farmer groups, KWT)	Two KWT demonstration sites established in cooperation with subdistrict extension officers	Y D33	Learning facility: KWT Jeumpa Puteh KWT Kasih Ibu	Increase the competitiveness of KWT products by producing organic vegetables Apply the knowledge on their own vegetable gardens KWT found their niche product Increased income
	Conduct impact analysis of women's farmer group program before the establishment of the new program	Y D34	Guided the establishment of women farmers in the current project	Information available for a more effective KWT support by PPL
	30 women's farming groups (KWT) associated with the demonstration hubs are established and supported	Y D35-36	30 groups established to demonstrate the benefits of working in groups	Significant potential economic, social and community benefits
	Establish 30 small demonstration projects for extension staff to apply promising vegetable production technologies in conjunction with women's farming groups (KWT)	N D37-38	Thirty small demonstration plots were conducted by PPL. However, only 5 PPL delivering the reports **	Good information is not reported (missed opportunity)
3.4 Analyse, report and communicate key project results to research and extension staff, farmers and local government in the target districts (PC)	Annual data analysis and interpretation workshops conducted targeting researchers and students (1 workshop/year) (UNSYIAH)	Y D39	Increased capacity of students and UNSYIAH staff for data analysis and interpretation	Long-term research capacity is maintained Better information is derived from research
	Research results presented at UNSYIAH annual conference, and in scientific publications (PC: UNSYIAH0)	Y D40	Increased capacity of students and UNSYIAH staff to present scientific information at scientific meetings	Research outputs are disseminated
	Two district extension forums to inform extension staff about project activities, results and outputs, and to obtain feedback for finalising project publications (BPTP Aceh)	Y D41	Enhance peer-to-peer learning and information exchange Contributed to report on economic benefits from KWT activities	Knowledge of farmers and KWT increased in a range of crops and the practices Potential business opportunity identified

Activity	Outputs/ milestones	Completed (Y/N)	Application	Other realised or potential applications/impacts
	Three farmer group visits conducted within districts to key project sites (1/year) – PC BPTP Aceh	Y D42	Enhance peer-to-peer learning and information exchange	Forster long term networking between food crop farmers and women farmers
	Extension staff case studies booklet produced for final review (from 3.3) – PC BPTP Aceh	Y D43	The success story of 6 KWT was presented as a poster presentation in Australia. Booklets (400) have been distributed to BPP, KWT, PPL and local Dinas Pertanian across the four districts	Increase the credibility of KWTs to allow access to more local opportunities beyond this project

PC = partner country, A = Australia,

** The reports for these activities are not completed which reflects the lack of writing skills for the local agriculture extension officers. This indicates a need for further training and this needs to be communicated to the managing institution in Indonesia.

7 Key results and discussion

7.1 Activities 1.1 – 1.2: Characteristics of dryland farming systems in – Deliverable reports D1-D2, and D4-D7 (Appendix 1)

Socio-economic and soil surveys were conducted to understand existing practices and biophysical factors that contributed to the low crop yields.

Key points:

1. The socio-economic factors contributing to low crop yields include traditional low-input cropping practices applied on poor soil and in areas with insufficient seasonal rainfall, lack of information and the absence of support network, as well as the lack of capital to purchase inputs.

2. The survey confirmed that rural women in Aceh have limited employment opportunity and faced gender discrimination in various forms

3. Biophysical factors contributing to low productivity of dryland agriculture systems in Aceh include insufficient rainfall to support crop growth during the dry season, non-fertile soil, sloping land and insufficient drainage systems to cope with rainfall during the wet season.

4. Specific soil constraints identified are low soil C and N contents, low nutrient availability, especially N, K, Ca and Mg, and low base saturation. Low soil C and N contents are associated with low soil water holding capacity and poor soil structure.

5. Farming practices that increase ground cover, soil C and N contents and improved fertiliser management are key opportunities to close yield gaps for dryland systems.

7.1.1 Geography, demography and socio-economics

Aceh has 56,770,81 km^2 of land across 23 districts (289 subdistricts, 6,464 villages) occupied by 1,137,299 households (total population of 4,791,924). Agriculture is the largest occupation (46.53%), followed by trading (20.72%), services (17.06%), processing industry (4.05%) and others (11.04%). The province is dominated by forest and plantations. Rice fields and seasonal dryland farms are used for food crops and constitute about 10% of the total land area.

In the context of this project, dryland farming is defined as farming practices that 100% rely on rainfall or rain-fed farming. Across Aceh Besar, Aceh Barat, Pidie and Bireuen districts, dryland constitutes greater area compared to the irrigated area. However, farming activities and networks in dryland areas are not as well developed compared to those in irrigated farming systems, also known as lowland systems. Lowland rice farmers are well supported by the local government with strong farming networks and extension services.

Similar to farmers in the irrigated systems, dryland farmers source information from leading farmers, friends/family, the local agricultural field extension officer (PPL), non-governmental organisation (NGO), media (TV/radio/internet), or traders (input supplier or buyers); but reliable information is scarce. The opportunity to improve information transfer to dryland farmers include:

- improving/expanding knowledge and skills of PPL in managing dryland systems
- providing printed publications of good cropping practices on dry land
- increasing PPL capacity to transfer knowledge by increasing their activities.

The average landholding across the surveyed dryland area was between 0.25–0.50 ha per household and this is mainly used for growing wet season rice. Most farmers do not grow crops during the dry season, but the few farmers who do usually grow cash crops such as chilli, tomato, long bean, cucumber, shallot, spinach, kangkong, watermelon and cassava.

Characteristics and the socio-economic constraints for dryland farming systems in Aceh include:

- **Water availability:** insufficient seasonal rainfall is affecting farmer's confidence to grow a dry season crop. Without irrigation infrastructure, growing crops during the dry season is unaffordable for most farmers.
- **Lack of capital and unreliable input supply**: the lack of capital limiting farmers' access to acquire critical farming inputs. Good quality seed and fertiliser are often no longer available from the market when they need them and they often have to buy cheaper fake goods.
- **Market access and price fluctuation**: farmers are affected by access to markets and price fluctuation. The three modes of marketing include farm gate trading (traders/collectors coming to the village), the local wholesale market, or products sold at an urban market centre. Farmers' cooperatives/groups can increase the bargaining power of farmers.
- **Lack of credit available to smallholders**: farmers require cash for dryland farm operations. Most farmers use their own cash or borrowed funds that are repaid after harvest. A microfinance institution is not available or is too risky for them to lend to farmers during the dry season.
- **Traditional farming practices**: Dryland farmers in Aceh have in-depth knowledge about growing wet season rice. However, they are unfamiliar with growing dry season crops. Dry season crops are not common and are seen as a side activity that receives low inputs (limited fertiliser and labour allocation). Farmers who attempted to grow dry season crops achieved a low yield because of insufficient rainfall and fertiliser, and poor farming practices. The need for cash income forces most male farmers to work off-farm during the dry season. They typically migrate to the city for employment during the dry season and earn on average of about Rp.700,000 IDR (A$70) per month between April and August or up to A$500 for the season. There is an opportunity to improve production by improving farmers' knowledge on dry season crop growing, encouraging farmers to grow a high-value dry season crop using improved soil and fertiliser management.
- **Farm security for dry season crops**: In addition to the above challenges, growing crops in the dry season also presented a security risk from animal invasion. Some Aceh farmers have a few animals such as cows or goats, chickens or ducks. Cows or goats are impounded during the wet season to protect the rice crops. However because most farmers are not growing crops during the dry season, there is an established cultural practice in Aceh where farmers release livestock into the rice field after harvest, while they attend to religious or social/family events (i.e. wedding, circumcision). Any crop grown during the dry season needs to be fenced off, yet the cost of fencing is unaffordable for most farmers.
- **Insufficient agriculture extension support**: Field extension officers (PPL) play a key supporting role for farmers. Aceh has highly trained PPL to support farmers to grow wet season rice in lowland systems. However, there is no dedicated PPL for dryland and dry season crop farmers. Most PPL have completed high school education and have not undertaken university study. Although they have good practical skills in wet season rice systems, they lack the skills to transfer them to dryland systems. PPL are under-resourced and are rarely trained or skilled in growing dry season crops. Most PPL work on a daily casual arrangement, with no operating funds to visit their regular farmers, let alone to visit dryland farmers outside their lowland areas. Most PPL only visit farmers when there is a travel budget available under a special government program or from external projects. Many PPL are trained on integrated soil and crop management or pest management, but without travel support, they cannot transfer this knowledge or generate practice change.
- **Lack of farmers network:** Aceh has long-established cooperative farmers networks for wet season rice where farmers work in groups to manage their rice crops. However, such network does not exist in dryland systems or for dry season crops. Therefore there is no opportunity for peer-to-peer learning or collaboration for dry season crops.
- **Issues faced by rural women:** Rural women in Aceh face a number of social issues. They bear very high household responsibilities, have minimal input into the farm and family decisions and have limited access to finance. Although women spend a lot of time assisting with growing rice crops (weeding, harvesting and monitoring the crop), their contribution is not equally acknowledged. Most women are not able to work a full day as they are responsible for nurturing children, managing the household, helping elderly or sick relatives and helping their husbands in the field during the rice-growing season. Employment

opportunities are limited, leaving them financially dependent on their husbands. Women farmers who work as farm labourers received 20% less pay than their male counterparts for the same work. Additionally, the local culture, religious practices and traditional village lifestyle often suppress women's self-confidence and limit opportunities for education and personal development.

7.1.2 Climate and dry season cropping

Schmidt and Ferguson (1951) classified rainfall types based on wet and dry period ratios. Based on this classification, the climate type in Aceh Besar and Pidie districts (Table 20) has a serious water deficit during April–August to support crop growth. However, both districts have excess water during the wet season and are often subject to serious flooding and soil erosion after heavy rain due to the topography (Table 16) and insufficient drainage systems. In Bireuen the water deficit during the dry season is not as serious, but severe soil erosion upslope and flooding downslope are big issues. In Aceh Barat where rainfall is more evenly distributed, water trapped in low, wetland areas often become stagnant and are not used to grow dryland crops. The sloping dryland sites in Aceh Besar and Bireuen districts are affected by soil erosion and those located in the floodplain in Pidie and Aceh Barat districts are affected by flooding. The lack of conservation farming practices and insufficient drainage systems exacerbate both soil erosion and flooding problems. The absence of irrigation channel networks, distance from the river, and the topography amplify the water deficit issues faced by the dryland farmers.

Table 20. Biophysical characteristics of Aceh Besar, Pidie, Bireuen and Aceh Barat.

District	Climate type (Schmidt and Ferguson, 1951)	Slope/landform	Soil type or soil great group
Aceh Besar	C and D (mid humid to dry season)	8–25% (hilly)	Cambisol (Eutrudepts, Dystrudepts), Podzolic (Hapludults, Kandiudults), Andosol (Hapludands, Hydrudands), Gleysol (Epiaquepts), and Lithosol (Udorthents)
Pidie	B and D (mid humid to dry season)	sloping (3–8%) to hilly (16–25%)	Cambisol (Humudepts, Vertic Eutrudepts, Dystrudepts), Alluvial (Udifluvents), Gleysol (Endoaquepts), Regosol (Udipsamments), and Renzina/Mollisols (Haprendolls)
Bireuen	B (mid humid)	3–25% (hilly)	Cambisol (Dystrudepts), Podzolic (Hapludults), Gleysol (Humaquepts), Regosol (Udipsamments), Alluvial (Udifluvents), and Lithosol (Udorthents)
Aceh Barat	A and B (mid humid to wet season)	0–3% (flat land or lowland) and 8–15% (hilly)	Regosol (Udipsamments), Cambisol (Dystrudepts), Podzolic (Hapludults), Gleysol (Endoaquepts), Regosol (Udipsamments), Alluvial (Udifluvents), and Lithosol (Udorthents)

7.1.3 Topography, landform and soil types

A variety of soil types exist across the four districts (Table 20) including Alluvial (Udifluvents), Cambisol (Eutrudepts, Dystrudepts), Podzolic (Hapludults, Kandiudults), Gleysol (Endoaquepts, Epiaquepts), Regosol (Udipsamments), Lithosol (Udorthents), Renzina (Haprendolls) and Andosol (Hapludands, Hydrudands). They are categorised as Entisols, Inceptisols, Ultisols, Andosols and Mollisols (Soil Surveys Staff 2014) respectively, but the dominant order is Inceptisols. Mollisols are only found in Pidie dryland areas, while Andisols are only found in Aceh Besar. Outside the surveyed area, Oxisols, Alfisols and Spodosols are also present across the dryland area of Aceh (Balingtan 2015).

Inceptisols, Ultisols, Oxisols and Entisols are classified as low-quality soils because of their low water holding capacity and nutrient-poor parent materials. These soils are derived from sedimentary rocks and old volcanic tuffs which are dominated by 1:1 clay minerals and iron (Fe) and aluminium (Al) hydroxide oxides. Except for Entisols, these soils are highly weathered with solum of > 90 cm and have low soil fertility. Andisols, exclusively found in Aceh Besar, are developed from volcanic ash from Seulawah Agam Mountains, dominated by amorphous minerals, and are characterised by dark topsoil and andic soil properties. Mollisols are formed from limestone deposits (karst) with a mollic diagnostic horizon (Soil Survey Staff 2014). Both the Andisol (found in Aceh Besar) and Mollisols (found in Pidie) have medium fertility.

Entisols have diverse profile morphology and vary in quality depending on location. As a young and undeveloped soil with thin solum (Soil Survey Staff 2014), they are found as Regosol (Udipsamments), or Alluvial (Udifluvents) and Lithosol (Lithic Udorthents) across the studied districts. Regosols are low-quality soils because they have coarse-textured (sand). Lithosol (Udorthents) are classified as low quality because they have a very shallow solum. Alluvial (Udifluvents) develop from fertile river deposits and are considered good quality soils.

7.1.4 Soil physical and chemical properties

A summary of soil physical properties (Table 21) indicated high soil bulk density (BD), coarse texture and a low water holding capacity (WHC) for most soil types in the surveyed districts. These are the potential limiting factors for crop growth. The low permeability could be a constraint in the low lying areas while the high permeability could become a limiting factor in the higher areas or shallower soil types. High BD could occur either from clay accumulation or erosion (found in Cambisol, Podzolic and Lithosol). Areas with high BD and low soil WHC in Regosol (Aceh Barat and Pidie) are mainly due to the dominant sand fractions. The effects of unfavourable soil physical properties magnifies risk to soil erosion which is expressed by low or zero ground cover on dry hilly areas dominated by Podzolic, Cambisol, Lithosol and Andosol soils (Dariah et al. 2004). The lack of soil conservation practices by the local farmers contributes to low ground cover.

Table 21. Means or status of soil physical properties for each soil order (type).

Properties	Cambisol (Inceptisols)		Podzolic (Ultisols)		Alluvial (Entisols)		Gleysol (Inceptisols)		Regosol (Entisols)		Lithosol (Entisols)		Andosol (Andisols)	
Depth (cm)	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40
Texture	F	M	F	F	M	F	M	F	M	C	M	M	M	M
BD (Mgm^{-3})	1.22	1.16	1.24	1.29	1.02	0.92	1.26	1.32	1.27	1.31	1.27	1.31	1.31	1.31
WHC	L	H	H	L	H	L	L	L	L	L	L	L	L	L
Permeability (cm/hr)	M	M	L	L	M	M	L	L	Quick	Quick	M	Quick	M	M
Porosity(%)	L	M	H	L	H	L	L	L	L	L	L	L	L	L
ASI	L	H	H	L	H	M	L	L	M	M	L	L	L	L

BD = bulk density, WHC = water holding capacity, ASI = aggregate stability index, F = fine, M = medium, C = coarse.

Soil chemical properties (Figure 7) indicated that the fertility status is generally low in all districts as indicated by the following factors:

- The soil organic carbon (SOC) contents are low (< 20 g/kg) and generally higher in the surface (11.1–18.6 g/kg) than in the subsoil (6.4–15.9 g/kg)
- The total soil N (TN) content ranges from low to medium in the surface (1.7–2.3 g/kg) and low (< 2 g/kg) for the subsurface
- The available P is not limiting for production, except for soils in Aceh Besar
- Soil cation exchange capacity (CEC) levels are medium to high (21.8–40.8 cmol (+)/kg)
- Base saturation (BS) of soils are generally very low, except for Aceh Besar
- The exchangeable K levels are low (<0.2 cmol(+)/kg), except for soils in Aceh Barat
- The exchangeable Ca levels are low, being highest in Pidie and Aceh Besar
- The exchangeable Mg levels are low except in Aceh Besar (medium-high)
- Soil pH_{H2O} (5.9–7.6) tends to be higher in Pidie (7.61), but there are no potential production constraints identified with soil acidity
- The exchangeable Na and Al contents, and soil EC are negligible.

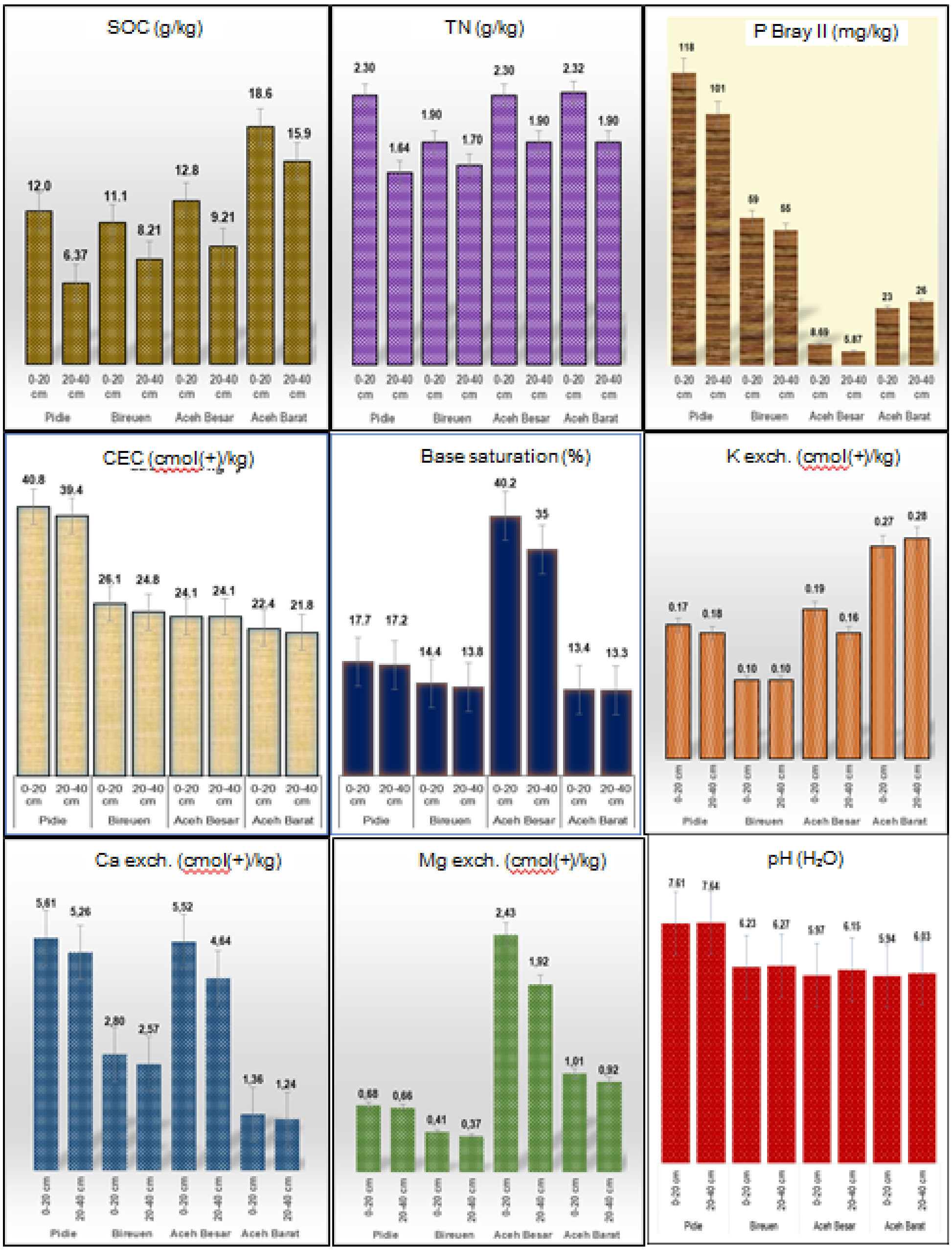


Figure 7. Mean values of soil chemical characteristics from the surface (0–20 cm) and subsurface (20–40 cm) soils in dryland farming systems of four districts in Aceh.

Although the cation exchange capacity and available phosphorus of these soils were high, the productivity of the soil was below potential, suggesting that yield is limited by the low availability of nitrogen, magnesium and potassium.

Table 22 shows that the main limiting factors contributing to low soil fertility are low soil organic matter or carbon content, low base saturation, low exchangeable cation and low total N. Soils with low organic matter have low cation retention capacity. Soil organic matter promotes the activity of microorganisms to release the nutrients from minerals (Bohn et al. 2007), promotes cation exchange capacity and provision of nutrient elements, and acts as a buffer against changes in pH (Stevenson 2008). Organic matter and fertiliser application were expected to improve the quality and fertility of these soils (Havlin et al. 2012).

Opportunities to reduce yield gaps of dryland crops include improving soil fertility via the addition of organic or inorganic fertilisers. Given that the soil nitrogen content is linearly correlated with the soil organic carbon content, increasing the soil organic carbon level to as high as possible above 20 g/kg is expected to increase soil nitrogen content and improve its productivity. Application of soil amendments has the potential to address these soil issues in the tropical regions (Sukartono et al. 2011). The improvement of soil organic carbon content will also increase soil water holding capacity and improve soil structure.

Table 22. Soil fertility status of different soil types/orders on drylands of four districts in Aceh based on their chemical properties.

Soil type/order	CEC	BS	P_2O_5	K_2O	C-organic	Fertility status
	Aceh Besar District					
Cambisol (Inceptisols)	H	M	M	M	L	L
Podzolic (Ultisols)	L	L	H	L	L	L
Lithosol (Entisols)	L	L	H	M	L	L
Gleysols (Inceptisols)	H	M	M	M	L	M
Andosol (Andisols)	H	M	M	M	L	M
	Pidie District					
Cambisol (Inceptisols)	M	L	H	M	L	L
Alluvial (Ultisols)	L	L	H	L	L	L
Lithosol (Entisols)	L	L	H	M	L	L
Gleysols (Inceptisols)	H	L	M	H	L	M
Renzina (Mollisols)	H	L	H	L	M	M
Regosol (Entisols)	L	L	M	M	L	L
	Bireuen District					
Cambisol (Inceptisols)	H	M	M	M	L	L
Podzolic (Ultisols)	L	L	H	L	L	L
Lithosol (Entisols)	L	L	H	M	L	L
Gleysols (Inceptisols)	M	L	H	M	L	M
Alluvial (Entisols)	M	L	H	H	L	M
Regosol (Entisols)	L	L	H	L	L	L
	Aceh Barat District					
Cambisol (Inceptisols)	H	L	L	L	L	L
Podzolic (Ultisols)	L	L	L	L	L	L
Lithosol (Entisols)	L	L	H	L	L	L
Gleysols (Inceptisols)	L	L	L	L	M	L
Alluvial (Entisols)	L	M	L	L	M	L
Regosol (Entisols)	M	L	L	L	H	L

7.2 Activities 2.1 – 2.3: Soil and crop responses to fertiliser and soil amendment in dryland systems of Aceh and NSW

7.2.1 Research in Aceh (A.2.1) – Deliverable reports D8-D12 (Appendix 2)

Key points:

1. Yield response to soil amendment and fertiliser application in Aceh is variable across crops and soil types between and within sites. Three out of 10 trials showed positive but inconsistent yield

response. Therefore it is too early to recommend the use of soil amendment for on-farm application.

In the Jantho site (Podsolic soil), a one-off application of 10 t/ha rice husk biochar (RHB) with 400 kg/ha of NPK or cow manure (CM) with 400 kg/ha of NPK fertiliser did not improve the yield of soybean or sweetcorn, nor did it improve soil chemical or physical properties within one season of the application.

On the same site/soil, mulching with 5 or 10 t/ha maize stubble + 400 kg/ha of NPK fertiliser increased the yield of maize by 45%, peanut by 39% and soybean by 92%. The application of 10 t/ha mulch did not increase soil carbon nor did it affect other soil properties or soil water holding capacity.

In the Muara Tiga site (Cambisol soil), amending the soil with RHB alone or CM mixed with NPK fertiliser doubled the soybean yield but did not affect maize yield.

Yield of the adjacent peanut crop was not increased when soil was amended with up to 20 t/ha of cow manure combined with compost.

In both the Jantho and Muara Tiga sites, the yield of monoculture corn or soybean was higher than the respective yield under mixed cropping. The land equivalent ratio was > 1, indicating that land productivity is improved under mixed cropping. However, soil fertility must be improved to take advantage of the greater LER with mixed cropping.

In the Darussalam site (Entisol soil) with the peanut experiment (E, Figure 4), the application of 2.5 and 5 t/ha of CM or RHB or cocopeat biochar (CP) did not increase yield. When RHB and CP rates were increased to 10 t/ha, yields responded positively. However, a higher CM application (10 and 20 t/ha) did not increase peanut yield.

In the same site, the crop rotation experiment (F, Figure 4) produced mixed results. Kangkung yield (first crop in the rotation) responded positively to the application of 2.5 t/ha CM + 50% recommended NPK fertiliser rate. The subsequent maize yield (second crop in the rotation) was improved when RHB or CM was applied together with N and K fertilisers. RHB and CM or fertiliser applied individually did not improve yield. The third crop (soybean) was not well managed (heavily infested by weed and pest) therefore the true yield response is unknown.

The exploratory study on the role of microorganisms in drought management indicated that arbuscular mycorrhizal fungi (AMF) and cellulotic fungi (CF) inoculation lowers proline content in maize leaves, suggesting their potential to increase drought tolerance of maize. However, further evaluation including field testing is required before the technology can be recommended.

Jantho (Podsolic soil)

All results presented for research activities in Aceh are extracted from experimental reports from UNSYIAH which are presented in Appendix 2. For the Jantho site, it is inside the folder D12 (experimental reports), files 1B and 2B.

In a short-term trial on the Podsolic soils of Jantho (Figure 4, experiment A), the application of 10 t/ha rice husk biochar increased soil organic C content from 0.57% to 1.08%. However, the high variation of responses means that the increase was not statistically different (Table 23).

Table 23. Soil chemical changes at 45 and 95 days after planting (DAP) of soybean in a degraded Podzolic soil amended with various organic materials.

Soil Chemical variables	SCA	45 DAP					SL	95 DAP					SL
		A_0	A_1	A_2	A_3	A_4	A_0	A_0	A_1	A_2	A_3	A_4	
pH H_2O	6.83	6.15	6.19	6.44	6.22	6.12	ns	6.03	6.04	6.21	6.10	5.90	ns
C-Org (%)	0.57	0.96	1.08	0.79	0.73	0.71	ns	1.12	1.11	1.14	1.02	1.06	ns
N-total (%)	0.15	0.16	0.18	0.16	0.18	0.21	ns	0.14	0.14	0.15	0.15	0.14	ns

P-Av. mg/kg)	2.08	14.98	18.68	25.5	25.08	28.69	**	9.14	12.55	10.27	12.61	14.43	ns
Exc.K cmol(+)/kg)	0.12	0.18	0.20	0.25	0.19	0.22	ns	0.19	0.22	0.21	0.22	0.28	ns

A_0 = NPK 400 kg/ha (control), A_1 = biochar 10 t/ha, A_2 = cow manure 10 t/ha, A_3 = biochar 10 t/ha + NPK 400 kg/ha, A_4 = cow manure 10 t/ha + NPK 400 kg/ha, SCA = soil character before the amendment, SL = significance level where ns = non-significant and ** = significant at P = 0.01.

The application of NPK fertiliser or cow manure only to soil (without biochar) increased soil C content to about 0.71%. This could be due to rapid decomposition of the added or the native soil organic matter under the elevated soil N.

Except for available soil P at 45 DAP, none of the soil properties responded to the application of either rice husk biochar or cow manure (Table 23). The increased available P in all treatments is mainly due to the added P contained in the fertiliser and the amendments. The 10 t/ha cow manure + NPK treatment had the highest available P due to higher P content of the manure (23.4 mg/kg) compared to 12.9 mg/kg in the biochar. At harvest, the available P was similar for all treatments.

Yields of soybean and corn were not affected by soil amendments (Table 24). However, the marketable cobs and number of sweetcorn seeds per cob were significantly increased in soil amended with cow manure + NPK. This suggests that N added from NPK fertiliser or soil amendments alone were not enough to achieve maximum crop yields, but were sufficient to support the formation of corn cobs and seed.

The estimated amount of N applied in the 10 t/ha cow manure + 400 kg/ha NPK is about 104 kg. This exceeded the 40 kg N requirement for soybean (Salvagiotti et al. 2008) and 83 kg N requirement for corn (Jellum and Kuo 1996) and indicates a low nitrogen use efficiency in this system (Raun and Johnson 1999), probably through leaching or volatilising. Therefore, to improve the fertility of a severely degraded soil such as this Podzolic, more than 10 tonne of cow manure is likely to be needed (Abujabhah et al. 2016), together with management practices to minimise losses.

The high rate of soil amendment required might not be economically viable for most smallholder farmers in Aceh for the following reasons. Firstly, farmers either only have a small number of livestock (2–3 cows or goats) or no livestock, therefore manure production is low. Second, the sale of manure is prohibited under the local sharia law. Therefore farmers who do not own livestock will need to collect manure from a neighbour’s field or pay someone to collect it for them. This would involve high costs for labour or transportation. Therefore it is not easy to obtain a large amount of manure. Buying composted manure is not a cheap option, with a cost of about A$100 per tonne. Therefore, small but regular applications of manure or compost may be a more practical option for smallholder farmers in Aceh.

Table 24. Yields of soybean and sweetcorn grown under monoculture and mix-crop systems.

Variables	Soil amendments					SL	Cropping system		SL
	A_0	A_1	A_2	A_3	A_4		Monoculture (S_1)/(S_2)	Mixed Crop (S_3)	
Soybean									
Wt/100seed (g)	18.60	18.40	18.40	21.40	22.10	ns	20.80	18.80	ns
Seed/plant (g)	15.60	15.10	17.80	18.10	14.70	ns	15.90	16.60	ns
SeedWt/plot (kg)	0.90	0.90	1.00	0.90	0.80	ns	1.30	0.50	**
No.of imperfect seed/plant	8.90	9.80	10.30	9.73	8.56	ns	7.75	11.20	*
Yield (t/ha)	1.17	1.16	1.40	1.27	1.16	ns	1.82	0.60	**
Sweetcorn									
FWseed/cob (g)	117.20	82.60	114.00	108.50	117.00	ns	124.80	90.90	**
FWcob/plant (g)	222.70	192.80	208.50	230.50	235.80	ns	254.40	181.70	**
FWcob/plot (kg)	13.30	12.10	11.10	12.90	15.60	ns	14.90	11.10	**
Marketable cob/plot	30.20	31.80	27.30	34.70	47.70	*	44.60	24.10	**
No of seed/cob	409.00	352.00	398.80	449.80	469.20	*	478.30	353.30	**
FWcobW husk (t/ha)	18.10	16.50	15.07	17.50	21.10	ns	20.30	15.10	**

Variables	Soil amendments					SL	Cropping system		SL
	A_0	A_1	A_2	A_3	A_4		Monoculture (S_1)/(S_2)	Mixed Crop (S_3)	
LER	1.10	0.70	1.00	1.50	1.01	*	-	-	-

A_0 = NPK 400 kg/ha (control), A_1 = biochar 10 t/ha, A_2 = cow manure 10 t/ha, A_3 = biochar 10 t/ha + NPK 400 kg/ha, A_4 = cow manure 10 t/ha + NPK 400 kg/ha, FW = Fresh weight, SL = significance level where ns = non-significant, * = significant at P = 0.05, ** = significant at P = 0.01.

Although crop yields were not significantly different between treatments, the yield of sweetcorn obtained by using NPK fertiliser only improved from 8–10 t/ha to 18 t/ha, suggesting that any soil and crop management intervention could improve existing crop yields.

For both crop types, the monoculture cropping system produced significantly higher yields compared to the mixed-crop system due to less competition for resources and solar radiation (Table 24). Monoculture soybean produced 1.82 t/ha compared to 0.63 t/ha in the mixed-crop system. Whereas for sweetcorn, the cob yield under the monoculture system was 20.3 t/ha compared to 15.07 t/ha in the mixed-crop system.

The land equivalent ratio (LER) was >1 for most treatments (Table 24), suggesting that there are potential benefits for mixed-cropping, which is consistent with the findings of Wibowo et al. (2013). However, to maximise the benefit of mixed-cropping, soil fertility constraints must be managed.

In the mulch evaluation study (Figure 3, experiment M), the use of mulch combined with fertiliser improved yields of maize, peanut and soybean (Table 25) and the increase tended to be consistent with mulch application rate. Fertiliser alone improved the yield of maize and peanut but not soybean. This may suggest the moisture conservation effect of mulching helps nutrient uptake.

Table 25. Mulch and fertiliser increased yields of maize, peanut and soybean. The letter following the mean values indicates differences.

	Calculated mean yield (t/ha)		
	Maize	Peanut	Soybean
Control (Nil)	9.05a	3.60a	2.61a
400 kg/ha NPK	10.21b	4.95b	2.88a
400 kg/ha NPK + 5 t/ha mulch	11.34c	6.07c	4.02b
400 kg/ha NPK + 10 t/ha mulch	13.19d	5.00b	5.00c

Muara Tiga (Cambisol soil)

The original experimental reports from UNSYIAH for the Muara Tiga site are presented in Appendix 2, folder D12 (experimental reports), files 3B and 4B.

The soil in the Muara Tiga site was more fertile than the Podsolic soil in Jantho (Table 8). The organic amendment (Figure 3, experiment B) increased soil organic C content from 0.93% to 1.16% and available soil P from 27.9 ppm to 35.47 ppm at 45 days after planting (DAP). Both soil organic C and the available P were highest in soil amended with fertiliser and cow manure or A4 treatment (Figure 8). After 95 days the soil organic C become similar in all treatments, but the available P remained higher in the A4 treatment. However, soil amendment did not affect total soil nitrogen, soil pH or exchangeable K in either the monoculture or the mixed cropping system.

The cropping system had no effect on soil physical properties and water holding capacity or chemical properties at 45 DAP, but after 95 days, soil exchangeable K and available P were highest under the soybean monoculture (Table 26). There was an interaction effect of cropping system and amendment, with both soil porosity and aggregation performing best under soybean monoculture when cow manure was applied with the fertiliser. This is most likely due to the enhancement of both taproots and branch roots in the soybean root system in soil amended with cow manure.

The LER was > 1 in all treatments (Table 27), indicating there is yield benefit of planting the two crops simultaneously as a mixed-cropping system.

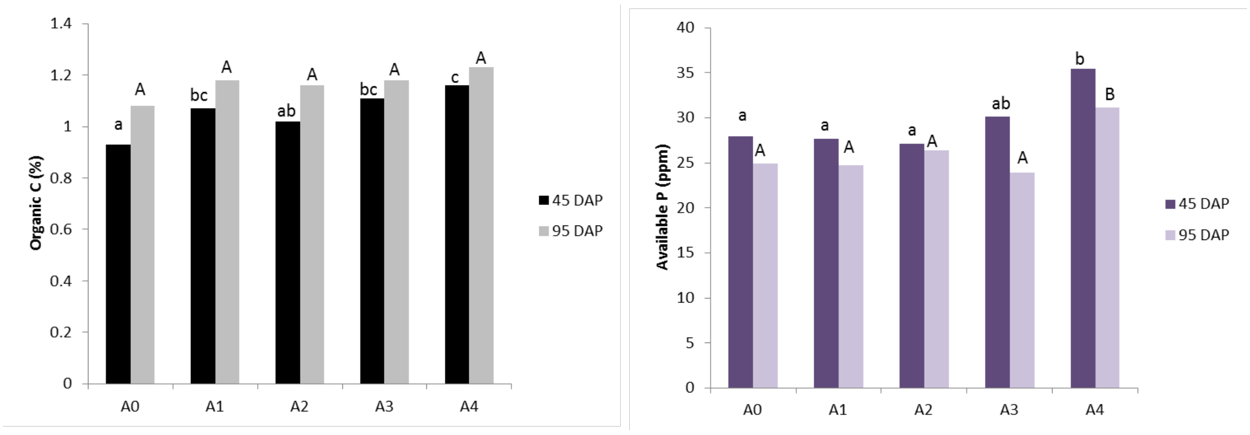


Figure 8. Mean values of soil organic C (left) and available P contents (right) in amended soil A0 (400 kg/ha NPK), A1 (rice husk biochar 10 t/ha, A2 (cow manure 10 t/ha), A3 (400 kg/ha NPK + rice husk biochar 10 t/ha), and A4 (400 kg/ha NPK + cow manure 10 t/ha) at 45 and 95 days after planting (DAP). Letters above the bars indicated differences between means and the capital letters refer to the 95 DAP.

Table 26. Exchangeable K and available P at 45 and 95 days after planting (DAP) under different cropping system/planting configurations.

	45 DAP		95 DAP	
	Exchangeable K (cmol(+)/kg)	Available P (ppm)	Exchangeable K (cmol(+)/kg)	Available P (ppm)
Maize monoculture	1.50	29.44	0.59a	25.01a
Soybean monoculture	1.52	31.43	0.79c	29.96b
Mixed crop soybean and maize	1.58	28.14	0.69b	23.70a

Means with different letters are statistically significant at $p < 0.05$.

Table 27. Mean yield of soybean and sweetcorn grown in amended soil

Soil amendment	Sweet corn (t/ha)	Soybean (t/ha)	Land equivalent ratio (LER)
A0: 400 kg/ha NPK	23.24	0.88a	1.81
A1: rice husk biochar 10 t/ha	19.17	1.57b	1.53
A2: cow manure 10 t/ha	25.43	1.45ab	1.41
A3: 400 kg/ha NPK + rice husk biochar 10 t/ha	22.86	1.34ab	1.42
A4: 400 kg/ha NPK + cow manure 10 t/ha	23.11	1.68b	1.42
	NS	*	NS

Means with different letters are statistically significant at $p < 0.05$

Soil amendment increased the yield of soybean but not sweetcorn or the land equivalent ratio (Table 27). Soybean yield was lowest in the unamended soil (A0) and increased when the amendment was added, reaching a peak when 10 t/ha of cow manure was applied with fertiliser. The yield tended to be lower when cow manure was used alone. The rice husk biochar has a low nutrient content, especially N and there is a possibility that it may tie up the applied nitrogen from the NPK fertiliser. This may explain the tendency of lower soybean yields under biochar + fertiliser treatment (A3) compared to that under the biochar only treatment (A1).

For the adjacent peanut experiment (Figure 4, experiment C), adding 10 t/ha compost or manure increased soil organic C content from 1.45% to 1.63% (0.18%), but combining compost and manure up to 20 t/ha only marginally enhanced it to 1.74% (further increased by 0.11%). None of the amendments increased total soil nitrogen or available P content and subsequently there was no effect on N and P uptake by peanut.

Compost and manure increased aggregate stability and soil permeability associated with a reduced soil bulk density (Table 28). The lower bulk density reflected the increased soil porosity which is expressed in the increased soil water content at field capacity (Table 28). This resulted in the soil water holding capacity increasing from an average of 30% to 32%.

Table 28. The yield of peanut and physical properties of soil sampled the day before harvest.

Treat	ASI	BD	WC@FC	Permeability (mm/hr)	Yield (t/ha) for each peanut variety				
	0-20 cm				Tuban	Hypoma	Bima	Kelinci	Gajah
S0	49.36a	1.27b	13.67a	15.95a	3.98	4.04	5.03	5.71	4.20
S1	51.52b	1.27b	14.57b	17.46ab	4.20	4.35	4.17	6.20	4.97
S2	51.61b	1.24ab	14.37b	19.10b	4.35	4.77	4.78	5.71	3.95
S3	54.32c	1.22a	14.928	19.72b	4.48	4.17	5.15	4.63	4.04
LSD=0.05	0.93	0.03	0.67	1.85					
	20-40 cm								
S0	51.96a	1.27b	-	16.74a	NA				
S1	53.00b	1.24ab	-	16.93a					
S2	53.99c	1.26b	-	18.42b					
S3	54.98d	1.23a	-	18.39b					
LSD=0.05	0.26	0.03	-	1.41					

*250 kg/ha of NPK was applied for each treatment. S0 = Nil amendment; S1 = 10 t/ha manure; S2 = 10 t/ha compost
S3 = 10 t/ha manure + 10 t/ha compost
ASI=Aggregate Stability Index; BD=Bulk density (Mg/m^3); WC@FC = Water content at field capacity
Means with different letters are statistically significant at $p < 0.05$.

Peanut yield obtained in all treatments (Table 28) more than tripled the national average yield of 1.2 t/ha (Table 1), and it was similar for all soil amendment treatments and the control. This demonstrates that amending the already fertile soil is not beneficial. This is an important message to the local farmers to discourage over fertilising or over amending practices. However, farmers need to be encouraged and guided to monitor the long-term productivity or fertility of their soil.

Darussalam (Entisol soil)

The original experimental reports from UNSYIAH for the Darussalam site are presented in Appendix 2, folder D12 (experimental reports), files 5B and 6B.

In the peanut experiment (Figure 3, experiment D), soil amended with 2.5 t/ha rice husk biochar (RHB), coco peat biochar (CPB) or cow manure (CM) did not improve soil C, N or P and subsequently did not significantly increase the yield of the first peanut crop. However, there was a tendency of yield increase in soil amended with 5 t/ha CP and CM (Figure 9).

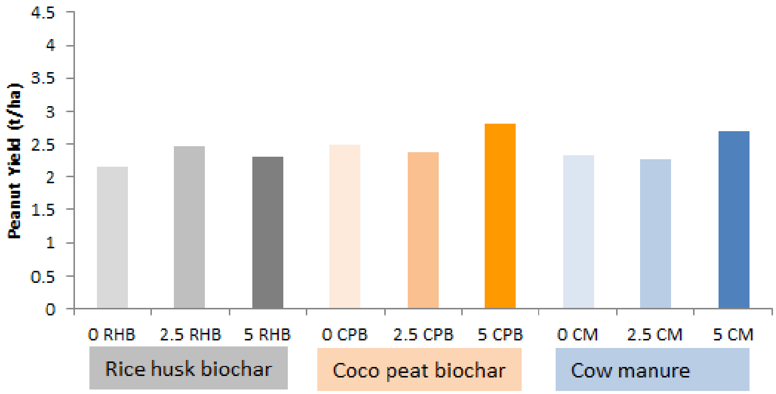


Figure 9. Rice husk biochar (RHB), coco peat biochar (CP) or cow manure (CM) did not significantly increase peanut yield when applied at 2.5 or 5 t/ha.

Therefore in the second peanut crop, the soil amendment rate was increased crop by adding 10 t/ha each of rice husk biochar (10RHB) and coco peat biochar (10CP). This addition significantly increased peanut yield compared to the soil amended with 5 t/ha. However, adding an extra 20 t/ha manure did not improve yield (Figure 10). The magnitude of the yield increase was greater in the rice husk biochar treatment compared to the coco peat biochar. Unfortunately, the analysis results of biochar have no been provided by UNSYIAH to explain the difference in the magnitude of the effect.

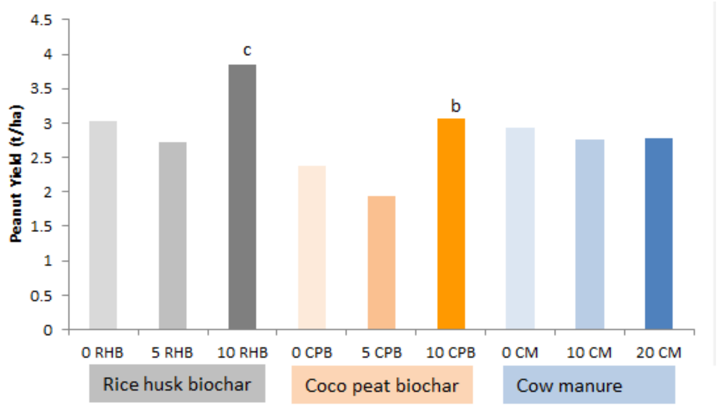


Figure 10. Increased rate of rice husk biochar (RHB) and coco peat biochar (CP) increased peanut yield, but the increased rate of cow manure (CM) to 10 and 20 t/ha did not significantly increase yield.

In the crop rotation experiment (Figure 3, experiment E), the first crop was kangkung, grown during January 2018. It was difficult to assess the treatment effect on yield and its trend and unexpectedly the control treatments (R1 and R2) yielded higher than most other treatments. However, the mean dry matter yields ranged from 1.01–2.34 t/ha (Figure 11) which is significantly higher than the average of 0.30 t/ha dry matter obtained by local farmers (Kresna et al. 2016). The highest kangkung yield was produced in soil amended with 2.5 t/ha cow manure + 166 kg/ha of NPK fertiliser (R18) followed by the control treatment (R1), 5 t/ha cow manure + NPK fertiliser (R20), and the second control treatment (R2). There was no consistent pattern of factors affecting the lower end of the yield response (i.e. yield < 1.5 t/ha), but the majority of the low yield was produced from no fertiliser treatment or with 50% recommended fertiliser rate treatment. When the low yield is obtained from soil amended with rice husk or rice husk biochar + fertiliser, it may indicate that the rice husk biochar tied up nutrients from the fertiliser.

There were no conclusive effects of the amendments on the soil physical properties (BD, porosity, permeability, water holding capacity and aggregate stability) or soil chemical properties (pH and EC, organic C, total N, available P, and CEC) measured after the kangkung plant was harvested.

The rate of soil organic amendment used in the experiment was increased for the second crop in rotation, i.e. maize (Table 12). Maize yield (Figure 12) was highest in soil amended with 10 t/ha of cow manure or rice husk biochar applied in combination with N and K fertiliser. However, the organic amendment must be applied with sufficient fertiliser to increase yield. The application of fertiliser alone did not increase yield. Amongst the fertiliser treatments, those with N and K fertilisers yielded up to 20% higher compared to other treatments.

There was no improvement in soil carbon, nitrogen, pH or CEC with the amendments but soil porosity, aggregation and soil microbial activities all increased.

The soybean crop produced low yields, which ranged from 0.07 to 0.41 t/ha due to badly managed trials as well as unmanaged pest and weed infestations. The soybean was also grown during the wet season and hence the flood may have caused cross-contamination of fertiliser or soil amendment treatments. Under this circumstance, yield comparison between treatments cannot be performed.

The yield of the fourth crop in rotation (choy sum) from this experiment has not been reported by UNSYIAH.

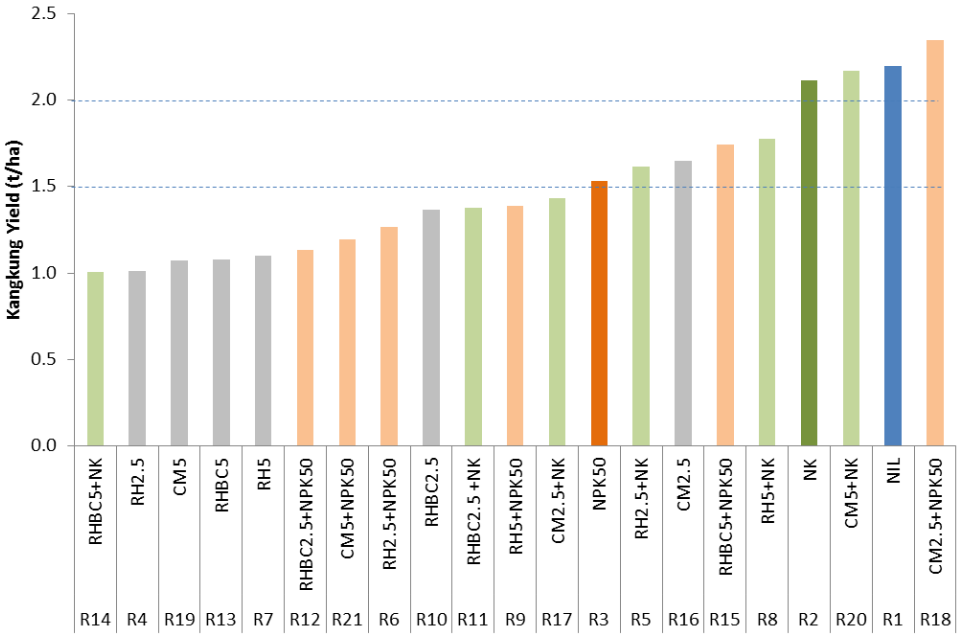


Figure 11 Dry matter yield of kangkung under various amendment and fertiliser.

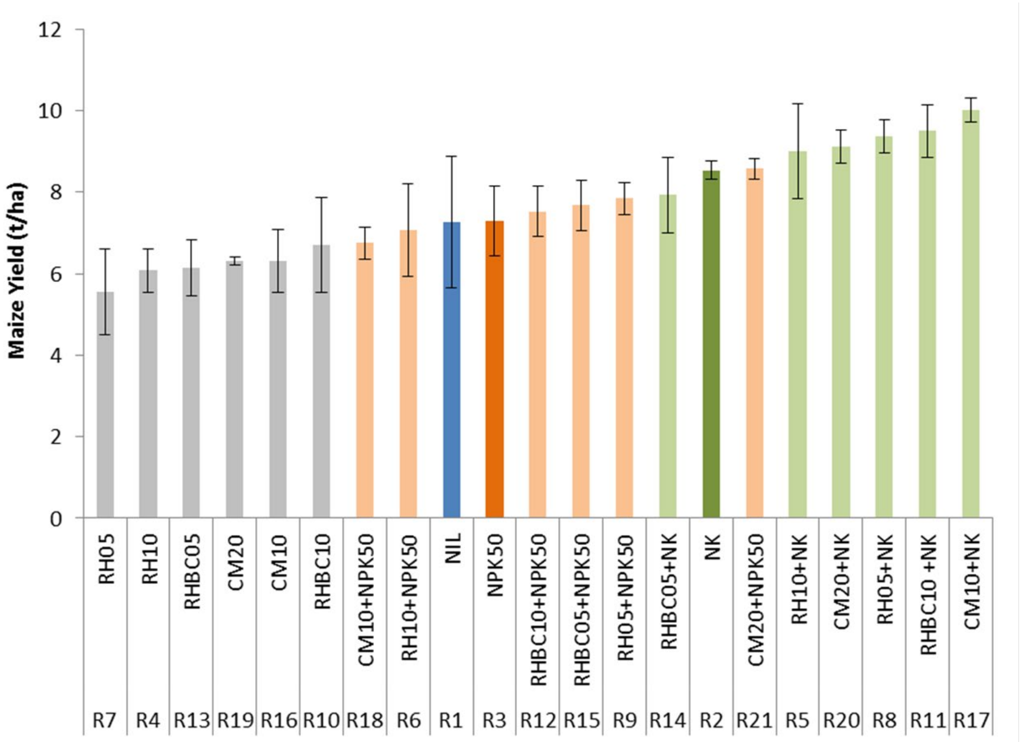


Figure 12. Soil amendment applied with fertiliser did not increase the yield of maize (grey bars) and those applied with N and K fertiliser (green bars) yielded more compared to those with NPK fertiliser.

Ie Seuum (Entisol soil)

The original report from UNSYIAH is in Appendix 2, folder D12, file 7C.

Experiment F (Figure 4) evaluated the influence of native arbuscular mycorrhizae fungi (AMF) and cellulotic fungi (CF) in drought management of maize in a pot experiment. Under drought conditions, plants contain multiple defence mechanisms including the accumulation of proline in the leaves and roots. The higher the plant stress, the higher the proline content. Arbuscular mycorrhizae fungi (AMF) inoculation lowers proline content in maize leaves (Table 29), suggesting it is increasing the tolerance level of plants to drought. Of the three dominant AMF species evaluated (Glomus sp. 4, *Acaulospora tuberculata*, and *Gigaspora cf gigantea*), the *Gigaspora cf gigantea* has more potential to improve plant growth and lower proline content compared to *Acaulospora tuberculate. Cellulotic Fungi* (CF) (Isolate A 51.) is better than isolate L 3.1 in improving maize growth under water stress, but the combination of the native arbuscular mycorrhizal fungi and cellulolytic fungi did not significantly overcome water stress.

Table 29. Proline content of maize leaves (ppm). Means with different letters are statistically significant at $p < 0.05$ by the Duncan means comparison test.

AMF inoculant	**CF inoculant**			**Means**
	No CF	A 3.1	L 5.1	
No AMF	8.32	7.75	6.80	7.62 b
A. tuberculata	7.86	6.81	6.77	7.15 ab
G. gigantea	6.38	6.59	6.57	**6.51 a**
Means	7.52	7.05	6.71	

7.2.2 Demonstration farm to show benefits of incorporating dry season crops in crop rotation (Activities 2.2) – Deliverable reports D14-D18 (Appendix 3)

Key points:

1. This is the first study evaluating the viability of dry season cropping in Aceh dryland systems. The results from this study can form a basis for the local agricultural researchers to build a long-term evaluation in order to obtain a greater and longer-term understanding about the viabilities of dry season crops under changing biophysical or market environments.

2. In both the Lambaro Biluy and Blang Keutumba sites, the new practices introduced include skip-row planting 2:1, improved fertiliser management, and improved production and use of compost.

3. In the Lambaro Biluy village with spring water from the mountain during the dry season):

a. Growing two crops per year is viable and with low risk of crop failure. Growing peanut as the second crop after rice was highly profitable
b. The potential gross margin from growing dry season crops ranged from Rp.1,592,000 (A$159) for dryland rice to Rp. 25,840,000 (A$2,584) per ha
c. The dry season crops demonstrated over the three-year crop rotation were dryland rice, maize, soybean, chilli and onion. Based on the gross margin obtained, the local farmers indicated their preference to grow peanut or mungbean
d. Peanut crops responded positively to ZA and KCL fertilisers and need to be integrated into their fertiliser management package
e. Organic amendments do not produce immediate effects and need to be viewed as a long-term investment. A small dose (1–2 t/ha) of compost applied seasonally gradually improved crop yields and gross margin.

4. In the Blang Keutumba village a drier area without spring water in the dry season:

a. Mungbean is the most profitable dry season crop. However, the risk of crop failure is higher
b. The cost of compost outweighed the benefits and it was not profitable when farmers used compost they bought.

6. There is a need to evaluate the long-term economic benefits of organic amendment in a range of soil and climatic conditions in Aceh before it can be recommended to farmers.

Lambaro Biluy

Compost was one of the technologies introduced to farmers in Lambaro Biluy. Compost (1.5–2 t/ha) was added to each dry season crop grown between 2016 and 2018. Farmers made the compost using a mixture of 70% cow manure and leftover feed, 20% rice stubble, 10% rice husk and aided by fermenting agent EM-4 or M-Dec. Although the use of compost did not increase the total soil organic carbon significantly, the absence of compost reduced soil carbon contents from

3.67% in 2016 to 2.51% in 2018. This indicates that regular addition of compost to soil could maintain soil carbon, while without compost, soil carbon will gradually decline.

The first dry season crop introduced to the 2 ha area was dryland rice (padi gogo). Because this was the only rice crop grown in this village for the season, it suffered multiple pests and disease issues, resulting in lower than expected yields. However, farmers were still making a small profit (Table 31). The second crop in the rotation was the normal wet-season rice aimed at evaluating fertiliser use efficiency. The third season (dry season) crops of peanut, chilli, red onion and dryland rice were grown to provide farmers with options other than padi gogo. The crop selection for the subsequent seasons was based on the most profitable crop from the previous season. The cropping profitability was manipulated by various soil, fertiliser and crop management practices. For example, in the first wet-season rice crop in 2016 (crop#2), the Jarwo super technology (skip row 2:1, a new variety of Inpari32, 1.5 t/ha compost and better fertiliser management) was implemented and yield increased from 4.5 to 5.45 t/ha. This translated to an increased gross margin (GM) of about A$418/ha (based on the price of Rp.4,400 /kg). Continued improvement in soil and fertiliser management increased the yield of the rice crop in the fourth season to 6.1 t/ha, leading to a GM increase of A$430/ha (Table 25). The gradual addition of compost and better fertiliser also improved the rice crop yield. In the first cropping season, the Batutegi rice yielded 2.6 t/ha, but in the third season, this increased to 3.1 t/ha, doubling the GM from A$159/ha to A$341/ha.

The GM from growing dry season crops in the order of highest to lowest is peanut, red onion, chilli and padi gogo. Dryland rice is the least attractive option because it has the lowest GM and as long as its GM is lower than other dry season crops, the dry season rice will be at the bottom of their preference list. To grow a profitable rice crop in the dry season, the following conditions must be met: (1) it must not be grown in isolation (i.e. must be grown by all farmers in the village) to minimise risks of damage by village livestock, wild pigs and monkeys; (2) it must be supported and inputs subsidised by the government as part of the food security measure; (3) there needs to be sufficient water for the crop, and (4) yield must exceed 3 t/ha. The final decision for choice of dry season crop will depend on the available capital and ability to manage risk.

Peanut was the dry season crop with the highest gross margin of up to A$2,584/ha. The revenue from growing onion and chilli was greater than from peanut, but the costs of growing onion and chilli were much higher due to the cost of black plastic mulch, eroding the gross margin. Peanut yield responded positively to improved fertiliser management. The use of sulphur fertiliser (ZA) increased the yield of Kelinci peanut from 2.5 t/ha (third season) to 3.27 t/ha (fifth season). When KCL is also added, yield increased further to 3.44 t/ha. Yields from the local peanut variety responded similarly to ZA fertiliser and KCL fertiliser. Yield response to fertiliser application will clarify the traditional belief amongst local farmers that dry season crops do not require fertiliser.

Crop yields and gross margin from Lambaro Biluy crop rotation from 2016 to 2018 (Table 31) indicates that regardless of crop choice, dry season crops are profitable. However, the amount of gross margin obtained is determined by the crop choice and market price. The range of gross margins from growing dry season crops was from around A$159/ha for dryland rice to A$2,584/ha for peanut (based on a conversion rate of Rp.10,000 IDR to A$1). This represents a new farm income for farmers who would not traditionally earn during the dry season. For those who work off-farm during the dry season, this represents a potential income increase of up to $A2,084/ha/year.

The summary of gross margin range (Table 30) shows that growing either one or two crops per year is profitable, but growing two crops per year is more profitable. In addition, the rice crop grown is mainly used for family consumption. In contrast, the harvests from the dry season crop are sold for cash which enables farmers to fund secondary family needs. The ratio of gross margin to variable cost value is lower when farmers grow two crops per year, reflecting the higher costs, and therefore higher risks. The extra money obtained from growing two crops per year has allowed some farmers to renovate their houses and improve their living conditions.

Table 30. Comparison of gross margin that could be obtained from one crop or two crops per year.

	Gross margin (GM) range (Rp/ha)		The GM to variable cost ratio (GM/VC) range	
	Min GM	Max GM	Min	Max

1 crop/year	4,400,500	15,740,800	0.36	1.28
2 crops/year	5,992,500	37,382,933	0.26	1.13

This study is the first and only evaluation of the viability of dry season cropping in the dryland systems of Aceh. Therefore, there was limited opportunity to have multi-year replication for crop gross margins.

The participating farmers in Lambaro Biluy have indicated their commitment to continue growing peanut during the dry season after the completion of this project. Other farmers in the village have are also indicated that they will grow peanut with the participating farmers. This will extend the peanut growing area from 2 to 59 ha and involve 95 farmers (an increase of 84 farmers from 11 farmers currently involved in this project). Two of the participating farmers (Pak Sanusi and Pak Arifin) have already started saving peanut seeds and are planning to produce peanut seeds for the village. Both farmers were introduced to a peanut breeder from the Indonesian Legume and Tuber Research Centre to learn about peanut seed production.

The local market price of peanut for consumption ranged from A$1 to A$1.50 per kg and if sold as a seed, it is higher (A$2.0 per kg). For the peanut crop that generated a gross margin of $2,584, the selling price was A$1.35 per kg. If the price drops to the minimum price of A$1 per kg, the gross margin will become A$1,380 per ha, while rising the price to A$1.50 will produce a gross margin of A$3,100 per hectare. However, for a seed producer, it could result in a gross margin of A$4,820 per hectare.

Although there was no long-term opportunity to reproduce the results from this demonstration, the results provide a basis for a future long-term assessment by the local agricultural researchers about the profitability for dry season crops in Aceh. Farmer’s incomes are always prone to market price fluctuation and climate and thus they will always need to assess their risk profile. For example, Aceh was earmarked by the government of Indonesia to be the main producer of the national soybean needs. However, soybean imports lowered the soybean price to a level that it is unattractive for the farmer to grow soybean. Mungbean fetched a higher price than soybean, but the variety accessible to the local farmers requires frequent harvests, hence the high cost of production. Other dry season crops evaluated such as onion or chillies have high production costs compared to peanut. Therefore, at this stage, peanut is the first crop choice for the dry season by farmers in the Lambaro Biluy village.

The future opportunities identified from the Lambaro Biluy rotation include:

1. dry season cropping should be taken opportunistically when there is water flowing from the mountain
2. crop rotations can include wet season rice and a dry season crop that could include red onion, chilli, peanut, soybean and dryland rice. Peanut is the most profitable dry season crop
3. farmers are now able to produce and use compost on dry season crops for a long-term gain
4. refining soil and crop management practices to close the rice yield gap from the current2.9 t/ha to the target yield of 7 t/ha
5. long-term viability evaluation of dry season crops that will cover a wide range of seasonal and market price variations.

Blang Keutumba

Growing dry season crops in the dryland areas without an alternative source of water such as in Blang Keutumba is highly risky and can result in crop failure and a negative return regardless of the growing season. In the dry season of 2016, a negative return of Rp. 2,261,000/ha (approximately A$226/ha) was recorded from growing soybean. In the same year, the wet season rice is grown with compost also yielded a negative return of Rp. 2,477,000/ha (A$247/ha) (Table 32).

Yields of the first dry season crops introduced in Blang Keutumba were far below the provincial average, but there was a small profit made from maize and mungbean. Although soybean yield was marginally higher than mungbean, the soybean crop incurred an economic loss because of the lower price. The labour cost of growing mungbean is higher because it requires multiple harvests. However, the market price of mungbean was almost three times that of soybean. Based on market price, growing soybean is not recommended. Mungbean will be one of the crop choices in the following dry season with compost.

In the second season, adding 2–5 t/ha of compost to soil did not improve rice yields and the profit was eroded by the cost of compost. Growing rice without compost (farmer's standard practice) was more profitable. Amongst the new rice varieties introduced, Batutegi yielded the highest grain that is comparable to farmer's usual practice (approximately 4 t/ha) and this was higher than the average rice yield (2.5 t/ha).

The residual effect of compost from the second season (rice) and the additional 2 t/ha of compost added in the third season doubled mungbean yield (from 0.6 to ~ 1.2 t/ha) and improved the profitability of mungbean by up to 5 times (to A$110/ha). The yield of mungbean grown using farmer's practice (without compost) in the third season also increased to 0.9 t/ha, but the costs of extra fertiliser and compost eroded the profitability of mungbean by up to 27% (from A$1,101/ha to A$796/ha), which is similar to the profitability obtained with farmer's standard practice without compost (approximately A$700/ha). The soybean yield increases with and without compost could have been caused by seasonal rainfall variation. However, no rainfall data is obtainable from Bireuen regency for 2016. Total rainfall between April–July 2017 was 287 mm, less than half of the same period in 2015 (659 mm).

The organic amendment takes 9–12 months to produce an effect. Yields of maize (var Bisi 18) increased from 3.75 t/ha in the first season to ~ 6.3 t/ha in the third season as a result of the residual effect of compost applied in the second season. Without compost residue, Bisi's yield was 4.8 t/ha. Amongst three maize varieties introduced, Bisi 18 is the most profitable variety.

The profitability of growing maize during the dry season is in the range of A$289 to A$1,014/ha, which is slightly less than for mungbean (A$223–A$1,094/ha), but growing maize is easier than mungbean, because of the harvesting process. Mungbean crop does not mature all at once so it requires multiple harvests. Therefore farmers may still opt for growing maize or tending pasture crops to allow more time spent with family.

The main challenge faced by dryland farmers in Bireuen is the lack of rainfall and the absence of alternative water sources for dry season crops. The high risk of growing crops in this system and the risk of changing climate was experienced when the wet season dryland rice failed because of drought. The wet season rice was planted in November 2017. Photos of crops taken in February 2018 showed that rice grown on amended soils were greener than those without compost. However, the prolonged drought during what is traditionally the wet season failed all rice crops. The risk of drought is much higher for the dry season crop.

The main pest faced by dryland farmers in Blang Keutumba is wild pigs. The crop must be fenced off and many local farmers have no resources to do this.

Based on the experience with the demonstration site in Blang Keutumba, growing dry season crops carries higher risks of crop losses compared to growing dry season crops in Lambaro Biluy because of the lack of alternative water sources in the dry season. If farmers are prepared to take the risks, the dry season crop that gave them the highest gross margin is mungbean (Table 32).

As proposed by Lakitan and Ghofar (2013) to reduce crop failure during the dry season and to make dry season cropping attractive to smallholder farmers in Aceh, the local government need to provide access to water supplies (pumping of groundwater or rainwater harvesting) for supplementary irrigation during dry seasons. This could be facilitated by improving the government's understanding of dryland systems by effectively communicating research findings from this project.

Table 31. Crop yields over three years farm demonstration rotation in Lambaro Biluy village in the Aceh Besar district.

Year	Crop	Planted	Harvested	Crops	Variety	Tretaments	Yield (t/ha)	Selling Price (Rp/kg)	Variable cost, VC (Rp./ha)	Revenue (Rp./ha)	Gross Margin, GM (Rp./ha)	GM/VC Ratio
2016	1	20/06/2016	20/09/2016	Dry Land rice	Situbagendit	Cow manure (1.5 t/ha), recommended NPK (15:15:15): 250 kg/ha, ZA (22% N) 200 kg/ha, SP-36 (36%P205) 50 kg/ha. Skip-row planting 2:1 (10:20:40 cm) was introduced	3.50	4,800	11,320,000	16,800,000	5,480,000	0.48
					Batutegi		2.60		10,888,000	12,480,000	1,592,000	0.15
	2	5/12/2016	4/03/2017	Wet Season Rice	Inpari 32 (50%)	Three rates (50, 75 and 100%) of recommended inorganic fertiliser. The 100% rate = ZA 125 kg/ha, Urea 125 kg/ha, NPK 300 kg/ha. All treatments also received compost 1.5 t/ha; and Liquid organic fertiliser (LOF) 3L/ha as part of the Jarwo super package	4.00	4,400	12,605,500	17,600,000	4,994,500	0.40
					Inpari 32 (75%)		5.20		12,781,750	22,880,000	10,098,250	0.79
					Inpari 32 (100%)		5.45		12,540,000	23,980,000	11,440,000	0.91
					Situbagendit (50%)		3.80		12,319,500	16,720,000	4,400,500	0.36
					Situbagendit (75%)		4.10		12,297,750	18,040,000	5,742,250	0.47
					Situbagendit (100%)		4.80		12,452,000	21,120,000	8,668,000	0.70
2017	3	23/04/2017	13/09/2017	Peanut	Kelinci	Compost 2.0 t/ha + NPK 250 kg/ha + Sp-36 100 kg/ha	2.50	15,000	20,400,000	37,500,000	17,100,000	0.84
				Chili	Lado	Compost 2.0 t/ha + NPK 250 kg/ha + Sp-36 150 kg/ha + Urea 50	1.75	25,000	39,086,000	43,750,000	4,664,000	0.12
				Red Onion	Bima Brebes	Compost 2.0 t/ha + NPK 250 kg/ha + Sp-36 150 kg/ha + Urea 25	2.63	30,000	66,500,000	78,900,000	12,250,000	0.18
				Dry Land Rice	Batutegi	Compost 2.0 t/ha + NPK 250 kg/ha + Urea 100 kg/ha + ZA 100	3.10	4,700	11,157,000	14,570,000	3,413,000	0.31
	4	10/01/2018	14/04/2018	Wet Season Rice	Inpari 30	NPK 350 kg/ha + ZA 250 kg/ha + Petroganic 500 kg/ha	6.10	4,600	12,319,200	28,060,000	15,740,800	1.28
					Inpari 30	NPK 350 kg/ha + ZA 250 kg/ha	4.60		11,585,200	21,160,000	9,573,800	0.83
2018	5	1/07/2018	23/09/2018	Peanut	Kelinci	Compost 1,500 kg/ha +NPK 200 kg/ha +KCl 75 kg/ha	3.02	13,500	20,812,500	40,770,000	19,957,500	0.96
						Compost 1,500 kg/ha +NPK 200 kg/ha+ZA 100 kg/ha	3.27		20,725,000	44,145,000	23,420,000	1.13
						Compost 1,000 kg/ha +ZA 125 kg/ha+SP36 100+KCl 75 kg/ha	3.44		20,600,000	46,440,000	25,840,000	1.25
						NPK 200 kg/ha	2.48		19,950,000	33,480,000	13,530,000	0.68
					Local	Compost 1,500 kg/ha +NPK 200 kg/ha +KCl 75 kg/ha	2.16		19,812,500	29,160,000	9,347,500	0.47
						Compost 1,500 kg/ha +NPK 200 kg/ha+ZA 100 kg/ha	3.04		19,725,000	41,040,000	21,315,000	1.08
						Compost 1,000 kg/ha +ZA 125 kg/ha+SP36 100+KCl 75 kg/ha	3.22		19,600,000	43,470,000	23,870,000	1.22
						NPK 200 kg/ha	1.90		18,950,000	25,650,000	6,700,000	0.35
	6	13/12/2018	20/03/2019	Wet Season Rice	Inpago 8	Petroganic 500 kg/ha+ ZA 250 kg/ha+ NPK 350 kg/ha	4.15	8,000	11,675,200	33,200,000	21,524,800	1.84
						ZA 250 kg/ha+ NPK 350 kg/ha	3.21		11,138,200	25,680,000	14,541,800	1.31

The currency conversion rate used: 1AUD=Rp.10,000 ; The total variable cost reflects total operating costs including seed, fertiliser, machinery operations and labour cost to produce and harvest the crop), but does include any allowance for the farmers own labour (time) to manage the farm.

Table 32. Crop yields over three years farm demonstration rotation in Blang Keutumba village, in the Bireuen district

Year	Crop	Planted	Harvested	Crops	Variety	Treatments (t/ha)	Yield (t/ha)	Yield (Rp./kg)	Variable cost, VC (Rp./ha)	Gross Margin, GM (Rp./ha)	GM/VC Ratio
2016	1	18-23 Jul 2016	Sept-Oct 2016	Maize	Bisi18	Urea and NPK 300 kg/ha each	3.75	3,800	9,981,250	4,268,750	0.43
				Soybean	Anjasmoro	NPK 300 kg/ha	0.64	5,500	5,781,600	-2,261,600	-0.39
				Mungbean	Unknown		0.58	14,000	5,882,700	2,237,300	0.38
	2	Oct 2016	Mar 2017	Wet Season Rice	Inpago 8 (kompos 2 t/ha)	300 kg NPK and 200 kg Urea; with compost (2 and 5 t/ha) NPK is apply 100 % of 14 dap, urea is apply twice; 30 dap and 45 dap in line system	3.11	5,000	10,888,500	4,661,500	0.43
					Batutegi (kompos 2 t/ha)		4.22	5,000	11,277,000	9,823,000	0.87
					Inpari 41 (kompos 2 t/ha)		2.44	5,000	10,654,000	1,546,000	0.15
					Inpago 8 (kompos 5 t/ha)		2.78	5,000	13,773,000	127,000	0.01
					Batutegi (kompos 5 t/ha)		4.00	5,000	14,200,000	5,800,000	0.41
					Inpari 41 (kompos 5 t/ha)		2.22	5,000	13,577,000	-2,477,000	-0.18
					Farmer Practice *		4.20	5,000	9,270,000	11,730,000	1.27
2017	3	Apr 2017	Aug 2017	Mungbean	Unknown	NIL fertiliser	1.18	14,000	5,452,480	11,011,520	2.02
					Unknown	NPK 300 kg/ha	1.28	14,000	6,952,440	10,939,560	1.57
					Unknown	2 t/ha compost + NPK 300 kg/ha	1.24	14,000	9,416,180	7,957,820	0.85
					Unknown	Farmer's practice (NIL compst, irregular planting, broadcast fert)	0.90	14,000	5,682,000	6,918,000	1.22
				Maize	Bima 15	Compost residue 2 t/ha	5.60	3,800	13,615,000	7,665,000	0.56
					Sukmaraga		4.77	3,800	13,392,000	4,718,000	0.35
					Bisi18		6.30	3,800	13,801,000	10,139,000	0.73
					Bima 15	Compost residue 5 t/ha	6.33	3,800	16,801,000	7,139,000	0.42
					Sukmaraga		5.10	3,800	16,482,000	2,898,000	0.18
					Bisi18		5.97	3,800	16,714,000	5,972,000	0.36
					Bisi18	Farmer practice (NIL compst, irregular , broadcast fert)	4.80	3,800	10,452,000	7,788,000	0.75
2018	4	1/11/2017	1/03/2018	Wet Season Rice	Inpago8	Compost 2 t/ha	FAILED	Prolonged drought from Jan to Apr 2018. At 45 DAP, crop grown in the amended plot were greener than those in the NIL organic matter plot. This indicated that OM can help prolonged the surviveal of crops during drought			
					Inpago9		FAILED				
					Inpago10		FAILED				
					Inpago8	Farmers parctice and NIL compost	FAILED				
					Inpago9		FAILED				
					Inpago10		FAILED				
	5	1/04/2018	1/08/2018	Mungbean	Unknown	NIL fertiliser	1.17	14,000	5,446,600	10,933,400	2.01
					Unknown	NPK 300 kg/ha	1.26	14,000	6,929,900	10,640,100	1.54
					Unknown	2 t/ha compost + NPK 300 kg/ha	1.27	14,000	9,444,600	8,335,400	0.88
					Unknown	Farmer's practice (NIL compst, irregular planting, broadcast fert)	1.02	14,000	5,799,600	8,480,400	1.46
				Maize	Bisi 18	Compost 2 t/ha	6.25	3,800	13,618,750	6,407,250	0.47
						Compost 5 t/ha	6.78	3,800	16,784,125	6,965,875	0.42
						Farmer's practice (NIL compost, irregular , broadcast fert)	5.27	3,800	11,310,050	14,434,950	1.28
2018	6	Oct 2018	Mar 2019	Wet Season Rice	Inpago 8	NIL fertiliser	Report is not received				
						NPK 300 kg/ha					
						2 t/ha compost + NPK 300 kg/ha					
						Farmer's practice (NIL compst, irregular planting, broadcast fert)					
					Batutegi	2 t/ha compost + NPK 300 kg/ha + 200 kg/ha urea					

The currency conversion rate used: 1AUD ~ Rp.10,000 The total variable cost reflects total operating costs including seed, fertiliser, machinery operations and labour cost to produce and harvest the crop), but does include any allowance for the farmers own labour (time) to manage the farm.

7.2.3 Activity 2.3: Research in Australia – Deliverable report D19-D25 (Appendix 4)

*Tamworth experiment 1 – A long-term evaluation of nitrogen fertiliser use efficiency and yield of a tropical pasture (*Digitaria eriantha *cv. Premier) in soil amended with poultry litter biochar*

1. The poultry litter biochar (PLB) increased nitrogen and phosphorus uptake of digit grass by up to 19% and 30%, respectively, resulting in a 19% increase in herbage mass; adding biochar on its own did not affect yield.

2. PLB increased the nitrogen availability from fertiliser and the use efficiency of the nitrogen fertiliser.

The herbage mass (HM) yield of the digit grass increased with higher N rates and fluctuated with seasonal rainfall (Figure 13) as expected. When the soil was amended with 10t/ha of poultry litter biochar and nitrogen fertiliser, 500–1,230 kg DM/ha was produced. While biochar improved yields within the first five seasons, it was not always significant and the extent of this improvement decreased over time. The yield improvement achieved for the biochar with 50 kg N/ha treatment decreased from 19%, 10% and 8%, respectively for the first, second and fourth seasons. Similarly, for the 100 kg N/ha amended with biochar treatment, the relative increase in HM was 7.7%, 11% and 6.6% for the second, third and fifth seasons, respectively.

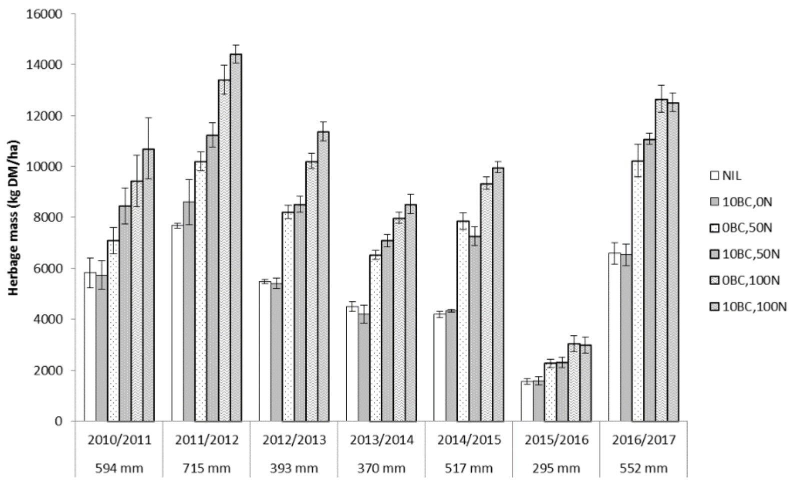


Figure 13. Mean annual herbage mass from 2011 to 2017. The cumulative rainfall during each growing season is indicated on the X-axis.

There was a general trend of increased N uptake of up to 20% in biochar-amended plots during the first four seasons, and for the 100 kg N rates, this increase was significant during the third and fourth seasons. For a given N rate, the agronomic efficiency of applied nitrogen was higher in the biochar treatment for most seasons (Table 33). The increased N uptake by pasture in soil amended with the poultry litter biochar could be due to the increased N availability (Chan et al. 2008).

Table 33. The mean increase of DM/kg of N applied (Agronomic N use efficiency). The value inside the brackets indicates the standard error of the mean.

kg/ha N	t/ha Biochar	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17
50	0	25 (5)	51 (6)	55 (4)	41 (3)	73 (8)	14 (4)	73 (19)
	10	54 (14)	53 (9)	62 (10)	58 (4)	59 (7)	14 (5)	91 (7)
100	0	36 (11)	57 (5)	47 (3)	35 42)	52 (3)	15 (3)	61 (7)
	10	50 (9)	58 (6)	60(5)	43 (7)	56 (2))	14	60 (3)

In the first season, biochar increased the AEN by 115% in the 50 kg N treatment. From the second season onwards, the increase of AEN due to biochar reduced to a maximum of 42%. While Slavich et al. (2013) reported an increased AEN in soil amended with biochar for a single season, we found that the poultry litter biochar used in this study has a potential to increase AEN over multiple seasons.

The cumulative nitrate leached out from the pot study (Figure 14) showed that biochar (5t/ha) increased available nitrogen and that at a higher rate of 10 t/ha, could lessen the effect. The increased available N with biochar is consistent with the increased N uptake and N use efficiency found in the field pasture experiment (Table 33).

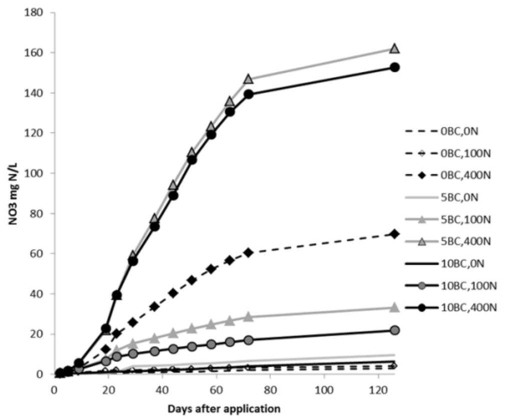


Figure 15. Higher cumulative nitrate concentration in the leachate collected from biochar-amended soils over time indicates the higher available N.

The poultry litter biochar improved P uptake, regardless of N rate or season (

Figure 16), and P and N uptake were correlated (Figure 17). The increased P uptake in the presence of biochar was most likely due to the higher availability of P in the poultry litter biochar. However, the magnitude of this increase is affected by both N fertiliser rate and N uptake and is consistent with that reported in a Ferralsol (Slavich et al. 2013). The strong linear correlation between N and P uptake (Figure 17) supported this. Biochar increased the P uptake by 5–22% under the zero and 50 kg N treatments; while under the 100 kg N treatment, it was up to 30%.

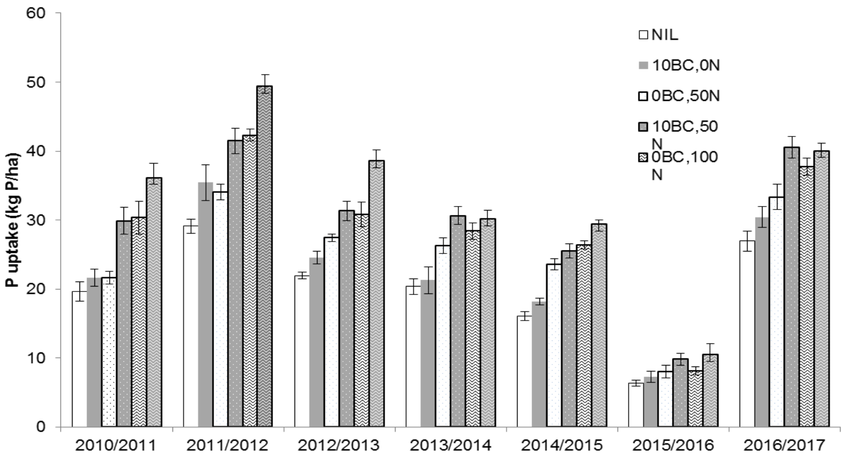


Figure 16. Mean phosphorus uptake of each treatment over time.

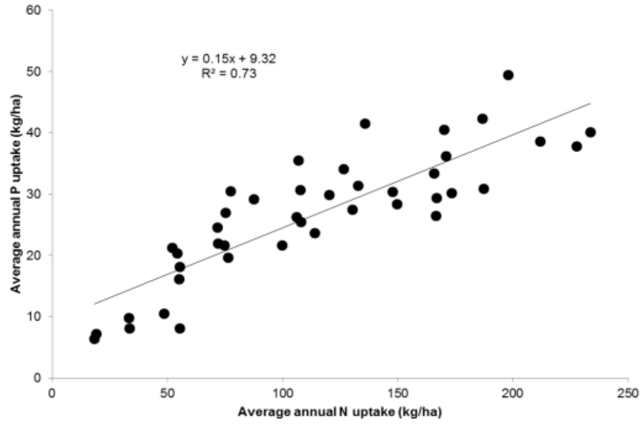


Figure 17. The linear correlation between nitrogen uptake and phosphorus uptake.

Tamworth experiment 2 – A long-term effect of poultry litter biochar on soil fertility when biochar is applied individually or in a mixture with either cow manure or maize stubble

1. Soil amended with poultry biochar elevated soil carbon and nitrogen for at least six years.

2. The biochar showed the potential to increase the longevity of soil nitrogen and carbon from other organic materials such as manure and stubble when applied together.

The calculated C content of the mixtures was consistent with the measured values in each mixture and the linear scatter between the measured and calculated C content was close to 1:1 (i.e: calculated C values = 0.97 measured C values, R^2 = 0.98).

Total nitrogen, total carbon, available P and soil pH of the unamended soil (Figure 18, C open circle) were the lowest at all sampling times as expected. All amendments increased these soil parameters (Figure 18). Adding cow manure (M, open triangle) increased soil nitrogen content to ~ 0.21% ($P < 0.001$), whereas adding maize stubble (S, open square) increased it only to ~ 0.14% ($P < 0.05$). However, within 12 months, the total soil nitrogen in the cow manure (M) treatment dropped significantly to ~ 0.14% and it remained between 0.14–0.17% for the 72 months. Adding biochar to the mixtures (M+ and S+ treatments) increased soil nitrogen more than adding M and S only. The elevation of nitrogen to > 0.2% due to biochar was maintained for up to 72 months, indicating the persistence of the nitrogen contained in biochar mixtures.

The addition of carbon-rich materials to the soil doubled the total soil carbon content initially but this decreased over time (Figure 18 top right). Initially, the total carbon in the M and S mixtures was ~ 3.6% compared to 3.1% in C+ mixture, but the total carbon content in the M and S mixtures significantly decreased to ~ 2.2% within six months and fell to below 2% within 24 months. In all biochar mixtures (C+, M+ and S+), the elevated soil carbon content also decreased sharply from ~ 5 to 3% within the first six months but remained above 2.9% for the 72 months, indicating the persistence of carbon contained in the biochar. The majority of carbon loss occurred within the first six months followed by a more gradual loss from 24 months onwards. It is likely that the presence of soil organic matter stimulated the co-mineralisation of the more labile carbon components of biochar within the first six months of the burial.

The cumulative nitrogen loss (Figure 19, left) was highest in the M treatment with the total loss of ~ 0.06% (a drop from 0.21 to 0.15%) over the 72 months. The inclusion of biochar (M+) almost halved the total nitrogen loss over the same period, indicating a degree of preservation of the manure by the biochar as suggested by Ngo et al. (2013). The loss of nitrogen in the S treatment was insignificant because of its low nitrogen content, and there was a slight gain in total N, but adding biochar to stubble (S+) seemed to enhance this nitrogen gain. In the absence of other organic materials, total nitrogen loss with or without biochar was negligible (~ 0.01%) indicating that the nitrogen contained in the biochar is stable against degradation.

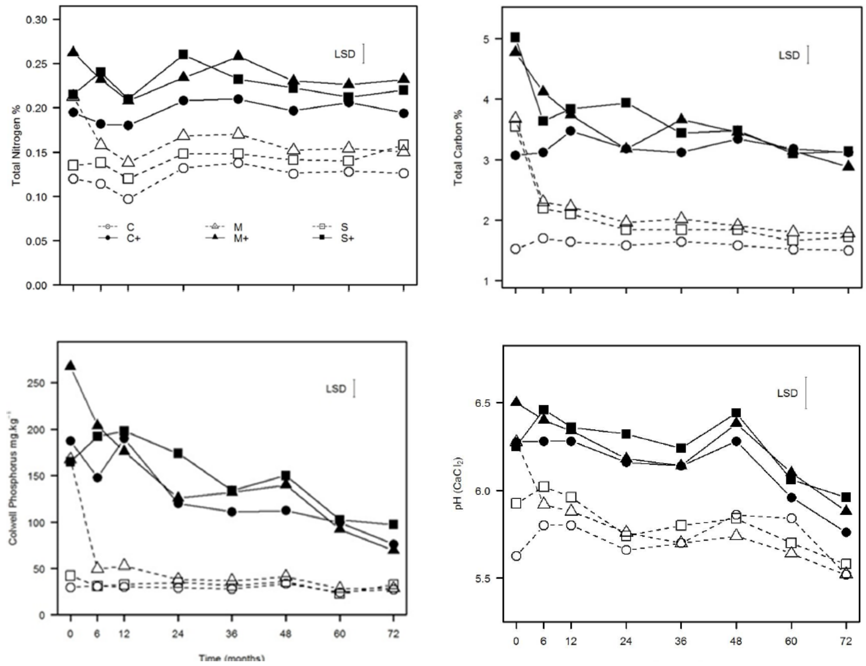


Figure 18. Biochar increased soil nitrogen, total carbon, available phosphorus and soil pH for at least 72 months.

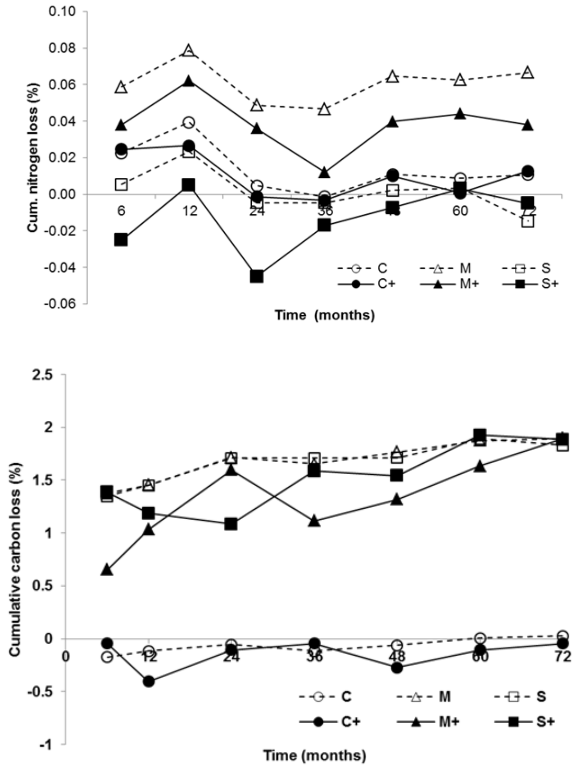


Figure 19. The cumulative loss of nitrogen (left) and cumulative carbon lost (right) over time.

Total carbon loss from the stubble treatments (S and S+) was similar (~ 1.9%) after six years. In the first 24 months, the loss was lower in S+ compared to S, but from 36 months onwards carbon loss was similar between the two (Figure 19, right). In the manure treatments (M and M+), total carbon loss was also ~ 1.9% (19 mg/g) after six years. However, the loss during the first 60 months was 0.12–0.72% less in the M+ compared to the M, indicating a degree of protection of manure by biochar in M+, as found by Ngo et al. (2013) and Zimmerman et al. (2011). Our study indicated that this protection lasted for 24 months when biochar was mixed with maize stubble (extremely high C:N ratio), and 60 months when biochar was mixed with cow manure (medium C:N ratio). We did not find any evidence of biochar accelerating carbon loss as suggested by Wardle et al. (2008).

Breeza, NSW Australia: Soil water, water productivity and soil carbon dynamics under undisturbed grassland, cropping and agroforestry on a Black Vertosol in the Liverpool Plains of NSW

Key points:

1. The below-average annual rainfall during the period of study justified the assumption that all water lost from soil profiles equalled evapotranspiration. Therefore, runoff and deep drainage were assumed negligible in the calculation of soil water balance.

2. The annual water use of trees over the six years was comparable to those under grassland and was below the water use of wheat crops sown in 2014.

3. Depending on the season, the transpiration efficiency (biomass yield/mm) for the crop was 10–28 kg DM/mm, for grassland 1–23 kg DM/mm and for trees was 29–58 kg DM/mm water. The grain crop WUE was 3–22 kg grain/mm.

4. The fallow efficiency of the Black Vertosol at Breeza was between 20 and 23%, but in severe drought (2018) it was as low as 0.3%.

5. Physical roots were observed down to about 180 cm under crops, 250 cm under undisturbed grassland and > 580 cm under trees. However, the estimate of maximum active root depth (from water extraction) was in the range of 160–180 for crops, and 80–100 cm under both trees and grassland. For grassland, this was consistent with the location of peak chloride concentration in the soil profile.

6. The peak of chloride concentration under grassland at 80–100 cm deep compared to 500–600 cm under cropping, suggests that the conversion of perennial vegetation/native grassland to annual cropping induced deep drainage. The slow accumulation of chloride at 80–100 cm under the planted trees indicates reduced leaching.

7. Cropping activities reduced soil C by around 1% over five years. Over the same period, the undisturbed grassland accumulated soil C by 25% while trees accumulated 7%. Therefore, maintaining perennial vegetation in cropping system could offset the loss of soil carbon due to cropping.

8. The calibration equations for EM38 to measure soil water storage are now available for the Black Vertosol at Breeza to be used for future research on this site.

Rainfall

The annual rainfall during the study was consistently below the long term AAR of 111 years (Figure 20) and was lower than the atmospheric demands (Figure 21). Therefore it is reasonable to assume zero runoff and deep drainage, and that water loss from the soil profile is due to the crop evapotranspiration.

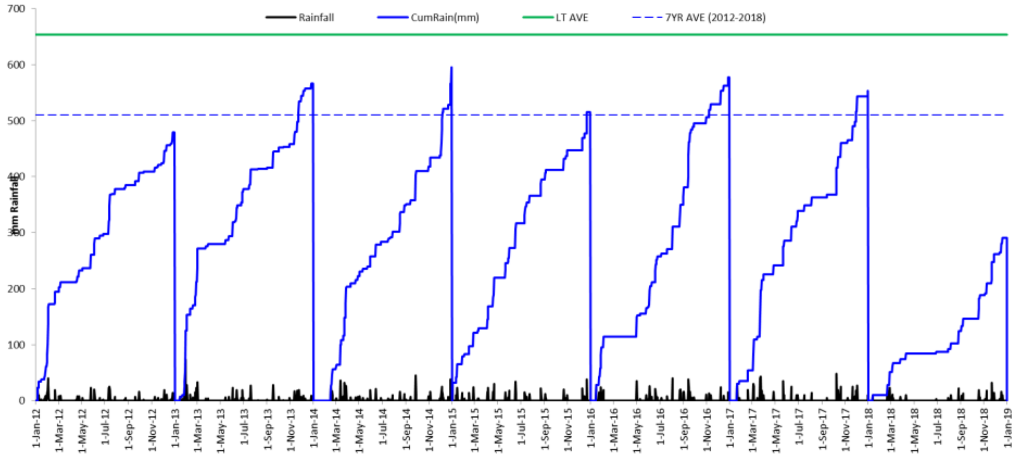


Figure 20. Daily and cumulative annual rainfall for the Liverpool Plain Research Station from 2012–2018.

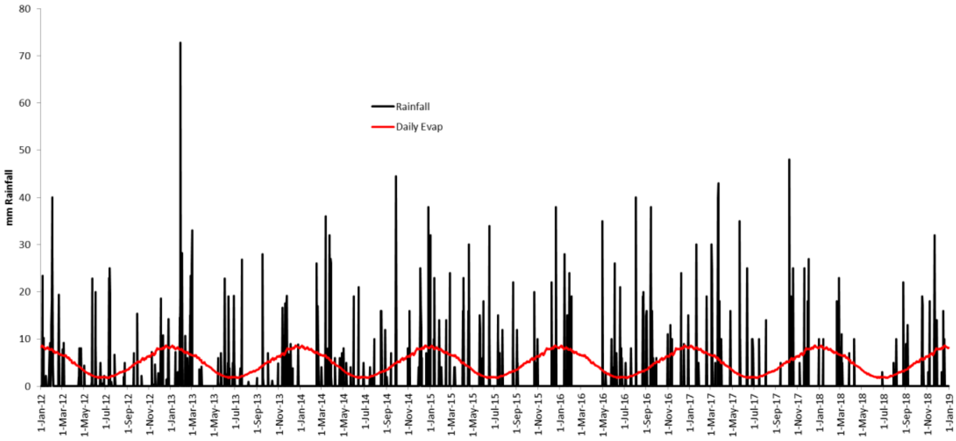


Figure 21. Daily rainfall from 1 January 2012 to 31 December 2018 at Breeza and 111 year average of daily evaporation (red line).

Soil water, water use and water use efficiency

The changes in soil water storage were more distinctive in the 0–180 cm depth zone under cropping, in the 0–80 cm zone under grassland and the 0–60 cm zone under the tree system (Figure 22), which indicates the different active rooting zone for each land use. The fluctuations of water storage under cropping were more pronounced compared to those under grassland or trees and coincided with crop development/season and rainfall. Water storage was highest before, or at the time of sowing, and after significant rain and lowest at around harvest time.

When the soil was cored in 2012, tree roots were found to a depth of > 500 cm. Under the grassland, roots were observed to a depth of 250–300 cm and under crop to 160–180 cm deep. However, soil moisture extraction (Figure 23) indicated that the roots of trees and undisturbed grassland used water mostly from the surface zone. Trees and grassland use water throughout the year. Therefore the soil profile was never fully recharged or emptied. In contrast, stored soil water is used by annual crops during growing and refilled during fallow periods.

Given the lower ground cover under cropping compared to grassland and trees, the majority of water loss from cropping is likely to be through surface soil evaporation; a component that has not been measured separately in this study. Evaporative loss from trees and grassland could be assumed negligible because the ground cover was close to 100% under both systems and covered with thick litters.

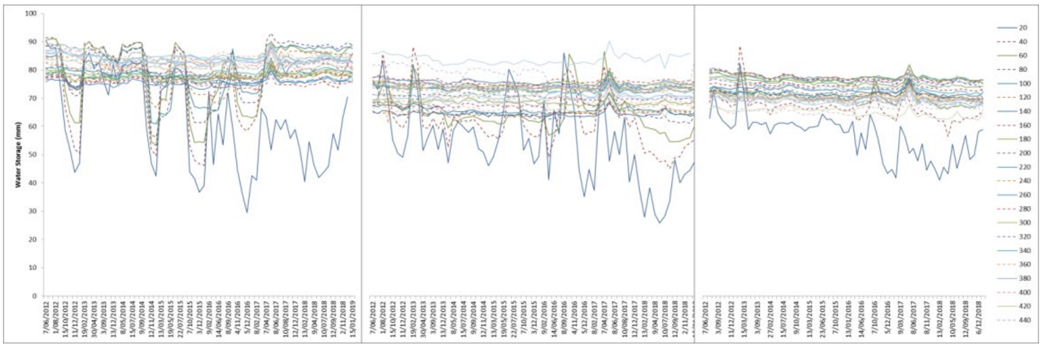


Figure 22. The dynamics of soil water storage (mm) at different depth zone under cropping (left), undisturbed grassland (middle) and trees (right).

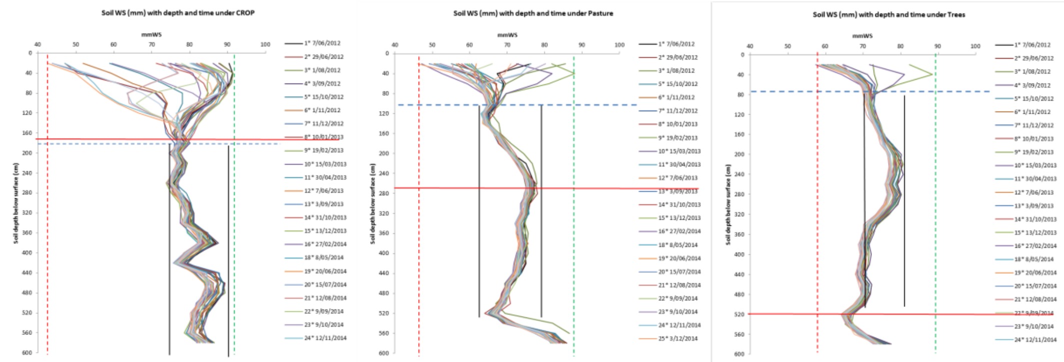


Figure 23. The active rooting depth (dotted horizontal blue line) is similar to the observed rooting depth (solid horizontal red line) under cropping (left) but is shallower under grassland (middle) and trees (right).

Cumulative annual evapotranspiration under this system is a function of annual rainfall in a non-linear fashion (Figure 24). The higher the annual rainfall, the higher the evapotranspiration indicating a higher proportion of rainfall reached soil profile with more rain. Evapotranspiration was highest during spring and summer and lowest in winter (Figure 25). The seasonal water use by trees was occasionally lower than by crops, but during the six years, the cumulative evapotranspiration from trees and grassland were 3,196 and 3,184 mm respectively, which was slightly higher than cropping (3,026 mm). The cumulative rainfall over the same period was 3,097 mm.

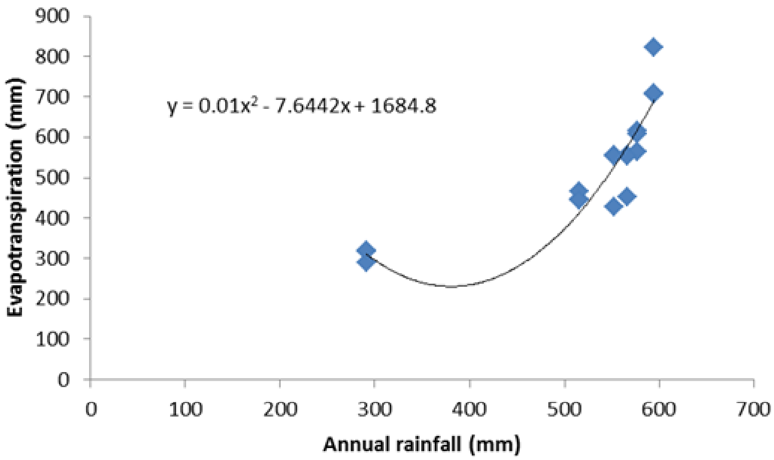


Figure 24. Evapotranspiration is a non-linear function of rainfall.

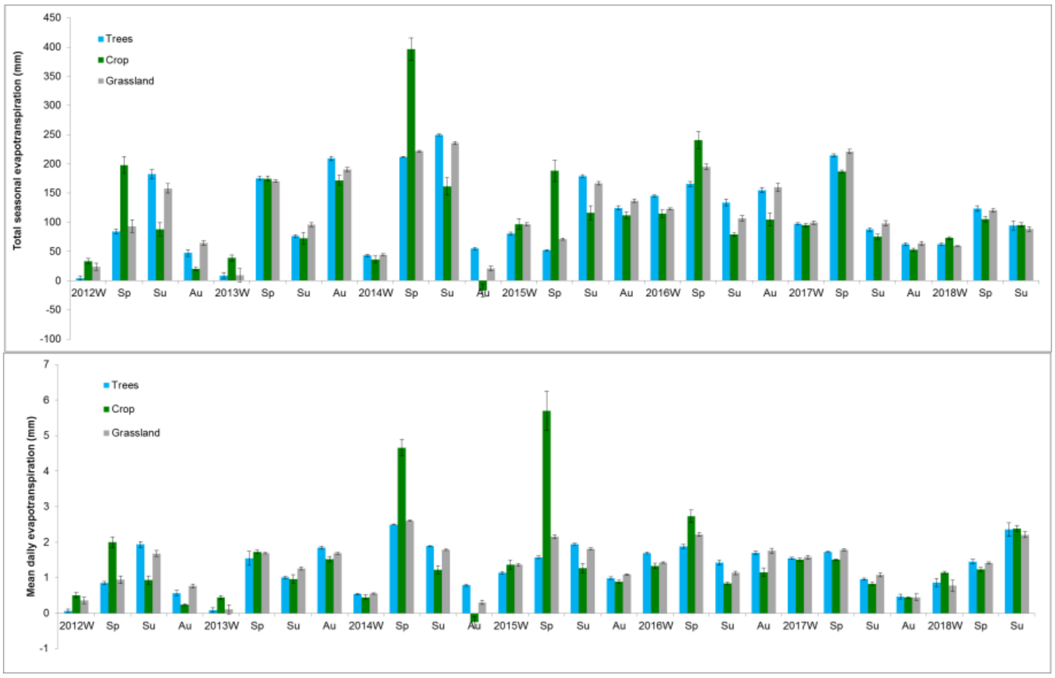


Figure 25. Mean seasonal (top) and daily (bottom) evapotranspiration of crop, grassland and trees.

The annual above-ground biomass yield was between 17 and 32 t/ha for trees (based on a conservative estimate of 50% survival rates) compared to 0.4–13.0 t/ha for grassland and 5.0–22.4 t/ha for cropping (Table 34). The annual water use of trees and grassland (perennials) was similar and resulted in WUE being higher for trees compared to grassland. There is a high possibility that the trees might have been accessing water from below 6 m depth, which is not captured by the neutron moisture meter. There was no sap flow measurement of tree water use in this study to confirm or quantify this. The WUE of wheat (27.7 kg/mm) is higher than the faba bean (10.1 kg/mm) (Table 34).

Table 34. Mean estimates of annual biomass yield (DM t/ha), water use and (WU) water use efficiency (WUE) of undisturbed grassland, planted agroforestry and annual cropping from 2013 to 2018. Also included are WEUgy (WUE of grain), TEbm (transpiration efficiency of biomass), stored rain (SR), and the estimate of Fallow Efficiency (FE) for cropping system. Values inside brackets are the standard error of the mean.

	2013	2014	2015	2016	2017	2018
Annual Rain (mm)	566.34	595.0	515.0	577.0	553.0	291.0
Undisturbed grassland						
DMbm(t/ha)	5.3(0.6)	8.6(0.7)	10.3(0.9)	8.1(0.6)	13.0(1.0)	0.4 (0.05)
WU (mm)	553.3(12.2)	709.0(2.9)	443.1(3.1)	607.1(2.8)	561.2(3.8)	320.1(3.2)
WUE(kg HM/mm)	9.6(1.2)	12.1(1.0)	23.2(2.0)	13.4(1.0)	23.4(1.9)	1.3(0.1)
Planted trees						
DMbm(t/ha)	32.0(6.1)	20.6(6.0)	20.0(7.5)	26.4(7.7)	17.0(7.9)	17.0(7.9)
WU	554.9(4.5)	705.3(4.9)	445.9(2.3)	616.7(4.0)	556.6(3.0)	316.2(2.8)
WUE (kg DM/mm)	57.6(11.0)	29.3(8.7)	44.7(16.7)	42.8(37.1)	30.5(14.2)	54.7(25.2)
Crop						
Crop type	Fallow	Wheat	Faba	Wheat	Fallow	Fallow
Grain (t/ha)	-	6.7 (0.63)	1.5	6.3 (0.4)	-	-
DMbm (t/ha)	-	22.4	5.0	15.7	-	-
WU (mm)	451.4(14.7)	823.9(15.7)	466.9(11.8)	565.2(20.2)	428.9(6.7)	289.9(7.1)
WUEgy (kg grain/mm)	-	8.8	3.2	11.1	-	-
TEbm (kg biomass/mm)	-	27.2	10.7	27.7	-	-
Stored rain(mm)	114.9	NA	NA	NA	124.1	1.0
Fallow Efficiency(%)	20.3	NA	NA	NA	22.4	0.3

Historical deep drainage

One of the objectives at the BFS study was to evaluate the interaction between water from agriculture (deep drainage) and groundwater recharge. However, the below-average rainfall (Figure 20) meant that there was no deep drainage during this study.

However, the historic deep drainage can be inferred from the change of chloride peak in the soil profile (

Figure 26) with the change of land use. Chloride accession from rainfall and dust in this region is around 30 kg/year (Young and McLeod, unpublished). Chloride is soluble but is not taken up by the plant as it moves with water, and its distribution in the soil profile can be used as an indicator of deep drainage. In this study, it is the conversion from grassland to cropping and from cropping to trees. In 2012 the peak of chloride concentration under the grassland occurred at around 100 cm depth under grassland and remained at the same level (300–400 mg/kg) down to 400 cm depth.

In contrast, under cropped soil, the bulge was deeper (580 cm depth). The shift in the chloride concentration peak indicated historical leaching under cropping over the 72 years. The shallower depth of the chloride bulge under the grassland is consistent with more stable water storage in the profile (Figure 22), attributed to the perennial nature of the grassland. In 2012, the chloride distribution in the soil profile under the planted trees was more similar to that of cropping as trees were planted into a cropping paddock and were only ten years old.

In 2017 the chloride bulge under cropping remained at 500 cm with a higher concentration indicating more accumulation, but unaccompanied by chloride reduction in the 0–200 cm zone. This indicated that the increased chloride concentration at 400–500 cm might have originated from leaching of the residual water from below the 200 cm zone (leaching from below crop rooting zone). Although the annual rainfall was not significant to cause significant drainage, the fallow periods might have contributed to some leaching, which is consistent with nitrate leaching observed during the same period (

Figure 26 right). Under the grassland, the chloride peak remained at around 100 cm. Under the trees, the bulge remained at ~ 60 cm depth. There was a slight accumulation from about 80 mg/kg to about 100 mg/kg, indicating that the hydrologic balance can be restored by replanting trees.

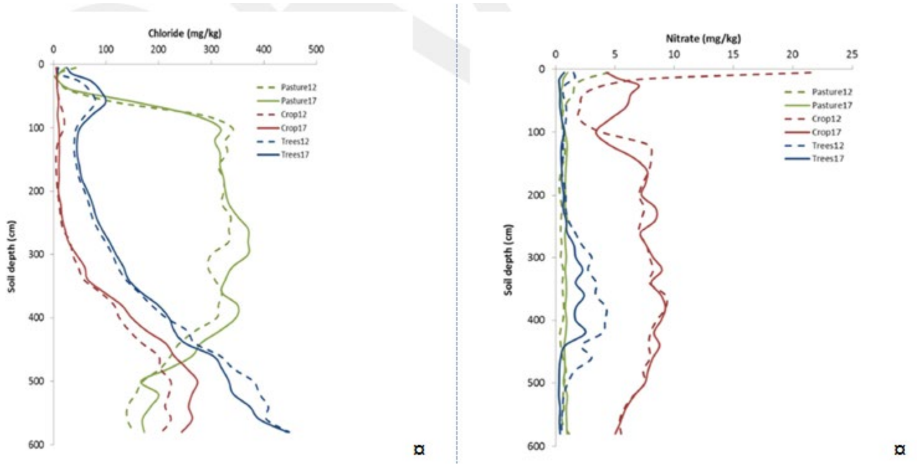
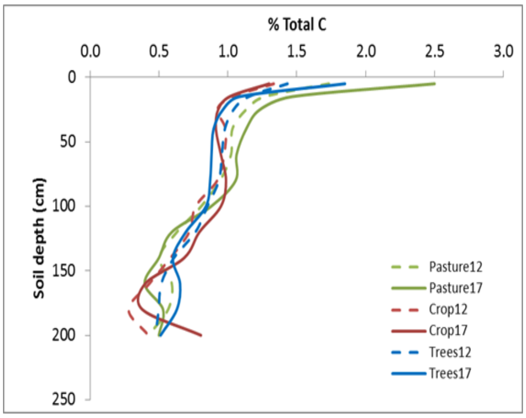


Figure 26. Changes in soil chloride and nitrate contents with depth from 2012 to 2017 under cropping, grassland and planted trees.

Soil carbon and nitrogen under different land uses

Grassland accumulated a higher level of soil carbon in the 0–30 cm root zone compared to trees while cropping reduced soil carbon (Figure 27, Table 35). The carbon accumulation or loss under all land uses is greatest at the 0–10 cm depth.



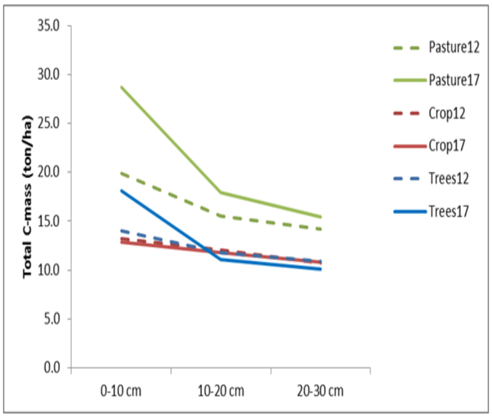


Figure 27. Changes in total soil carbon contents to 200 cm depth (left) and total carbon mass in 0-30 cm depth (right) from 2012 to 2017 under cropping, grassland and planted trees.

The changes in soil carbon content and storage are consistent with changes in nitrogen content (Figure 28), emphasising the close link between soil carbon and soil fertility. Despite regular fertilisation of the cropping paddock, the soil N level is not maintained or increased due to crop uptake or loss as nitrate (

Figure 26, right).

Table 35. Total soil carbon mass in 2012 and 2017 under trees, crop and grassland.

	2012	2017	% Change (5 yrs)
Trees	36.7	39.3	7.0
Crop	36.0	35.5	-1.0
Grassland	49.6	62.1	25.0

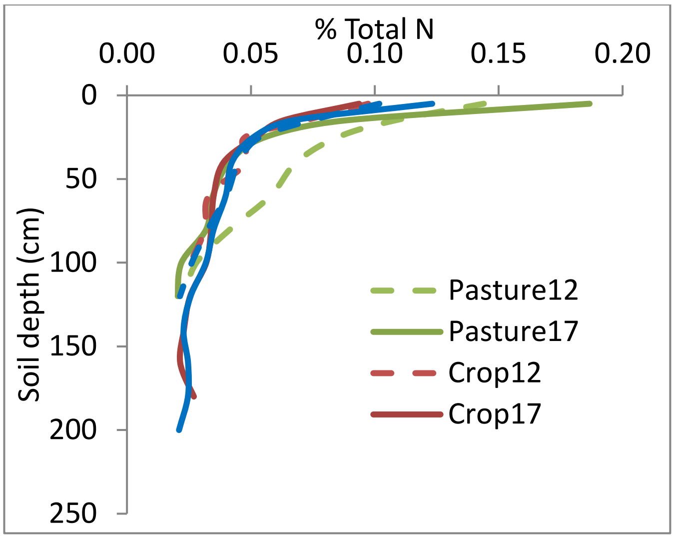


Figure 28. Total soil nitrogen content with soil depth in 2012 and 2017.

EM38 calibration to measure soil water

The EM38 are instruments designed to measure the apparent hydraulic conductivity of the soil. Because the EM38 is also sensitive to changes in soil water content, it is also used to monitor soil water, with an assumption that there is no rapid change in soil salinity level during the monitoring period. To use the EM38 to measure soil water, a site/soil specific calibration is required before use. The calibration equations for the EM38 to measure soil water at various soil depths was established (Figure 29) and is now available for future research in the Black Vertosol of the Liverpool Plains, Australia. Aceh project team members were trained to use EM38 for future dryland system research.

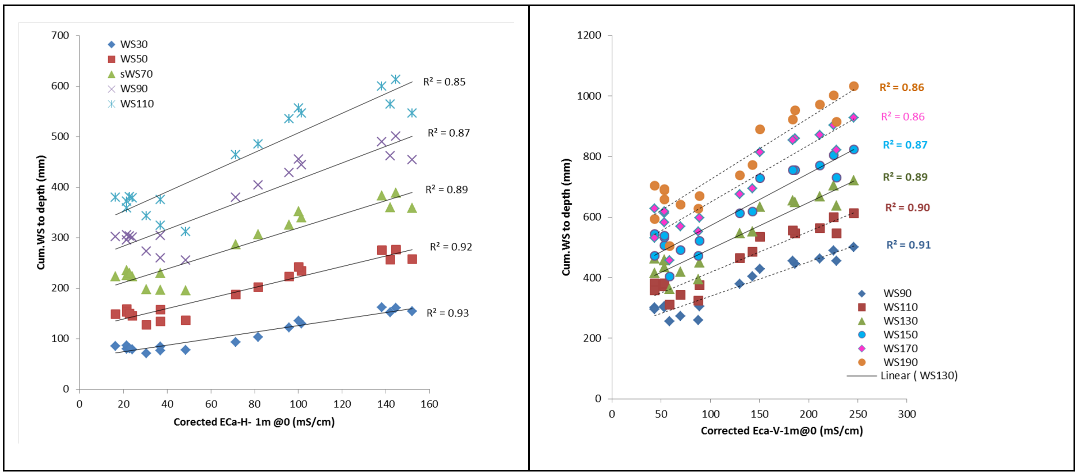


Figure 29. The calibration of EM38 for soil water measurement for the Black Vertosol of the Liverpool Plains NSW, Australia.

7.3 Activities 3.1 – 3.4: Strategies to enhance farmer social learning networks and increase food availability and diversity in Aceh

7.3.1 Activity 3.1: Training for over 40 field extension officers (PPL) – Deliverable reports D26-D30 (Appendix 5)

Forty-four local extension officers (PPL) participated in 2 stages of in-class training: (1) technical training on soil and agronomic management in dryland system and, (2) administration skill in preparing and reporting soil and crop demonstration. There were 27 PPL that were supporting women farmers, 2 PPL that were supporting food crop farmers, and 15 other PPL that were expected to do small demonstration activities.

The soil training covers: (1) basic soil functions to support crop and the associated physical and chemical properties that are closely associated with each function; (2) soil amelioration using organic amendment, biochar or rhizobium for legume crops; (3) integrated pest management for dryland and (4) the soil test kit for dryland.

The training on planning, conducting and reporting of demonstration activity was conducted to prepare the participants to apply the new knowledge to conduct small field demonstration (Activities 3.2 and 3.3.4).

7.3.2 Supporting adoption through PPL demonstration activities (Activity 3.2)

There were 15 PPL trained (in Activity 3.1) that were not involved in KWT. They were required to plan and conduct 12 small field demonstrations to apply the new knowledge acquired from the training, funded by the project. To obtain the funding, PPL need to submit a proposal to BPTP Aceh according to a set guideline. However, citing their commitment to a national program, the PPL found that the task challenging and no successful applicant was identified until 2018.

All the KWT PPL were also required to conduct small demonstration activities with their KWT groups after the training. Most of them did, but they did not record or write a report, citing lack of time as the main reason. Most of the reports collected by BPTP Aceh were verbal and qualitative observation reported by phone or text messages via WhatsApp.

The apparent lack of record-keeping and reporting culture necessitated the second training on proposal and report training, which was conducted by BPTP Aceh. Eight demonstration proposals were submitted following the training, but only four were relevant and eligible for funding and of these only two were reported. Although most PPL are passionate about supporting farmers and could do so through their field demonstration activities, the lack of writing skills is a major barrier to R&D in Aceh and this problem is widespread at all levels.

The summary from the two reports submitted (Appendix 6 D32) are: (1) the use of organic and inorganic fertiliser on peanut yield in Selawah Valley, Aceh Besar demonstrating that fertiliser improved peanut yield by 100 kg/ha (Table 36); (2) the use of organic and inorganic fertiliser on maize yield in Leubu Mee, Bireuen, resulting in an inconclusive role of organic fertiliser on maize yield.

Table 36. The effect of organic and organic fertiliser on yield of peanut in an unreplicated demonstration.

Treatment (fertiliser rates are equivalent weight/ha)	**Yield (t/ha)**
A = 2 t compost + 100 kg Urea + 250 kg SP36 + 150 kg KCL	1.5
B =50 kg NPK Phonska + 300 kg Dolomite	1.4
C =2 t compost+50 kg Urea+100 kgTSP+100 kg KCL+50 kg lime	1.5
D = 50 kg NPK + 300 kg Dolomite + 50 kg lime	1.4

7.3.3 Activities 3.3: 1, 2, 3 and 4: Improving the livelihood of smallholder farmers by building the capacity of rural women in Aceh – Deliverable reports D32-D37 (Appendix 6)

Key findings:

1. The participation of women farmer groups in the ACIAR projects was effective in building the capacity of women farmers across the study areas.

2. Women farmers could earn between A$402 and A$2,000 per year per person from growing vegetables in groups while learning new skills in soil and crop management, networking and communication, small business management and postharvest processing.

3. The benefits of being part of the group extended to improved social life, health and wellbeing of members while maintaining food security for their families.

Survey of impacts of KWT from the previous project

A survey of the impacts on women farmer groups (KWT) from the previous lowland project was conducted to guide the development of KWT groups in this project by identifying factors that encouraged the development of a group, enhanced or inhibited KWT development and activities, and factors contributing to the continuity of the group.
The report of this survey (attached in Appendix 6 D34) showed that factors affecting the decision to form or join a group include:

1. A shared desire of a number of women farmers to work together
2. The availability of PPL to guide the group
3. Motivation arising from observing the success of other KWT groups
4. The availability of land, start-up cash to purchase inputs and to cultivate the land
5. A desire to meet own family vegetable consumption needs
6. A desire to add to the family income.

Factors that are affecting the success and the continuity of a group include:

1. If the activity has become a source of income (beyond meeting family needs for vegetable)
2. Proximity to /availability of market
3. Highly motivated and creative PPL/group leader
4. Support from the local business leader
5. Support from local government (available land with some length of tenure, or equipment).

Factors that have led to group inactivity include loss of available land, extreme weather (flood or drought), difficulties with pest and disease, and loss of supporting PPL.

This survey also confirmed that income is a lesser motivation for the women farmers to join or form a KWT group compared to the social interaction, learning and skill development opportunities.

Supporting women farmer groups (KWT)

The project supported 725 women farmers in 32 groups (KWT) across Aceh Barat, Aceh Besar, Pidie and Bireuen districts (Table 37), consisted of 2 KWT demonstration sites and 30 ordinary KWT. The two KWT in the Pidie district were not as active as those in other districts and eventually fell out of the project. The two KWT demonstration sites are located in Aceh Besar and Bireuen districts (Figure 4). The original plan was to form 30 new KWT and 2 KWT demonstrations. However, in the period between the planning and initiation of this project, the government of Indonesia rolled out a national backyard food production program (KRPL), using a similar model to KWT. The funding per group for the KRPL program was 7–10 times the funding budgeted in this project, and this became a barrier to attract members to form new KWT. Therefore this project adapted by working with existing groups that missed out on the KRPL funding and were mostly dormant. Nine new KWT groups were established for this project (Table 37).

Most KWT groups in the current project used communal group activities on vacant village land. This group garden system was used as a learning site with a purpose to develop skills and confidence to grow vegetables and transfer the skills gained to growing vegetables in their own backyard. The group also provided them with the confidence in selling the produce from their own backyard as group products. The size of the group and individual gardens varied between 50 and 1,000 m^2.

Most KWT members were able to supply vegetables for their families and also produced extra income. Members typically consume a portion of the vegetables produced and sold the excess. The produce from individual member's gardens contributed to the volume of produce grown by each group and sold through the collective marketing pool. Most groups aimed to produce additional family income. In the process, the women also learned about financial management, networking and marketing.

The characteristics of the 32 groups were highly variable, but some common changes observed before and after involvement in the ACIAR project are summarised in Table 38

KWT activities in the two demonstration sites in Aceh Besar and Bireuen suggested that most activities were focussed on producing and using organic fertiliser and plant-based pesticides from local materials (Table 39). The vegetable types grown were similar between sites and groups across the four districts, being mainly bayam (local spinach from *Amaranthaceae* family), kangkung (*Ipomoea aquatic*a), sawi (choy sum, *Brassica chinensis*), eggplants, tomatoes, chilli, red onion and in some groups lettuce or cucumber. These vegetables are commonly used in Aceh and can easily be sold. One group in Aceh Besar (Kembang Tani) focussed on growing celery in addition to choy sum. The groups indicated that the high-value crops are difficult to sell unless they are near a large city centre such as Banda Aceh.

The groups experimented with a range of plant materials to produce organic fertilisers or pesticides, such as banana stem, bamboo stem or other agriculture wastes. All groups made compost from animal manure mixed with other organic waste such as rice husks, kitchen organic waste or the other plant materials. The PPL trained them to use decomposers obtained from local suppliers to speed up the composting process. The compost generally matured within about one week. They also trained them to make liquid organic fertiliser or bokashi and organic pesticide from local plant materials such as neem leaves.

Table 37. Name and details of KWT groups supported in this project

District	No	Supporting PPL	KWT name	Location	Members	Leader	Formed	Notes
Aceh Besar	1	Khaidir, SP	Hidup Maju	Beurandeh, Mesjid Raya	35	Jamaliah Jalda	Jan 2016	New **
	2	Zulaiha Hanum	Bungong Jeumpa	Lamtrieng, Kuta Baro	15	Nursiah	2010	
	3	Dessy Novianti	Teratai Meuguna	Ruyung, Mesjid Raya	30	Maulidar	2013	**
	4	Irmawati, A. Md	Evorbia	Lambada Peukan, Darussalam	15	Fitriawati	2014	**
	5	Inda Wahyuni. SP	Kembang Tani	Cucum, Kuta Baro	30	Nurhayati	2013	
	6	Mira Handayani	Jeumpa Puteh	Beuraden, Peukan Bada	30	Asmiati	2014	Demo **
Aceh Barat	7	Afrida, SP	Seulanga Dara	Alue Lhok, Bubon	20	Maswina	2009	
	8	Cut Mutia, SP	Ingin Maju	Alue Bakong, Bubon	25	Ikhwanita	2012	
	9	Yulinar	Tunas Barona	Pasi Pandan, Woyla	22	Aminah	2012	**
	10	Ulfajriati	Baru Kembang	Ulae Blang, Bubon	15	Nurhalimah	Dec 2012	
	11	Supriyani, SP	Bunga Mawar	Peunia, Kaway XVI	15	Fatmawati	Jan 2016	New **
	12	Supriyani, SP	Suka Maju	Peunia, Kaway XVI	23	Masriana	Jan 2016	New **
	13	Yulinar	Bungong Ban Keumang	Padang Jawa, Woyla	20	Cut Mariana	2007	
	14	Supriyani, SP	Sabe Pakat	Pasi Kumbang, Kaway XVI	20	Hj. Nurhafsah	Jan 2016	New
	15	Ulfajriati	Taman Saudara	Ulae Blang, Bubon	15	Khadijah	Sept 2015	New
	16	Cut Mutia, SP	Ingin Maju	Alue Bakong, Bubon	15	Mariana	2012	
Bireuen	17	Agustina, SST	Sri Maju	Batee Timoh, Jeumpa	20	Laina Wati	2015	New
	18	Nilawati, S.TP	Sayur Mayur	Seulembah, Jeumpa	20	Nuraini	Jan 2016	New
	19	Radhiah	Harapan Jaya	Paloh Panyang, Jeumpa	20	Fauziah	Jan 2016	New
	20	Zulfajar, SST	Jeumpa Keubiru	Ujong Blang, Kuala	20	Maryamah	2013	
	21	Mulyawati, sp	Mita Raseuki	Bayu, Peusangan	30	Ida Riani	2013	
	22	Zulhijjah Pang, SP	Tani Seulanga	Dayah Mesjid, Kuta Blang	30	Wardah	2013	
	23	Teja Warni	Mawar	ulee Glee, Makmur	30	Ti Aminah	2013	
	24	Fitri Yanti	Beuna Sabe	Rancong, Kuta Blang	20	Nurhayati	2013	
	25	Ismawati, SP	Bungong Kupula	Rheum Baroh, SP. Mamplam	30	Iryani	2013	
	26	Anita Rahayu	Rahmat Mulia	Puuk, Peulimbang	30	Anita Rahayu	2014	
	27	Salma	Jeumpa Puteh	Lueng Kuli, Peusangan Selatan	30	Mariana ben cut	2013	
	28	Zulhijjah Pang, SP	Ranup Seulaseh	Kerumbok, Kuta Blang	20	Nurhayati	2011	
	29	Nilawati, S.TP	Bungong Seulanga	Blang Rheum, Jeumpa	20	Asnidar	2015	New
	30	Radhiah	Kasih Ibu	Blangbladeh, Jeumpa	15	Satriani	2011	Demo **
Pidie	31	Zulfajri Umran*	Bungong Meulu*	Pulo Tu, Simpang Tiga	25	Fadliah	2012	
	32	Fachrizal*	Bangun Nanggroe*	Buloh Peudaya, Padang Tiji	20	Jamaliah	2014	

*Very low participation in the project and eventually fell out; **Obtained local govt. support between 2016-2018 based on their activities in this ACIAR project.

Table 38. Key changes observed in KWT groups before and after receiving support from the project.

Group name and location	Before involvement in the project	After involvement in the project
1. Hidup Maju, Beurandeh Aceh Besar 2.KWT Mawar, Peunia, Aceh Barat	●No group existed ●Women had no activities other than looking after the family ●Did not know how to grow vegetables ●Had to wait for their husband to return from the sea to have money to buy food ●Families consumed few vegetables	●Group formed and women have activities outside the home ●Obtain new knowledge ●Can eat vegetables every day ●Extra family income ●Open to additional information ●Obtain support from local government and business ●Can prepare a family meal earlier in the day as they are not waiting for their husband to earn and to give them money
3.Teratai Meuguna, Ruyung, Aceh Besar 4. Jeumpa Puteh, Beuraden Aceh Besar 5. Evorbia, Lambada Peukan, Aceh Besar 6.Tunas Barona, Pasi Pandan Aceh Barat 7.Kasih Ibu, Blang Bladeh Bireuen	●Groups were not active ●Women worked individually ●No focus on crop type ●No coordinated marketing strategy and market power ●Sales were dominated by the middleman/agent ●Used traditional farming methods ●Markets were difficult to access ●Used chemical fertiliser	●Groups became active because they were supported by extension staff ●Group's garden becomes a learning facility ●Incorporated use of organic fertilisers and organic pesticides ●Growing vegetables guided by market demand ●Organised crop plantings and rotations to provide a continuous supply to the market ●Group organisation and cooperation lead to a greater and more consistent supply ●Greater access and bargaining power in the market ●Easier to access information ●Easier for extension staff to disseminate information ●Access to local government support programs

The vegetable seeds were initially provided by the project through their supporting PPL. A number of groups have also learned to produce and keep seeds of common vegetables such as bayam and sawi and some are starting to produce cucumber seeds. The ability to produce and share seeds between groups will allow more freedom to grow a greater variety of crops without being dependent on outside support. Excess seeds produced are either distributed or sold to the people outside the group in the village.

Table 39 Typical activities in KWT demonstration sites in Aceh Besar and Bireuen.

Technology	Crop type	Others
Aceh Besar		
The use of banana stem-based compost and urea	Kangkung, pakcoy, bayam, eggplant and red onion	• The use of banana stem-based compost with octobacter • Production of rice husk biochar • Production of plant-based pesticide • Making MOL (local microorganism) extract
The use of rice husk biochar and banana stem-based compost for seedling medium	Tomato and chilli	
The use of plant-based pesticide	Kangkung, pakcoy, bayam, eggplant and red onion, tomato and chilli	
The use of manure and rice husk	Kangkung, pakcoy, bayam, eggplant and red onion	
Bireuen		
The use of organic fertiliser and liquid organic fertiliser	Kangkung, bayam, lettuce, sawi, red onion, eggplant	• Making compost • Making MOL (local microorganism) extract • Production of plant-based pesticide
The use of rice stubble mulch	Red onion	
The use of goat manure	Kangkung	

Technology	Crop type	Others
The use of manure and chemical fertiliser	Kangkung, bayam, lettuce, sawi, red onion, eggplant	

The typical costs of growing vegetables on 500 m^2 of garden are outlined in Table 40

Table 40. Typical cost of production for vegetables (IDR rupiah)

Vegetable type	Seeds (IDR)	Fertilisers/compost (IDR)	Labour requirement
Kangkung	45,000	166,000	No actual record provided but it is averaged about: 1-2 hrs per day, 2-3 days per week
Sawi	50,000	150,000	
Bayam	15,000	No record, but the average reported is Rp. 10,000	
Eggplant	30,000		
Red onion	300,000	250,000	
Mini cucumber	Not specified but the total production cost for equivalent land size of 500 m^2 is Rp. 1,000,000		
Celery	Not specifid, but the total production costs including labour for harvest is Rp. 565,000		

The estimated conversion rate is A$1 for Rp.10,000 (2018)

The use of soil organic amendments in vegetables growing

Prior to their involvement in the project, many existing KWT groups used chemical fertiliser and pesticide on their vegetables. With access to news and social media, they were increasingly concerned about the potential health impacts on their family. They were also concerned about the cost of the chemicals. In response to this, this project trained KWT to produce and use organic fertilisers and pesticides made from organic kitchen waste or other plant materials as described in the previous sections.

In addition to making and using organic fertiliser, bokashi and pesticides, the groups were also trained to make and use biochar from rice husk or coconut shell as a soil amendment. Although the groups did not conduct a scientific assessment of their activity, the supporting PPL conducted basic demonstrations, comparing the vegetable responses to the amended and unamended soil to provide an evidence-based learning approach. Some of the reported results included:

1. adding fermented liquid fertiliser (made from papaya) alongside inorganic fertiliser, biochar and compost improved yields of corn and watermelon compared to those without
2. complete organic fertiliser (bokashi+compost+dolomite+fermented bamboo shoot) improved the yield of onion compared to those grown with inorganic fertiliser
3. the combination of inorganic and organic fertilisers tripled the yields of mini cucumber compared to compost only treatments.

Benefits of being part of KWT

The support provided by the project has brought social and health benefits to the members of the women farmer groups. It has also brought economic benefits as summarised in Table 41.

The potential family income from this activity ranged from A$405–$2,000 depending on the type of vegetable grown, the size of backyard, time invested and family priority towards the business (Table 41). This is a new source of income and is additional to what the family would have generated by only growing rice. Employment opportunities for most women farmers are limited or non-existent. The backyard vegetable growing provides the opportunity to create income while maintaining their current family activities and social responsibilities.

Table 41. Annual economic benefits (A$*) obtained by each member from six KWT groups, based on the equivalent of 500 m^2 land for the group garden or individual garden.

Source of benefits	Name of KWT group Jeumpa Puteh^	Teratai Meuguna^	Kembang Tani^	Suka Maju#	Tunas Barona&	Kasih Ibu^
Vegetables grown	Common + Onion	Common + mini cucumber	Common + Celery	Common + sweet corn	Common + cucumber	Common + lettuce
Share of sales of excess produce from group garden (gross margin)	78	30	20	50	30	50
Gross margin from own gardens**	300^^	600***	1800	200	400	600
Gross margin from fried shallot (post-harvest)	34	NA	NA	NA	NA	NA
Saving from growing own vegetables (instead of buying)	180	180	180	252	360	180
TOTAL benefits (A$)	593	810	2000	402	790	830

*based on an average exchange rate of Rp.10,000 IDR to A$1 (2018) Common vegetables = bayam, kangkung, sawi, eggplants and tomatoes or chilli. **sold on behalf of the group. ***The actual income/ member is A$1200 from 1000 m^2 of individual land; ^^ the actual income from the individual garden is A$30 because the land size/ member is only 50 m^2. The calculation of benefits reported have already considered the input costs but may exclude the cost of individual member's labour, which is typically 1–2hours/day for 2–3 days/ week. Cost of vegetables per day: ^A$0.5, #A$0.7, and & A$1.0.

For KWT Teratai Meuguna and Kembang Tani, the income from growing vegetables has become the primary family income and the husbands are now supporting this as a priority. Growing their own vegetables for family consumption provided an average annual saving of up to A$360 per family. The annual income from selling excess produce from group garden (A$20–$78) is relatively small compared to the potential income from each member's own garden (A$200–$1,800 per year), which reflects the focus for learning using the group garden.

The income obtained varies depending on the crop types, and the group's objectives and strategies, the market and the support from their PPL. For example, KWT Teratai Meuguna has established its focus on growing mini-cucumber. Their PPL and KWT leader is actively looking for ways to improve the growing strategies to maximise profits and promoting their unique produce within and outside the village. The group has a growing rotation system between members to ensure continuity of supply. However, they also managed planting time to match the peak demand for cucumbers during the fasting month to maximise profits. Membership for the Teratai Meuguna KWT is limited to 20 women, but they employ non-member women in the village to market the product to outside their normal market (i.e.UNSYAH campus to cater for students living around the university). KWT Kembang Tani elected to focus on growing organically grown celery and choy sum and is actively promoting the 'organic' concept as their competitive advantage to retain and expand their market. They also sell the celery in a smaller package to attract a larger market size. Both of these groups are becoming the role model for all other groups.

The women use the extra income from vegetable sales, mainly to meet family needs and support their children's education. For example, to purchase additional food items, school books and stationery, school uniforms or as pocket monies. Some women use a small amount of money for their personal needs (i.e. make up).

Most groups established a small loan system where members could access credit (A$20–$50) from the group account with interest that is added back to the group account balance. This was beneficial for emergencies or capital purchases. During the fasting month (Ramadhan) the group usually divided 2/3 of the total income (profit) equally between members to help with purchasing items required to celebrate Idul Fitri (i.e, new dinner set or clothing). The remaining 1/3 is kept in the group account.

Being part of a group produced other intangible benefits such as enhanced problem-solving and networking skills as summarised in Table 42. The PPL claimed that groups increased efficiency and effectiveness towards the learning process because learning in a group environment is less intimidating. This made the PPL job easier. Group activities also have recreational and social benefits, promoting participation, providing motivation, and peer learning opportunities.

Traditionally, the womens' contribution to the village economy was not recognised within the village bureaucracy. However, their participation in KWT could change this. For example, the group leader from KWT Jeumpa Puteh (Ismiati) was invited to the island of Java for a study tour to an onion growing region. This was her first time leaving the island of Sumatera and her first plane ride. The opportunity given to the KWT leader improved the self-worth and the social standing of the group within their village and has led to an invitation to participate in other village meetings.

Working as a group also gives the women market power. The pooling of products to ensure continuous market supply also allowed them to determine their price instead of accepting the agent’s price offer. As a group, they are also able to choose the most suitable marketing strategy and increase the efficiency of their time. For example, instead of taking the produce to the market, the Teratai Meuguna and Kembang Tani groups invited the agent (wholesale buyer) to the farm. Other groups that sell common vegetables such as kangkung or bayam conduct farm gate selling where the purchase harvest the vegetables they need.

The group also learn to differentiate their product and establish its competitive advantage. For example, by focusing on niche products such as mini cucumber, celery or organic choy sum. The Kembang Tani KWT used an innovative packaging strategy to enhance sales and increase the price; others use strategy to increase market size by reducing pack size for a cheaper price.

The active promotion and marketing and by determining focus, the group built a certain reputation. The seven groups listed in Table 38 or Table 41 are reputable groups that are often invited to participate in the local government programs such as KWT competition or be appointed to carry out specific government initiatives such as the development of the red onion or soybean industry. Participation in the local government program will generate opportunities for training or obtain new equipment. For example, based on the local government’s assessment of their activities, KWT Jeumpa Puteh was invited to participate in the development trial of a red onion industry. They were provided with seeds, nursery facility, water tank, post-harvest processing equipment (stove, cooking utensils), packaging and labelling equipment, as well as training and study tour opportunities.

Table 42. Summary of benefits from involvement in the KWT groups

Type of benefits		Description
Social	Self -esteem Self- actualisation	Confidence from new knowledge and skills Confidence from success Recognition for contribution to the village economy and reputation Definition of individual goals
	Empowerment	Understanding how to find information and test ideas The reward for effort (access to food and income) Contribution to family income Strength through group cohesion
	Community	Social and recreation Support and motivation between the group members Group learning drives more productive individual gardens Learning from peers Delegation and sharing of responsibilities Working together as a group to create networks

Type of benefits		Description
Economic	Saving	Self-sufficiency growing vegetables - not buying vegetables (AUD $180–$360 per year)
	Group	Selling excess produce Removes the buyer agent for price information Group can provide financing options
	Markets	Cooperation leads to better supply and marketing options
	Family income	Between AUD $402–$2000 (Table 41)
Health	Nutrition	Access to fresh and better quality vegetables More vegetables consumed by families
	Pesticide usage	Improved understanding of pesticides and reduced use on food crops
	Mental health	physical work and a happy work environment
	Social	Many families are involved in the groups Workload and responsibilities can be shared Contribute to the reputation of their village
Increased capacity	Equipment/facility	Equipment and assets can be purchased and shared by the group
	Increased access to information and support	Information, village finance and government programs
	Skills	Farming, business management, marketing and distribution, and communication and networking

Potential health benefits from involvement in KWT include improvements in family nutrition through the increased consumption of fresher and better quality vegetables and or extra income that allows access to more nutritious food. The women farmers in Aceh showed a strong interest in healthy food and most are suspicious about the chemicals used to produce vegetables sold in the market. Therefore they are passionate about organic growing though the term organic is often used loosely. Greater awareness of pesticides and a reduction in the use of chemical pesticides is also expected to have long-term health benefits. The creation of a relaxed and happy working environment was observed by the women to have improved their wellbeing and sense of worth.

One interesting aspect of KWT in Aceh is that they appeared to be more collaborative rather than competitive. When one group excelled in one type of commodity, others would be keen to learn of their strategy, but these other groups will try not to compete for the same commodity in the same market catchment, so they do not disturb the market price.

This collaborative nature also observed between members within a group. For example, the Teratai Meuguna group has 20 members. The rotation to grow cucumber is managed informally based on a common understanding and consideration between members. There is no written roster system or agreement in place, other than active verbal communication between members and the leader about their intention and readiness to plant. The leader said that there has never been a competition arise between members to grow at any given time. If they already have enough members planting at a particular time, the others will happily grow other vegetables until their turn comes to plant cucumber. The PPL (Dessy) and the KWT leader indicated that this informal system is currently working well and has not presented any strain/issue between members or between leader/PPL with members. Dessy indicated that members treat each other fairly and value their progress together as a group above the individual progress.

For theTeratai Meuguna group, each cucumber growing season costs each member about Rp.2 million IDR (A$200) and the profit is about Rp. 3 million IDR (A$300). To provide all-year-round supply of cucumber to the market, each member grows an average of three cucumber crops per year plus the common vegetable (kangkung, bayam or others) in between. This is a significant income so growing cucumber is now becoming a primary source of family income and their husbands are now involved in their small business. The average individual garden is about 1,000 m^2 and their husband helps with making the garden beds.

Dessy, the PPL for Teratai Meuguna group, is actively looking for new innovative ideas and had started experimenting to produce cucumber seeds with the group. She also introduced natural methods to manage pests and diseases such as refuge crops, natural insect traps and crop rotation. In addition, Dessy is actively seeking innovative ways to improve soil fertility such as using green manuring in addition to compost and organic fertilisers.

The KWT component of the project increased the technical capacity of the women farmers in Aceh to grow and market vegetables and for postharvest processing. Information exchange between groups during project forums increased their knowledge about growing and marketing different types of vegetables. They have also learnt about local funding sources they could access after the completion of this project. Seven KWT groups have successfully obtained additional support from the local government to expand their activities (see notes in Table 37) and details inTable 43.

Table 43. Details of local support obtained by seven KWT groups.

No	KWT	Source	Year	Program	Type of support
1	Teratai Meuguna	DP* Aceh Besar	2017	Development of soybean industry	funds (unspecified amount)
2	Jeumpa Puteh	DP Propinsi Aceh	2016	Development of red onion industry	seeds and fertiliser
		Badan Penyuluhan dan Ketahanan Pangan Aceh Besar	2016	Enrichment	funds (unspecified amount)
		DP Propinsi Aceh (APBN	2017	Development of soybean industry	seeds, fertiliser and chemicals
		DP Propinsi Aceh (APBN-P)	2017	Post-harvest equipment	equipment to make fried nion
3	Hidup Maju	Zulfikar Aziz, PKS	2017	Enrichment	hand tractor
		Bantuan benih	2016	Seed development company	Vegetable seeds
4	Tunas Barona	Dinas Pangan Aceh Barat	2018	Enrichment	seeds and fertiliser
		Dana Desa	2017	Village Fund Program	equivalent A$2,500
5	Bunga Mawar	DP Aceh Barat	2017	Development of melon industry	seeds, fertiliser and chemicals
	Suka Maju	Dinas Pangan Aceh Barat	2017	Enrichment	funds (unspecified amount)
		DP Aceh Barat	2017	Development of sweet corn industry	seeds, fertiliser and chemicals and funds
6	Kasih Ibu	Dinas Ketahanan Pangan Bireuen	2018	Enrichment	seeds, fertiliser and chemicals
7	Evorbia	Zamzami Ahmad DPRK Aceh Besar	2017	Enrichment	seeds, fertiliser and chemicals

*DP= Dinas Pertanian

This project has empowered women farmers in Aceh through the increased technical capacity to grow backyard vegetables, marketing, small business management, networking and communication skills. Their success to obtain local government support and to expand their activity will increase the recognition for women farmers as food producers, gatekeepers and shock absorbers in food security as described in Brown et al. (1995).

Challenges faced by the KWT

The technical challenges faced by the KWT include a lack of a reliable source of water for hand watering, pests and diseases, market access and price fluctuations. The lack of water is the primary concern of the groups as also identified in the lowland system in ACIAR project SMCN/2007/040. The provision of water storage systems or low-cost drip-irrigation systems are likely to be the most cost-effective and practical solutions to allow the KWT hand-water their vegetable gardens (Luther 2010).

The distance to the large city market is the major barrier to incorporating higher-value vegetable crops such as sweetcorn or lettuce. To maintain a large market base, all groups grow the two most popular vegetables (bayam and kangkung) in addition to niche products (such as cucumber, celery, lettuce, red onion) or while discovering their potential niche products. Most groups considered diversification as a strategy to cope with market access and price fluctuation. The price of bayam or kangkung can range from Rp.1,000 IDR (A$0.10) during peak supply (good season) to Rp1,500 IDR (A$0.15) per bunch during low supply (drought of flooding).

The greatest challenges, however, are institutional and cultural settings. First, for the groups to continue to grow and develop, they require continuous support from local government. The PPL plays a critical role in this because without their PPL the KWT has no voice or communication channel to the local government. However, the PPL in Aceh are underfunded and mostly worked in a casual capacity and received a minimum level wage. They also lacked skills and training in supporting farmers to grow crops other than rice. Therefore without external project funds, the support that farmers can receive from PPL is limited and the limitation is greater in the dryland systems.

Second, the cultural setting in Aceh tends to limit opportunities for women. For example, the government of Indonesia rolled out an annual Village Fund Program (VFP) for many years. This fund covers infrastructure and capacity building activities with the purpose to stimulate economic activities at the village level that will enable villages to become economically independent (Departmen Keuangan RI 2017). However, KWT was only aware of the fund in 2017during the KWT forum, from a speech given by a representative from the ministry for women's empowerment. To access the VFP money KWT needs a representative in a budget planning meeting at the village. However, this meeting is usually attended mostly by men because it is conducted at night when family demands for the women's time are high. The supporting PPL, who are mostly female, may also not be able to present at this meeting. Given the local social and religious setting, many KWT members and leaders still lack the confidence to attend or speak in such a meeting. The women have no training in how to contribute to the village meeting. Thus far, only one KWT has successfully obtained funds from this program for an amount of A$2,500 (Table 43).

In addition, there is no local platform currently available for KWT in Aceh. Agricultural ministry's focus is on the food crop, not on vegetables, and the women empowerment ministry also have no place for KWT in their planning. The lowland project SMCN/2007/040 initiated a framework for a formation of KWT network in Aceh. The groups enthusiastically embraced it. However, their enthusiasm must not have been in line with the local government priority and nothing further has happened since the lowland project was completed in 2012.

To overcome these challenges, BPTP Aceh will need to continue to support KWT through technical training and persistently lobby the local government and local businesses to support KWT to push for the formation of a formal (funded) KWT network in Aceh.

Challenges faced by the supporting PPL

The challenges faced by their supporting PPL include the lack of tenure and the lack of operating resources. Most of PPL rely on external funds to cover their operating costs. Therefore it is difficult for them to focus on delivering supports to farmers.

The casual workers do not receive support for communication or to travel to farmers and resources provided are insufficient for daily operations, so PPL often have to purchase motorbike fuel with their own money, to conduct their duties. In 2018, my understanding was that a newly recruited PPL is working under an arrangement that they work for 12 months but only get 10 months salary. I have heard from few PPL that they often do not receive their casual pay for several months.

Although there is an increasing trend for university graduates to work as PPL, many of the existing PPL do not have higher education level and attended only a one-month training in a PPL Training Centre after high school, to become a PPL. The low education level is reflected in their skills in writing, data recording and reporting.

One PPL (Devi) who has completed a Master's degree through this ACIAR project commented that the wide range of education level presented a challenge in collaborating and communicating between PPL. This affects the quality and continuity of support they provide to farmers. PPL who are reading and learning (such as Devi or Dessy) tend to be more innovative and are favoured by farmers. But they are also favoured by the higher-ranking government official and often inundated by other duties or tempted with a more lucrative office position.

The training and development activities provided through this project is new to most PPL involved. To be effective, the local government (their employer) need to build on this with follow up training and practices.

7.3.4 Activity 3.4.1: Capacity building and communication

Capacity building for farmers and advisers (see 8.3.1 -8.3.3))

Capacity building for students and researchers: annual data analysis and interpretation workshops (Activity 3.4.1) –Deliverable D39 (Appendix 7)

Training activities conducted include:

1. Three workshops on data analysis and interpretation for students to prepare them for research and to write up their thesis.
2. Technical training for soil analysis and technical training for
    a. Soil sampling and analysis for UNSYIAH students
    b. Biochar production for PPL and UNSYIAH staff
    c. Operation of EM38 equipment to measure soil electrical conductivity and to measure soil water for research student and UNSYIAH academic staff
    d. APSIM crop model simulation for UNSYIAH academic staff and students

Communication and dissemination (Activities 3.4: 1,2,3,4,5)

Presentations at scientific forums (Activity 3.4.2) –Deliverable document D40 (Appendix 8)

Project results are regularly presented at scientific forums within and outside Aceh, with over 26 publications produced (Section 11.2). In 2017, UNSYIAH organised a national seminar on dryland agriculture systems attended by delegates from Indonesian universities and research organisations. In 2018, six project presentations were made at the Australian Soil Science conference (Section 11.2.). One of this poster papers has been invited to be published in a special edition of the journal Soil Research).

Extension forums (KWT groups- Activity 3.4.3) – Deliverable D41 (Appendix 9)

Four KWT communication forums were conducted in 2017 at district and provincial levels with the objectives of:

1. to provide an opportunity for KWT groups and members to share and exchange experience, information, highlight challenges, achievements and opportunities
2. to develop networking and collaboration between groups
3. to develop local government awareness about KWT activities and encourage them to provide ongoing support for KWT after the completion of the ACIAR project.

The district-level KWT communication forums were conducted between July and August 2017 in Aceh Besar, Aceh Barat and the Bireuen districts, attended by (40, 42, and 52, respectively) members and local guests.

The KWT provincial forum was conducted on 13th–14th September 2017 in Bireuen. This was attended by 111 members. The invited speakers include those from Balai Penyuluh Pertanian (the body that oversees the PPL), Dinas Pertanian (district level), Food Security department, and Office of Women Empowerment.

This forum was communicated via ACIAR's website (http://aciarblog.blogspot.com.au/2017/09/aciar-supporting-women-farmers-in-aceh.html)

Farmers to farmers visit (Activity 3.4.4) to enhance peer-to-peer learning (see Deliverable report D42 Appendix 10)

Four farmers to farmers visits were conducted during the period of 28–30 August 2018, with the following details:

1. 28 Aug 2018: A visit to KWT Jeumpa Puteh, Beuraden village, in Peukan Bada subdistrict with focus discussion on the agronomy and post-harvest of red onion. This was attended by 28 participants representing five KWT and farmers from the Lambaro Biluy demonstration site.
2. 28 Aug 2018: A visit to KWT Bungong Ban Keumang, Cucum village in the Kuta Baro subdistrict with a discussion focus on the agronomy of celery sawi, kangkung and bayam. This was attended by the same participants detailed above.
3. 29 Aug 2018: A visit to the Lambaro Biluy demonstration site to discuss the agronomy of peanut on dryland. This visit was attended by 28 participants representing six KWT from Aceh Besar and farmers from Beuraden village, Peukan Bada.
4. 30 Aug 2018, 25 KWT members from Aceh Barat and Bireuen districts visited the three locations above.

Farmers to farmers visit is a highly effective dissemination tool and should be conducted more often. It is also enjoyable for all KWT members attended because they have limited opportunities to travel outside their village. The visit to other villages widens their perspectives.

Publications and case studies of PPL demo projects (Activities 3.4.5)–Deliverable report D43 (Appendices 9, 11)

Project publication materials produced from the women farmers groups include:

1. Eight posters presented at the women farmer group forums (see Appendix 9 D41)
2. Four hundred leaflets that were distributed by BPTP Aceh to members of KWT, PPL and BPTP on the agronomy organic fertiliser and plant-based pesticide of padi gogo (Appendix 11)
3. Ir. Nazariah has distributed 400 case study booklets highlighting success stories of six KWT groups to relevant local government institutions and KWT groups across the study districts (Appendix 11).

4. Eight KWT posters were displayed and distributed during the provincial level communication forum. Titles of these posters are:
    a. Women Farmers: Food security warriors for a 21st-century family
    b. Activities for women farmer's empowerment: describing methods to equip women, farmers, to actively participate in the decision making in the farming community of Aceh.
    c. The contribution of KWT to food security: Support provided to KWT member to meet the fresh food needs for the family in terms of quantity, quality and diversity of fresh vegetables.
    d. The contribution of KWT to family finance: describing the role of women farmers to contribute to family income through participation in KWT activities (grow own vegetables, sell the excess, utilising group's micro-credit system, and contributing to the group's growth)
    e. The contribution of KWT to family and community health (assuming that increased consumption of fresh (and organically grown/less chemical used by KWT) and diverse vegetable types or having more money to buy meat or fish from selling vegetables could improve family nutrition)
    f. The collaboration between PPL and KWT and Penyuluh Pertanian Lapangan (PPL), describing the critical role of PPL as the source of information and active supporters of PPL
    g. PPL roles in KWT that include training and demonstration of good crop agronomy, production and use of organic fertiliser and plant-based pesticide, and postharvest processing.
    h. Group work, we CAN: a slogan poster that emphasises the power of groups in production, diversity, marketing and capital
4. Electronic media publication including TV Aceh and youtube: https://youtu.be/ppz8yZ6kRqo and https://youtu.be/4hyeo1ZL2xo, and
5. the Australian ABC TV coverage
    a. Landline package https://www.abc.net.au/news/2018-11-17/working-together:-australian-aid-helping/10508006
    b. Feature article: https://www.abc.net.au/news/2018-11-17/australian-dryland-farming-project-in-aceh-indonesia/10504670
    c. Facebook video https://www.facebook.com/LandlineABC/videos/760014597684983/
6. Social media: KWT's and project's group chats in WhatsApp and Facebook
7. Project fact sheet submitted to ACIAR with annual reports in 2016,2017, and 2018
8. ACIAR online communication
    a. https://www.facebook.com/ACIARAustralia/posts/1858816620876895
    b. **ACIAR YouTube version for international viewers**: https://www.youtube.com/watch?v=wFNpOzHd9ro&feature=youtu.be

8 Impacts

8.1 Scientific impacts – now and in 5 years

Before this project, there was limited agronomic and soil resource information on dryland agriculture systems in Aceh. It was known that dryland farmers are not as well supported as those in the lowland rice areas, crop yields are below potential, and farmers' income is low. This project has delivered new scientific information on soil characteristics and production constraints for these areas, and has guided soil and crop management research and demonstration. The new soil information produced by this project will leave a lasting legacy to future dryland agriculture communities and its development in Aceh and Indonesia.

Project publications produced and presented at local, national and international scientific forums are enhancing the understanding of global scientific communities about dryland agricultural systems in Aceh. A conference paper submitted to the Australian National Soil Conference in November 2018 has been selected for inclusion in a special edition of 'Soil Research" journal.

This project has challenged the perceptions and practices of the Aceh agricultural research community, and they now could apply an integrated approach of soil fertility, soil quality, crop yield, environmental health and the economic benefits to end-users. The evaluation of soil organic amendment has helped partners' understanding of the sustainability concept in their research.

In NSW Australia, the biochar experiment added understanding of its potential role in increasing nitrogen availability and the use efficiency of applied nitrogen fertiliser. It also added to the understanding about the long-term benefits of biochar in improving soil fertility.

The evaluation of soil water and carbon over time in NSW added to the understanding of soil water behaviour under different vegetation and confirmed the potential role of perennial vegetation to maintain and sequester soil carbon.

The EM38 and NMM calibration equations to measure soil water are now available for future research in the NSW DPI Breeza field station and are currently being used in GRDC co-funded sorghum research in NSW Australia.

8.2 Capacity impacts – now and in 5 years

The project has fostered an enhanced collaboration between BPTP Aceh and UNSYIAH which will strengthen future agricultural research and development activities and subsequent agricultural productivity in Aceh.

Technical training activities and interactions with soil and crop scientists from the national institutes (Bogor) in Aceh and Australia have improved project partners knowledge and skills in conducting agricultural research, data analysis and interpretation. The capacity building and extension program directly reached 725 women farmers, 16 food crop farmers, 44 field extension officers, and 51 university students, and more than 100 local farmers local farmers participated in local extension acitvities.

The scientific writing and scientific communication skills of UNSYIAH's students and project staff have improved through participation in local and national conferences and seminars, and annual presentations during project reviews. These skills are important in securing future research funding for UNSYIAH and BPTP Aceh, employment for graduating students and most importantly in informing government policy relevant to farming communities in Aceh.

Farmers in Aceh have new and increased skills in growing dryland crops, producing organic fertiliser from local materials, postharvest technology, marketing, teamwork and networking.

Women farmers gained new knowledge in production and use of soil amendments, organic liquid fertilisers, crop management, postharvest processing, group and networking skills, and small business and marketing skills.

The post-harvest skills obtained by the women farmers through the training is the most effective way for them to build small home-based food businesses.

8.2.1 Expansion of university research capabilities

Attendance and presentation at the National Soils Conference 2018 in Australia broadened the research perspectives and networking of UNSYIAH and BPTP Aceh staff. UNSYIAH project staff have used this experience to develop ideas for future research projects and publications. Prof. Sufardi interacted with many Australian soil scientists and gained feedback and he is now planning many additional papers.

This project has enabled students and UNSYIAH staff to develop and undertake a large and coordinated systems-based, collaborative approach to agricultural research. This is a large improvement from the isolated pot trials UNSYIAH students did in the past. This project has widened their perspective on integrated research and provided them with an opportunity to work independently and as part of a team in a collaborative environment. This is a critical factor for determining success in their future career and life.

The project has introduced UNSYIAH researchers and students to consider the sustainability aspect of the agricultural system in their future research, and move away from ‘instant’ approaches to fix soil problems by applying more fertiliser.

The field research infrastructure established at UNSYIAH Darussalam campus will become a valuable research training facility for future UNSYIAH agriculture students.

A student placement program with KWT groups increased their awareness and interest in food production. Several of the students reported that they had no farming background, but the project has sparked their interest in food production.

The annual workshops on data analysis, data interpretation and project presentation, initiated by the project have increased the confidence and capabilities of Indonesian project staff and students in data analysis and interpretation, scientific writing and communication including public speaking in English.

In this project, students were required to independently conduct soil analysis in the lab and operate field equipment, building the student’s technical skills in basic laboratory analysis and equipment use.

UNSYIAH staff involved in the project have been able to use the project as their research model and leverage to obtain supplementary research funds from the government of Indonesia.

UNSYIAH staff claimed the project model and international connections and interactions with foreign scientists had changed student’s perception of fieldwork. UNSYIAH staff previously found it difficult to find suitable students. Student’s observation of training and treatment in the ACIAR project has changed this. Some past students (Bsc) have returned to further their education (MSc degree). This has been strengthened by Kinki University in Japan inviting students from Aceh to visit Japan to build the next level of research collaboration through PhD student research.

The project has increased the credibility of UNSYIAH as a research and education provider in Indonesia. The ACIAR project played a significant role in the recent University and Study Program accreditation to meet the Indonesian University standards. UNSYIAH claimed that their involvement in the ACIAR project significantly strengthens their accreditation proposal and success.

8.2.2 Increased skills and knowledge of local PPL in supporting farmers to grow dry season crops

The project has trained 44 local field agriculture extension officers (PPL) in:

1. The production and use of organic fertilisers and pesticides in vegetables
2. Crop selection strategies for the dry season crops and dryland systems
3. Management of diverse farmers' groups
4. Communication skills through project forums, with media, and report writing.

The project equirement of the PPL to develop new skills to plan, conduct and report demonstration activities laid a foundation for improve conduct of R&D. This will improve the quality of support they provide to farmers.

8.2.3 Introducing soil amendments to dryland agriculture

Before their involvement in the project many students, field extension officers and farmers in Aceh have some awareness that compost is good for the crop and some had heard about biochar. Few understood the concept of soil organic matter and soil carbon, and its role in soil fertility and the nutrient cycle. The practical components of this project have enabled a hands-on approach to the production and application of soil organic amendments and monitoring the influence on soil, crop yield and gross margins. The production and use of biochar, in particular, is new knowledge for many students and field extension officers.

8.2.4 Increased technical and research skills using EM38 to measure soil salinity and soil water in the field

After Aceh's 2004 tsunami, NSW DPI and ACIAR introduced EM38 technology to help Aceh's agricultural field officers monitor soil salinity levels. Three EM38 units were procured by the tsunami projects for Aceh.

BPTP Aceh (Ir. Irhas) was trained to use EM38 to monitor soil salinity during the tsunami rehabilitation projects. He has trained UNSYIAH staff and students in the use of EM38 to measure soil apparent electrical conductivity. In March 2018, Dr Malem McLeod conducted follow-up training on the specific use of EM38 to measure soil water for UNSYIAH staff and students. The project calibrated the EM38 to measure soil water in NSW. This increased capacity will reduce reliance on the neutron moisture meter. It is expected that EM38 will be commercially adopted in NSW farming systems to assess pre-sowing moisture levels and irrigation scheduling. This is a transferable and applicable technology for water and agriculture research in Aceh's dryland system.

8.3 Community impacts – now and in 5 years

8.3.1 Farming and the wider community

The participation of KWT in the ACIAR project has proven to be effective in building the capacity of 725 women farmers across the study areas. Through group activities, the women farmers have obtained financial benefits, learnt new skills (vegetable growing and postharvest processing), and developed an information exchange within and between groups. Further, they formed productive networks that enhanced their communication, organisational management, marketing and small business skills.

The positive impacts of being part of the group to these women are not only in the form of increased income but also in the social impacts, the health and wellbeing of members, and most importantly strengthening family food security. The success of the women groups who participated in the project is expected to continue to influence women farmers outside these groups in this communal society. Therefore it is expected to have a positive impact on other members of the community into the future

The on-farm demonstration activities have built skills and knowledge of farmers and their local agriculture field extension officers. It has provided the opportunity for others from the same village and districts to observe the new farming practices and production outcomes. Farmer groups and networks are expected to be formed from their experience in this project.

The proximity of Darussalam research site to the University housing complex attracted interest and enabled interaction with the residents. The research activities project has helped to increase awareness of the urban community about food production.

8.3.2 Economic impacts

Incorporating dry season crops such as peanut, maize, mungbean and soybean into rotation could provide extra income for smallholding farming families in Aceh, when there is sufficient water. Dry season crop could generate a profit between A$159 to $2,584/ha/season, for rice and peanut, respectively. As this was the first and only study into the viability of dry season cropping in Aceh, future works will be required to assess the long term economic performance of dry season crops.

Women farmers involved in the project reported substantial monthly saving by growing their own vegetables and generating extra income from selling excess produce. Each women farmer could generate income between A$402–A$2,000 per year from growing vegetables in their backyard. The level of income obtained is determined by the type of vegetable gown, the size of land, family support, and how the marketing is managed. The collaborative nature between KWT members and the magnitude of food business in Aceh minimises the threat of market saturation.

Women groups have used their involvement in the project as leverage to obtain local government funding to support the development of a small business (i.e. selling fried red onion instead of raw onion). Subsequently surrounding farmers can apply the same approach to their business.

8.3.3 Social impacts

The willingness of dryland farmers to grow crops during the dry season, if conducted carefully, may prevent the agriculture workforce from seeking urban employment. This will mean that families can stay together throughout the year in their rural community.

The PPL (Devianti) in Lambaro Biluy demonstration site reported that the project had helped the families within the group stay and work together. Devianti said that all male members of her group had been successfully encouraged to work on the farm alongside their wives during the dry season. This is a big cultural shift for Aceh’s men who usually leave the village for other jobs during the dry season. When their wives were interviewed by the ABC TV reporters, the women said they are very happy to have their husbands stay in the village with them all year round.

The research funds provided through the project have helped 51 UNSYIAH students to complete their fourth-year research without burdening their parents. This has significantly increased the number of student completing tertiary studies.

Women farmers involved in the project have also reported increased physical health and wellbeing and happier households. They have also enjoyed the increased recognition from their village leaders and visiting officials, and for some the opportunity to travel as a result of their activities in KWT.

8.3.4 Environmental impacts

This project increased awareness of organic fertiliser options and their potential to reduce chemical fertiliser needs. The reduced use of synthetic fertilisers will reduce chemical runoff and diffuse pollution from farms.

The adoption of biochar will keep persistent carbon in the soil. There is potential for future adoption of biochar in Aceh because there are abundant local materials and can be produced with simple technology.

8.4 Communication and dissemination activities

Communication and dissemination activities conducted to promote the project's work on dryland agriculture system in Aceh to the local and international communities to ensure future impacts include:

1. Six papers presentation in the 2018 Australia National Soil Conference. One or the papers has been selected for inclusion in a special issue of "Soil Research" journal
2. A national seminar on dryland agriculture systems. This event was organised by UNSYIAH as part of the project's communication output and was attended by students and academics from various universities in indonesia
3. Four KWT communication forums, each attended by KWT members and local and provincial government and policymakers
4. Four farmers-to-farmers visits within and across project's districts
5. The distributions of 400 leaflets on the production and use of organic fertiliser BY BPTP Aceh to the local agricultural agency offices and PPL
6. The distribution of 400 copies of case study booklets by BPTP Aceh highlighting success stories of six KWT groups to the local agricultural agency offices and PPL.
7. Social media network by project coordinators and members
8. Media (TV Aceh and the ABC TV) coverage that can be viewed by local, national and international audiences; as well as
    a. ABC Landline package: https://www.abc.net.au/news/2018-11-17/working-together:-australian-aid-helping/10508006
    b. ACIAR YouTube version for international viewers: https://www.youtube.com/watch?v=wFNpOzHd9ro&feature=youtu.be
    c. ABC Feature article: https://www.abc.net.au/news/2018-11-17/australian-dryland-farming-project-in-aceh-indonesia/10504670
    d. ABC Facebook video: https://www.facebook.com/LandlineABC/videos/760014597684983/
    e. ACIAR Facebook post: https://www.facebook.com/ACIARAustralia/posts/1858816620876895
9. Project final review peresentation in the Lambaro Billuy village that was attended by the whole village population.

9 Conclusions and recommendations

9.1 Conclusions

Smallholder farmers in the dryland systems of Aceh can increase their income by growing crops during the dry season in addition to growing wet season rice. The inclusion of dry season crops in the rotation could generate additional income of between A$159/ha/year for dryland rice and A$2,584/ha/year for peanuts.

Farmers are historically hesitant to crop during the dry season because of the risk of low yields or crop failure. Low crop yields are caused by both socio-economic and biophysical factors. The socio-economic factors include the traditional cropping practices where no fertiliser is applied to inherently poor soil, and the lack of information and extension support for dry season or dryland farmers. The biophysical factors include insufficient seasonal rainfall and infertile soils originating from poor parent materials. In addition, the landscape is prone to runoff and soil erosion.

The low soil fertility is caused by low soil carbon and nitrogen, and low availability of other important nutrients. The low soil carbon resulted in low soil water holding capacity and poor soil structure. Management practices that increase soil carbon and nitrogen and improve fertiliser management are required to increase crop yields for Aceh's dryland systems.

Improved fertiliser application method, rates and timing increased yields by 19–26% for dryland rice, 29–33% for wet season rice, 39–69% for peanuts, 29–32% for maize and 8–25% for mungbean. However, using biochar, compost or manure to increase soil carbon and nitrogen contents did not produce increased yields that were either consistent or reproducible. Therefore further evaluation is needed before recommending biochar, compost and manure as a soil amendment to Aceh's farmers.

The project also identified that family income can be increased by supporting women farmers to grow vegetables in their backyards. Growing backyard vegetables by women farmers can generate additional family income of A$402–A$2,000 per year. Building the capacity of women farmers also had social benefits which included the positive impact from improved recognition for women's role in the community, improved food security and family health and wellbeing. Their ability to earn income facilitated a shift from financial dependency to becoming self-reliant and in some cases entrepreneurs.

The increased income from growing dry season crops and backyard vegetables resulted in improved living conditions for participating farmers and reduced seasonal urban migration for employment.

The project increased the agricultural capacity in Aceh by directly supporting 725 women farmers, 16 food crop farmers, 44 local field extension officers, 51 university students and 10 project staff in Aceh. Through research and demonstration activities, they were trained to produce and use compost, liquid fertiliser, and biochar and to use improved crop and fertiliser management strategies. The involvement of university students will strengthen future agricultural research capacity in Aceh.

The project's findings were communicated widely through 26 written scientific publications which include six papers presented in the 2018 Australia National Soil Conference, currently 13 student's theses have been submitted to UNSYIAH, a national seminar on dryland agriculture systems organised by the project in Aceh, four KWT communication forums, four farmers-to-farmers visits, distributions of leaflets on the production and use of organic fertiliser and case study booklets highlighting success stories of six KWT groups. In addition, the project's activities and findings were also broadcasted through electronic, the Indonesian and Australian television (ABC Landline program and the associated ABC online platforms), social media, Youtube and ACIAR website. The communication activities in Aceh also reached over 100 farmers and over 25 local government officials from across the study districts.

In Australia, the evaluation of poultry litter biochar as a soil amendment showed that biochar increased the availability and use efficiency of applied nitrogen fertiliser leading to a 19% increase in herbage mass of digit pasture. The biochar also increased and maintained higher soil carbon content for at least six years. The evaluation of landuse effects on soil carbon showed that cropping reduced soil carbon by 1% over five years while under trees and natural grassland soil carbon content increased by 7% and 25%, respectively, for the same period. This suggests that the loss of soil carbon due to annual cropping activities may be offset by replanting trees or maintaining natural grassland in farming systems. Alternatively, a carbon-rich material such as biochar could be applied to soil as an amendment.

This collaborative research co-funded by ACIAR and NSW DPI included the lead university in Aceh (UNSYIAH) and the Indonesian provincial and national agricultural agencies (BPTP Aceh). The research in Aceh was the first and only study that attempted to evaluate dryland agricultural systems and one of the very few comprehensive dryland studies in Indonesia. The scientific knowledge generated about Aceh's dryland soils will inform future agriculture research and development to support Indonesian food security. The Australian evaluation of biochar improved the scientific understanding about its use to improve nitrogen fertiliser use efficiency. This will add to the body of international scientific knowledge on the use of biochar.

9.2 Recommendations

This project recommends:

1. For ACIAR: to use the women farmer group (KWT) program in Aceh as a model for soil management and food security projects in developing countries.
2. For farmers and project partners in Aceh:
    a) farmers in Aceh to continue to grow crops during the dry season with support from BPTP Aceh and PPL
    b) women farmer groups continue to be encouraged to grow vegetables in their backyards with support from BPTP Aceh and PPL
    c) BPTP Aceh to encourage local government to provide supplementary irrigation infrastructure (i.e groundwater pumps) for dry season crops
    d) BPTP Aceh to promote the benefits of growing vegetables by women to local government and encourage them to provide water storage options and enable women farmers to hand-water their vegetable gardens
    e) BPTP Aceh and UNSYIAH to work collaboratively on the long-term assessment of compost, biochar and manure and quantify their economic benefits
    f) ongoing commitment from UNSYIAH and BPTP Aceh to maintain and increase research, reporting, and scientific writing capabilities.
3. For NSW DPI:
    a) further investigate and develop biochar practices in NSW to allow further quantification of the benefits from reduced nitrogen fertiliser requirements and increased soil carbon
    b) consider mechanisms to support developing a biochar industry in NSW
    c) continue to encourage the maintenance of perennial vegetation in farming systems to offset the loss of soil carbon under intensive cropping.

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10.2 List of publications produced by this project

10.2.1 Conference and journal publications

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10.2.3 Student thesis submitted to the University of Syiah Kuala, Banda Aceh, Indonesia

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11 Appendices

Most deliverable reports are in Bahasa Indonesia, hence are not included in this document, but are included in the Appendices. To manage the file size, most appendices are provided in a shared folder in Google drive for ACIAR and CM9 for NSW DPI (OTPF 13/137#7 INT19/59304). The folder contains all the deliverable reports (D1-D43) and the relevant supporting documentation.

11.1 Appendix 1: Deliverable reports D1-D7

11.2 Appendix 2: Deliverable reports D8-D13

11.3 Appendix 3: Deliverable reports D14-D18

11.4 Appendix 4: Deliverable reports D19-D25

11.5 Appendix 5: Deliverable reports D26-D30

11.6 Appendix 6: Deliverable reports D32-D38

11.7 Appendix 7: Deliverable report D39

11.8 Appendix 8: Deliverable report D40

11.9 Appendix 9: Deliverable report D41

11.10 Appendix 10: Deliverable report D42

11.11 Appendix 11: Deliverable report D43