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2 Executive summary

Cereal crop yields are generally low in central Myanmar. Widespread crop under-performance and the need for appropriate soil fertility management in Myanmar was identified as a key limitation to the production of the main cereal crops of rice and maize. Given the well-known benefits of fertiliser use – the basis of the first “green revolution” when combined with modern crop varieties and irrigation – it may be expected that fertiliser research and utilisation would be widespread in Myanmar. However, this appeared not to be the case, and there was also little economic information on efficient and cost-effective fertiliser use in central Myanmar.

The project was led in Australia by the University of Melbourne (UoM) and by Yezin Agricultural University (YAU) in Myanmar. A small research component on fertiliser quality, and large-scale field demonstrations with farmers, were conducted in collaboration with the Land Use Division (LUD) of the Ministry of Agriculture, Livestock and Irrigation (MOALI).

The principal concept of the project was that nutrient management, particularly through nitrogen fertiliser management, has the potential to improve rice and maize yields and the incomes of small-scale farmers. YAU has a focus on tertiary education and building capacity to conduct research was incorporated into the project.

The objectives of the project were addressed by four integrated and contemporaneous subprojects for RD&E in Myanmar, with supporting activities in Australia:

1. Establish the biophysical basis for appropriate fertiliser use for rice and maize crops in central Myanmar.

2. Determine and address economic and policy related constraints to adoption of improved rice and maize production by fertilisation;

3. Build capacity for the long-term improved nutrient management at the farm level, through training of YAU staff; and

4. Develop decision support systems for rice and maize in central Myanmar and for intensive vegetable production in Victoria, Australia, by integration of the results of the biophysical and social-economic sub-projects.

These original objectives were little changed between 2014 and 2021, although less emphasis was given to research in Australia, and additional supporting research and capacity building was conducted in Myanmar. The project was subject to initial delays in gaining Myanmar government approvals, project execution was hampered by inflexible arrangements for receiving and utilising funds in Myanmar, and was followed by COVID-19 related prohibition on travel, and then civil disturbances after February 2021.

The project focussed on central Myanmar and had field sites located in a broad alluvial valley near Zeyathiri (Yezin) and Tatkon (both Nay Pyi Taw Union Territory), and Taungoo (northern Bago Region). The principal objectives of the agronomic trials were to define the responses of summer rice, monsoon rice, and monsoon-season maize to N fertiliser applied as broadcast urea. Additional field experiments were conducted to compare N fertiliser application methods for summer rice by comparing ‘alternative best practices’ with farmers' practice at a common N rate. Comparisons of urea deep placement with surface broadcast applications were included.

Field trials with rice were supported by research on dissimilatory nitrate reduction to ammonium (DNRA) to investigate the mechanisms by which paddy soils without external nitrogen inputs maintain nitrogen nutrition of rice and ensure moderate yield levels, and with N-15 tracer to determine the fate of applied N. It was shown that DNRA exceeded denitrification by a factor of eight in low N fertilised rice paddies, while DNRA was almost half of the denitrification rate of highly N fertilised rice paddies. These findings, and the observed results from our N response trials with rice, indicate that unnecessarily high N fertilisation do not provide yield or financial benefits, but rather promote native soil N mining and high N losses, where ~50% of fertiliser N applied is lost or unaccounted for. Biological N_2 fixation compensates for moderate yields in monsoon seasons, so fertiliser rates exceeding 30 kg N/ha are not advisable.

Measurement of the recovery of N from split applications of urea applied at 10 days after transplanting (DAT) and at panicle initiation (PI stage) showed that the current farmers' practice of applying N fertiliser in two equal split doses is inefficient and that the first dose of N fertiliser at 10 DAT should be reduced to 1/3 of the total and application of the remaining 2/3 of the N dose around active tillering stage (35 DAT) should prove beneficial.

Economic analyses of responses of rice to urea fertiliser showed that for monsoon-season paddy rice with small yield responses at Taungoo and Yezin, and with the current prices of urea and rice, that the Economic Optimum N Rate to achieve a 100% Return on Investment (EONR100), that is likely to be of interest to farmers, was only 30 kg N/ha. It was concluded that N applications above that applied in compound fertiliser before transplanting should not be applied to rice grown in the monsoon season, or at least limited to a maximum of 30 kg N/ha. Current recommendations to farmers should be updated to reduce urea applications to monsoon-season rice.

For dry season irrigated rice at Taungoo the EONR100 was much higher (120 kg N/ha) because of the much greater potential yield response to N fertiliser. The field trials showed that yields can be increased from approx. 4 t/ha to 6-8 t/ha in the irrigated dry season with the existing varieties. For dry season rice it was shown that statistically significant yield increases were obtained up to 77.6 kg/ha. In one dry season and at one location, raising the N fertiliser application rate to 160 kg N/ha led to significantly higher grain yield compared to grain obtained from an N input of 77.6 kg/ha. The economic results show a (risk adjusted) recommended N rate of 120 kg N/ha. There is clearly scope for increasing rice production in the dry season where irrigation is available, both from agronomic and financial points of view. There are opportunities for farmers to increase incomes from savings made by reducing urea applications to monsoon season rice, and by increasing urea application rates (using the recommended spilt: 1/3 DAT, 2/3 PI) on dry season irrigated rice.

Rice yields and soil nitrogen dynamics from applications of urea by deep placement (UDP) in the form of briquettes placed below the soil surface between transplanted seedlings was compared with surface broadcast urea. The recovery of labelled urea in the plants in the UDP treatment was greater than surface broadcast urea regardless of the seasons and locations. In general, UDP was promising allowing reductions of the total rate of urea application, with potential financial and environmental benefits. However, the results for grain yields were inconsistent between sites. Further research would be worthwhile if feasible and adoptable on-farm mechanisation of deep placement becomes available.

Concerns had been expressed about fertiliser quality and there had been claims of adulteration of fertilisers. However, it was found that fertiliser quality of samples collected in the project area was adequate, and that the fertiliser composition generally corresponded with that on the label.

For monsoon season maize there was a marked increase in grain yields with fertiliser N inputs, from ~2 t/ha with zero fertiliser N input to more than 8.5 t/ha with 250 N/ha, in 2017. Maize yield and N uptake increased from zero to 180 kg N/ha fertiliser inputs but there was no significant increase in crop yield or N uptake above that, indicating that 180 kg N/ha was likely to be the maximum N rate for maize at Laythar. At Tatkon, 180 kg N/ha or 250 kg N/ha resulted in the highest yields of monsoon season maize, depending on the season. Current N fertiliser use on maize is insufficient for increasing grain production or for optimising farmers' incomes, and N application rates can be increased to around 200 kg N/ha.

For the main crop in the region, monsoon rice, the estimated economic benefits to smallholders in the project area amounted to approximately $A 1.2 million, depending on the extent of change. Over 4 years, a cost reduction of 10% per year over the rice production area could save $A 2 million. For maize, the survey results show that many farmers apply substantially less than the Department of Agriculture recommendations and the economic rate based on the potential yield responses to N fertiliser found by the project. Up to $A 1 million increased farm income is indicated if maize in the project area is produced using more N fertiliser.

Economic gains from re-directing the application of N fertiliser to crops other than monsoon-season rice of the lowlands, the predominant crop in central Myanmar, to more responsive, and higher value, crops, may be possible. There is no benefit from an increase in N fertiliser rates applied to monsoon season rice but there are potential benefits from increased N fertiliser applied to maize crops in the same season, or to high-value crops such as vegetables. Restrictions imposed by Myanmar Government policy that limits the size of loans for non-rice crops should be reconsidered and could result in closer to optimal N fertiliser rates applied to maize.

Whilst the use of inadequate rates of N fertilisers may decrease overall crop production and result in suboptimal farmer incomes, excessive applications of N fertilisers represents losses to farmers and may contribute to degradation of air and water quality. Implementation of our findings of reducing N to monsoon season rice will reduce N losses to water and the atmosphere and could also lead to development of "organic" rice production that could attract a price premium in export markets, and a reduction in the N footprint of this, the dominant, crop in central Myanmar.

The project successfully transformed a teaching laboratory to one capable of high-quality analyses of a range of soil and plant properties in numbers sufficient to support field research. Significant progress was made in increasing safe laboratory operations, managing data, and problem solving. Three project-funded staff were trained and successfully operated the laboratory and two permanent YAU staff received sustained training. It was found that successful interventions could be achieved by adapting, rather making marked changes, and several independent small research projects were implemented by YAU within the purview of the project.

Our interactions with farmers in the study showed that the concept of a smartphone decision support tool in providing prescriptive advice was inconsistent with what many farmers actually want. Farmers felt that discussion groups were more likely to be a better learning environment and preferred a learning-based tool rather than a prescription-based tool. It was apparent that a discussion support approach (DSA) is more promising than a prescriptive-instructive approach in gaining acceptance of IT-based resource materials by farmers to transfer improvements of fertiliser (and other) management cropping practices. It is proposed that farmers, extension officers, and applied researchers be made aware of the social media (Facebook) page under development, and encouraged to comment, post, and ask questions.

It is recommended that:

- The integrated agronomic and economic findings for the fertiliser management of rice and maize be summarised for communication to next users. These will include recommendations on both timing and rates of fertiliser applications, as presented above. Large-scale demonstrations of improved fertiliser management for farmers were implemented in early 2021, but current civil disturbances are preventing planned interactions with farmer groups. It is recommended that the crop demonstrations be restarted when safe to do so.
- The findings can only influence the target farmers if they are presented in a form that they a familiar with, and receptive to. Information in the form or graphics and short videos should be packaged in a social media format such as Facebook, which could be a key tool for discussion-based meetings between farmers and extension or other field staff such as those from the private sector.
- That support to Myanmar be provided to present the case for revising the policy of loans that favour fertiliser applications to monsoon-season rice at the expense of other crops (including irrigated summer season rice).
- Capacity building of Myanmar collaborators in research and supporting facilities, particularly laboratories, should be a priority in future, particularly in agencies willing to commit to research over the necessary timeframes.
- Further development of the approach of this project, starting from determining farmers' objectives and culminating with materials to support discussion-based interactions with farmers could be made, perhaps in generally similar countries such as Cambodia and Lao PDR.
- The responses of monsoon rice to applied N, if applicable to paddy rice production elsewhere, have implications for 'sustainable intensification' R&D strategies. A high-input high-output management strategy promoted for monsoon rice is unlikely to be successful if the yield responses to added N fertiliser are relatively low, or flat, and has increased risks of environmental detriments. A low N input model for monsoon rice leading to more resilient and sustainable farming systems in low-income countries is a potential area for further R&D.

3 Background

Agriculture is the most important sector of the Myanmar economy and accounts for 40% of GDP and 34% of export income. About 70% of the population of 51.4 million live in rural areas (Ministry of Immigration and Population, 2014).

Central Myanmar, encompassing the Central Dry Zone (CDZ) and upper Bago Region, is a major agricultural region producing rice, maize, grain legumes, millet, sesame and sunflower, grown in rotation or as intercrops. The area is recognised as a priority area for the development of agriculture by Myanmar authorities, as communicated to ACIAR and other international agricultural agencies, because of the economic and social needs of the region coupled with development potential. The population of the CDZ and the Union Territory of Nay Pyi Taw is 8.7 million, with an additional 2.5 million in Bago (Ministry of Immigration and Population, 2014). Rainfall in central Myanmar is lower than elsewhere in the country, ranging from 1200 mm in the south to 900 mm in the north near Mandalay, and to 500 mm in the west near Nyaung Oo. The two main crops are rice and maize grown during the monsoonal rainy season. There is a network of irrigation systems servicing 450,000 ha across 130 schemes in Mandalay, Sagaing and Magway Divisions of the CDZ, and 400,000 ha in neighbouring Bago Division, where rainfall is higher, and double or triple cropping is possible.

Crop yields are generally low. Widespread crop underperformance and the need for appropriate soil fertility management in Myanmar have been identified by international agencies, including ACIAR (Koci, 2014, ACIAR Project SMCN/2011/047), and confirmed by field observations and consultations in and around Yezin, Nay Pyi Taw and Yangon. Given the well-known benefits of fertiliser use – the basis of the first “green revolution” when combined with modern crop varieties and irrigation – it may be expected that fertiliser research and utilisation would be widespread in Myanmar. However, the results of searches of existing information undertaken in-country on crop nutrition and fertiliser management for central Myanmar, made at the time of project formulation in early 2014, revealed that there is very little published information available. The annual research conferences of the Myanmar Academy of Agricultural, Forestry, Livestock and Fishery Sciences capture the main research outputs of the official agricultural research agencies of Myanmar each year. From 2001 to 2013 only 13 papers on soils and fertilisers in central Myanmar were presented, and of these only 6 are relevant to rice and maize (others refer to jute and tree crops). Of these studies only one (conducted in 1997) investigated yield responses to N fertiliser and the economics of fertiliser decisions. The others considered nutrient balances, rice varieties and fertiliser application methods. There is surprisingly little local scientific information, and very little economic information, on efficient and cost-effective fertiliser use in central Myanmar.

At the national level there appears to be good market prospects for rice and maize, which are exported from Myanmar, as well as being staple crops for local food security. A World Bank report (World Bank 2014) presented an analysis of the prospects for rice production by Myanmar which set ambitious targets of exporting 2 million tonnes of rice by 2014/15 and 4 million tonnes by 2019/20, although actual performance is lagging behind these targets. The opening of Myanmar’s economy and policy changes combined with improved market prospects for rice exports due to increasing regional demand for rice indicate good opportunities for expansion of rice production. This will provide opportunities for small-scale farmers to sell rice in excess of subsistence requirements as a cash crop. However, there are several constraints in addition to the need to raise yields, including the need to raise rice quality, and improvement of the infrastructure for milling and export facilities.

The World Bank (2014) noted that the most acute problems are at the farm level in the form of low productivity and the need to change farm practices required to match the demands of export markets.

The use of N fertiliser is notably smaller in Myanmar than other countries of Southeast Asia, and is held to be a principal cause of the low yields of rice (Denning et al. 2013; Lwin et al. 2013; Thwe et al. 2014). The average rate of fertiliser application in Myanmar is calculated at just 10 kg N/ha for cereals (rice, maize, sorghum, and wheat), compared with values of 90–170 kg N/ha for neighbouring countries.

Yields of irrigated rice near Nay Pyi Taw were in the range 2.8-4.3 t/ha, with a mean of 3.3t/ha, when no fertiliser was used, and modest rates of basal NPK fertilisers increased the mean yield to 3.7 t/ha (Thiha et al. 2010). Recent surveys of farmers' fields by ACIAR project SMCN/2011/046 indicate rice yields average around 2.5 t/ha, whereas 4 to 5 t/ha should be achievable with adequate fertilisation and crop management. Maize yields were around 1.85 t/ha and significantly smaller than elsewhere with similar agricultural conditions, even though hybrid varieties were grown by farmers (San et al., 2001). One bag per acre of N fertiliser (approx.125 kg urea/ha) applied to maize by farmers could increase maize grain yields to 3 t/ha; in comparison yields of 4.2 t/ha were obtained with the same fertiliser application in experimental plots (San et al., 2001), and greater yield increases are likely if balanced NPK fertiliser is applied. To avoid "mining," fertiliser N must be supplied to growing crops at a rate of about 25 kg N/t grain produced. Field surveys in the project area confirmed that nutrient management is a key factor limiting rice.

During development of the project it was clear that there was little capacity to conduct field research with associated laboratory support in central Myanmar. Stronger agencies, the Department of Agricultural Research (DAR) and Land Use Division (LUD) of the Ministry of Agriculture, Livestock and Irrigation (MOALI), were heavily committed to other activities, including other ACIAR projects. Yezin Agricultural University (YAU) was selected as the principal research partner. YAU is a key agriculture educational agency for the whole of Myanmar and has focussed on teaching rather than research. The project aimed to build research capacity at YAU with the objective of enriching its teaching, in accordance with the (then) Rector of the university. This objective was limited by ACIAR's directive in 2014 to emphasise research and development rather than capacity building. However, a specific subproject on capacity building was conducted with a focus on implementation of field work and analyses of soils and plants. A smaller role in the project was assigned to LUD, principally to access their township-level officers to enable local engagement with farmers. They we also given responsibility for fertiliser quality research as they are the agency responsible for regulation of fertilisers in Myanmar.

The project was initiated with a planning meeting in Nay Pyi Taw on 2-4 May 2016, in conjunction with ACIAR Project LWR/2014/075 (*Land resource evaluation for productive and resilient landscapes in the Central Dry Zone of Myanmar).* ACIAR funds for the project were received at the University of Melbourne in early June 2016 but Myanmar collaborators were not be able to access ACIAR funds until January 2017. In-country research activities were very limited in 2016 but included preparations, such as staff recruitment, planning, and protocol development.

Field trials in central Myanmar were established in January 2017. The execution of the project was constrained by administrative difficulties. By 2018 improvements were made for the management of project funds in YAU with the introduction of new financial reporting by YAU to UoM. The delayed start to the project was addressed by Variation 1 by extending the project by six months to terminate on 30 June 2020. It appears the project was extended for the University of Melbourne, but no extension was made at government-to-government level with Myanmar authorities. By July 2019 it was apparent that YAU and LUD had formal project termination dates in October 2019 and they were unable to receive funds from the University of Melbourne after that time. By the end of 2019 activities in Myanmar were curtailed by the inability to transfer funds to YAU or LUD, although field surveys were conducted by visiting UoM staff and the YAU laboratory was supported. All practical work ceased in early 2020 by the time of lockdowns as a result of the COVID-19 epidemic. The formal termination date for the UoM was re-set to 31 March 2021, although not all activities could be completed as originally envisaged because project travel was not permitted after March 2020. Field demonstration trials were implemented in Myanmar beyond the project period by LUD, but farmer involvement was limited, and communications within the country curbed, after the February 2021 change of government.

4 Objectives

The overall objective was to increase incomes and strengthen local food security of small-scale farmers and their families in central Myanmar by improved fertiliser use and associated crop management practices. To achieve this the original objectives of the project comprised four integrated and contemporaneous sub-projects for RD&E in Myanmar, with supporting activities in Australia:

1. Establish the biophysical basis for appropriate fertiliser use for rice and maize crops in central Myanmar.

2. Determine and address economic and policy related constraints to adoption of improved rice and maize production by fertilisation;

3. Build capacity for the long-term improved nutrient management at the farm level, through training of YAU staff; and

4. Develop decision support systems for rice and maize in central Myanmar and for intensive vegetable production in Victoria, Australia, by integration of the results of the biophysical and social-economic sub-projects.

The objectives, developed in 2014, were largely unchanged during the course of the project although in subproject 4 priority was given to research in Myanmar rather than Victoria, particularly during the difficult early stages of project implementation, and in the form of additional capacity building activities. Additional research was conducted on urea “super-granules” or briquettes, that were being promoted by the International Fertiliser Development Center (IFDC) elsewhere in Myanmar at the time. Additional research was also conducted on developing understanding of the fate nitrogen applied to soils cropped with rice and maize.

5 Methodology

The project's research was based on a programme of field investigations in Myanmar that integrated bio-physical and socio-economic research. The research was supported by capacity building at YAU, and a small complementary component on intensive vegetable production in Victoria.

The project focussed on central Myanmar and had field sites located in a broad alluvial valley near Zeyathiri (Yezin, Laythar) and Tatkon townships (both Nay Pyi Taw Union Territory), and Taungoo township (northern Bago Region), Fig. 5.1.1. The Zeyathiri and Tatkon sites are located in the southern, wetter part (approx. 1250 mm) of the Central Dry Zone (CDZ) whereas annual rainfall at Taungoo (approx. 1500 mm) exceeds that representative of the CDZ.

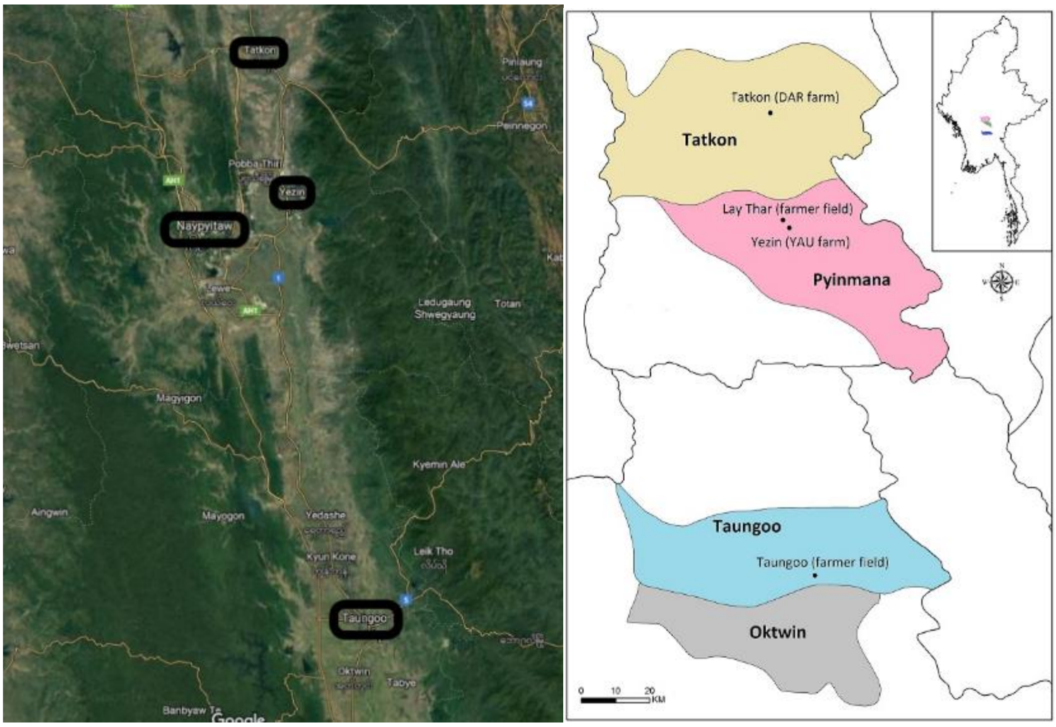


Figure 5.1.1 Locations of the experimental sites in central Myanmar

5.1 Field trials with rice and maize

The core of the crop research was field trials with rice and maize with a goal of improving nitrogen fertiliser use on rice and maize crop in terms of crop production and incomes of farmers. The responses of summer-season irrigated rice, monsoon rice, and monsoon-season maize to N fertiliser were determined. The data were utilised for both biophysical and economics analyses, including model development. For rice, additional trials were conducted to compare urea deep placement (UDP, as developed by the International Fertilizer Development Center, IFDC) to the local farmers' practice of surface broadcasting urea, on grain yield and nitrogen use efficiency (NUE).

5.1.1 Responses of rice to N fertiliser

Field experiments with rice: Replicated field experiments of identical design were established at two townships in central Myanmar to determine the response of rice to nitrogen (N as urea) fertiliser inputs. A site at Yezin (Zeyathiri Township) was located at the Yezin Agricultural University research farm and another at a farmer's field in Taungoo Township, in the north of Bago Region (Fig. 5.1.1) Both sites have alluvial soils with sandy loam top soils. Field experiments with three replicates at both sites were conducted for the summer and monsoon seasons in 2017, which continued for the summer and monsoon season of 2018 in the same field at Taungoo. The YAU research farm had an extended period of flooding in the 2017 monsoon season and the experiment was relocated to a farmer's field about 1000 m away within Sein Sar Bin village of Yezin (Zeyathiri Township). The properties of the soils at each site are presented in Table 5.1.1, and experiment activities and associated dates for 2017 and 2018 are presented in Table 5.1.2. Pedological descriptions of the soils and additional properties are presented in Appendix 11.1.

Table 5.1.1. Basic properties of the soils (0-10 cm) used for the field experiments with rice at Taungoo and Zeyathiri Townships

Site	pHw	EC	TC	TN	Olsen P	eCEC	Texture	PSA (< 2 mm size fraction)			
	pH units	dS m^{-1}	%	%	mg kg^{-1}	cmol(+) kg^{-1}	class	C %	Z %	S (f) %	S (k) %
Taungoo farmer's field	5.8	0.04	0.61	0.06	4	9.6	ZCL	9	16	64	11
Yezin research farm	5.5	0.19	1.1	0.09	7	5.4	CL-S	9	16	48	27
Sein Sar Bin (Yezin) farmer's field	6.5	0.08	0.96	0.18	10	-	SL	5	12	47	36

Table 5.1.2. Timelines of field activities for the summer and monsoon season rice crops at the Taungoo and Zeyathiri Townships sites in 2017 – 2018.

Sites	Activities	Dates			
		Summer 2017	Monsoon 2017	Summer 2018	Monsoon 2018
Taungoo	Seedling transplant	26 Feb	15 Jul	2 Feb	16 Jul
	First split fertiliser application (10DAT)	8 Mar	4 Aug	12 Feb	26 Jul
	Second split fertiliser (PI stage)	27 Apr	28 Sep	3 Apr	19 Sep
	Harvest	13 Jun	23 Nov	28 May	7 Nov
Yezin*	Seedling transplant	5 Mar	1 Aug	9 Feb	23 Jul
	First split fertiliser application (10DAT)	15 Mar	11 Aug	19 Feb	02 Aug
	Second split fertiliser (PI stage)	4 May	5 Oct	10 Apr	26 Sep
	Harvest	26 Jun	26 Nov	17 Jun	14 Nov

* A separate site was used for the experiment in the 2018 summer and monsoon seasons in Yezin.

The treatments for monsoon and summer season rice are summarised in Table 5.1.3. At each site, plots were installed with randomised complete block designs with 3 replicates, except for the farmer's field at Yezin which had four replicates and for which the T100 and T130 treatments were omitted. Experimental plots were 5 m × 5 m delineated by double bund walls 40 cm wide and 30 cm high. There was a one metre spacing between plots in each block and three metres spacing between blocks. To avoid the residual effects of fertiliser, the fields were not fertilised in the preceding season of 2016.

Table 5.1.3. Treatments of the rice trials for responses to urea in 2017 and 2018

Treatment No.	Treatment Name	N rate as urea (kg N/ha)
1	T00	0
2	T0	0
3	T30	30
4	T78	77.6
5	T100	100
6	T130	130
7	T160	160

The plots of all treatments, except for the nil control (T00), received basal applications of P as triple superphosphate at 40 kg of P/ha, S as gypsum at 25 kg S/ha, K as muriate of potash (KCl) at 25 kg K/ha (+ 2 later applications = total of 75 kg K/ha for each trial). The roots of the rice transplant seedlings, with the exception of T00, were dipped in a 2% Zn solution (as $ZnSO_4$) prior to transplanting in order to eliminate Zn deficiency. Twenty-day old rice seedlings were transplanted at a 20 cm hill-to-hill spacing with four seedlings planted on each hill. The plots were irrigated on a regular basis to keep the water depth between 5 cm to 20 cm.

The *Yadanar Toe* rice variety was selected for the field experiments for the dry season in 2017 as it was a common dry season variety grown by local farmers. In 2018, the variety *Sin Thukha* was selected for the Taungoo site, on the basis that it was a popular variety with farmers and was reputed to be more responsive to fertiliser inputs than *Yadanar Toe*. The *Sin Thukha* variety was also grown for the monsoon season crops in the experiment in 2017 and 2018.

5.1.2 Soil characterisation at project locations

Soil and plant measurements: Soil samples were taken to characterise the soils (Table 5.1.1) prior to the application of basal fertilisers and transplanting of seedlings. Each individual plot was sampled (0-20 cm) with a 5 cm diameter corer from 7 randomly located sampling points within the plots, excluding the outer 1 m wide area around the edges. At harvest, when the paddy surface water was drained, soil samples were again collected from each plot for bulk density determinations.

The central 1.8 m × 1.8 m of each treatment plot, comprising of 81 plant hills, was harvested by hand with sickles by cutting the plant just above the soil surface. The total grain weight was determined and the moisture content of the grain measured at harvest using a grain moisture meter. The total fresh weight of the biomass of the rice crop plants from the harvested area was measured and then air dried prior to being dried to constant mass at 65°C in an oven. The dried plant biomass was reweighed to calculate the dry matter biomass weight for the harvested crop plant (minus the grain). The harvested rice grain weight was adjusted to the standard 14% moisture content normally used for rice research. Both the dried biomass straw samples and the dried grain samples were ground to fine powders (< 0.25 mm) for later analysis.

Total N in the dried and ground grain and above ground straw biomass was determined using an adapted micro-Kjeldahl digest method (Horneck and Miller, 1998).

Subsamples of < 2mm air dry soil were finely ground (<0.15mm size) and the soil total N and total organic C contents determined using micro-Kjeldahl digestion with steam distillation (Method 7A1, Rayment and Lyons 2010) and Heanes wet oxidation (Method 6B1, Rayment and Lyons 2010) methods, respectively. Soil pH (1:5 soil/water Method 4A1), electrical conductivity (EC,1:5 soil/water extract Method 3A1), Olsen-P (Method 9C1), and CEC (Method 15D3) using the methods of Rayment and Lyons (2010) were determined on the <2mm ground dry soil samples. Soil mineral N (NH_4-N and NO_3-N) contents were determined on fresh soil subsamples stored on ice in the field prior to being promptly extracted with 2 M KCl on arrival at the laboratory, using the distillation method (Method 7C1, Rayment and Lyons 2011). Soil particle size analysis (PSA) was determined for the time zero control plot soil samples at each site using an adapted version of the pipette method (Method 17, Bowman and Hutka 2002), but finishing with wet sieving in line with international standards. PSA results are presented according to international standard particle size divisions for clay (<0.002 mm); silt (0.002 to 0.02 mm); fine sand (0.02 to 0.2 mm) and coarse sand (0.2 to 2 mm).

Larger scale soil characterisation: A preliminary soil survey was carried out in the Zeyathiri region in May 2017. Soil profiles were examined using a soil auger and according to a 1 km^2 grid imposed on the agricultural area. Three random soil auger samples were described using methods from the Australian Soil and Land Survey handbook (2009) from near the centrum of each grid. Not all grids were described at this time and remaining grids were described on subsequent visits. Additionally, in May 2017, the soil auger method was 'calibrated' against the soil pit methods used by the LWR/2014/075 project team at the four field sites. The preliminary survey helped to identify the main soil types in the Zeyathiri region. In December 2019, soils at all field sites and the main soil types in the Zeyathiri region were fully characterised in soil pits. Measurements of hydraulic conductivity by the ring infiltrometer method were also made in the surface soil and the most impeding layer below that. Descriptions of the principal soils are presented in Appendix 11.2.

Owing to the size of the task the main soils were described but not mapped and survey work focussed on the Laythar and Yezin upland and rice growing areas of the Zeyathiri region. This process was aimed to better understand the landscape context of soils used for fertiliser experiments and to inform crop modelling and DSS development.

5.1.3 On-farm rice trials on urea application methods

The focus of the final year's field experiments in the summer of 2019 was shifted to sites more representative of local farms, and in particular sites with low fertility, light soils, that had not been treated with atypical large rates of fertiliser in the past. The objective of these field experiments was to identify the best N fertiliser application method for summer rice by comparing 'alternative best practices' with farmers' practice at a common N rate.

Identical field experiments were conducted at Sein Sar Bin village, approximately 100 metres from the field trial conducted in the farmer's field at Yezin in 2018, and at an additional site at Taungoo, also near to the sites of the field trials conducted in 2017-2018. The experiments had randomised complete block (RCB) designs with 5 treatments and 4 replicates (Table 5.1.4). The treatments were:

- Control without N input.
- Common farmer practice (FP, as determined by subproject 2) of a 50:50 split of N fertiliser applications between active tillering (AT) and panicle initiation (PI).
- Application of most of the urea at transplanting and incorporation into the mud (75%N) with 25% N at PI as surface broadcast (PU treatment).
- An UDP (75%N) treatment with a supplementary 25% N application at PI; and
- A 3 split surface broadcast approach of applying 30% N at transplanting, 45% at AT, and 25%N at PI (SBC).

Table 5.1.4. Summary of on-farm trial treatments with summer rice 2019 at Taungoo and Sein Sar Bin village, Yezin

Treatment	Urea kg N/ha
Zero N (0 N)	0
Farmer Practice (FP)	70
Puddled in urea (PU)	70
Urea deep placement (UDP)	70
3-split broadcast (SBC)	70

This experiment used larger plots than the previous rice experiments (2017/2018), with plot dimensions of 7 m × 7 m delineated by double bund walls 40 cm wide and 30 cm high. The central harvest area was 3 m x 3 m. There was a 1 m spacing between plots in each block and a 3 m spacing between blocks. All plots received basal applications of P, K, and S. The day before transplanting 40 kg P/ha as triple superphosphate, 25 kg K/ha as KCl, and 10 kg S/ha as gypsum were applied. Additional applications of 25 kg K/ha as KCl were also applied to each plot at the active tillering (AT) and panicle initiation (PI) crop stages, to bring the loading of K to 75 kg K/ha. Twenty-day old rice seedlings (*Sin Thukha* variety) were dipped into a zinc sulphate solution prior to transplanting. At harvest, plants were harvested from the central harvest area of 3m x 3 m, and plant biomass and grain yields recorded.

5.1.4 Dissimilatory nitrate reduction to ammonium (DNRA)

This work was done to investigate the mechanisms by which paddy soils without external nitrogen inputs maintain nitrogen nutrition of rice and produce moderate yields. Soils were collected from Zeyathiri, Taungoo, Kyauktaga, and Kungyangon from sites with both long-term high (~100 kg N/ha) and low N input (0-25 kg/N ha) rice paddies. We used N-15 tracer, N_2-15 uptake, acetylene reduction assay and qPCR to simultaneously investigate N_2 fixation, DNRA, denitrification and related microbial gene abundances. We also determined how varying soil organic carbon-to-nitrate (SOC:NO_3^-) ratios affected nitrate partitioning between DNRA and denitrification by manipulating these ratios through labile organic carbon addition. Detailed methodology used in this study can be found in the publications listed in the section 10.2 (Pandey et al., 2019, 2020).

5.1.5 N-15 tracer methods

The 15-N tracer experiment was conducted within the same experimental plots and locations as described in 5.1.1 during the summer and monsoon season of 2017 and summer season of 2018. However, only four of the 7 available treatments (Table 5.1.3) were used for tracer studies: the control without N fertiliser input (T0), 30 kg/N ha (T30), 77.6 kg N/ha (T78) and 160 kg N/ha (T160).

Stainless steel microplots (80 cm × 40 cm × 40 cm) were installed within the main plots of the T0, T30, T78, and T160 treatments, 10 days after seedling transplanting. The microplots were driven to 20 cm depth and contained 8 plant hills (i.e., 2 rows of 4 plant hills). The microplots received N-15 labelled granular urea (10.1 atom% ^{15}N), instead of standard urea on the same day and at the same rate as urea-N application to the main plots (10DAT and PI stage). Two microplots were installed within the main plots of the T78 treatment to trace the fate of N-15 applied at the 10DAT and PI stages separately. This was done by applying the first split N dose as N-15 labelled urea and the second N dose as unlabelled urea in one of the two microplots, and the first split N dose as unlabelled urea and the second N dose as N-15 labelled urea in the second microplot. The N15 values from these two microplots were added to determine the total N-15 recovery in plants and soils in the T78 treatment. The water within all the microplots was maintained at the same level as the main plots by topping up the microplots with fresh irrigation water. The microplots were installed at a separate point within a plot each season. The N-15 microplots were not continued into the wet season of 2018.

At harvest, the crop plant material and the soils within each micro-plot area were sampled carefully immediately following the sampling of the harvest area of the main plots of all treatments at each experiment site. The crops were harvested at ground level and the grain separated from the plant biomass straw, and these samples were air dried and then dried to a constant mass at 65°C, and weighed. The micro-plot plant biomass straw and grain samples were initially milled to 2 mm following strict protocols to avoid cross contamination, and subsampled for milling to a fine powder (< 50 µm). Soil samples to 20 cm depth were also collected from the microplots and dried and milled to < 50 µm.

Total nitrogen, the nitrogen ^{15}N/^{14}N isotope ratios and total carbon content were quantified on weighed subsamples of dried ground soil (~50 mg) and plant straw and grain materials (~4 mg) from the N-15 micro-plots, using a mass spectrometer following combustion at the University of Melbourne stable isotope laboratory. Analyses were performed on an ANCA GSL elemental analyser paired to a Sercon Hydra 20-20 (isotope ratio mass spectrometer). Weight % (w/w %) data was calculated using the areas under mass spectrometer responses or TCD and calibrated against acetanilide sourced from ThermoFischer. Analysis was also performed on a Flash 2000 HT paired to a Thermo Delta V Advantage. Data were acquired using Callisto v6.27 or Isodat 3.0. In addition, the corresponding plant and soil samples from the zero N treatment (T1) plots were used as the natural abundance control samples for these analyses and subsequent calculations.

5.1.6 Urea deep placement

In addition to the 7 treatments described in the section 5.1.1 (Table 5.1.3) an additional treatment, urea deep placement (UDP), was included in the trials at Taungoo and Yezin in the summer and monsoon seasons of 2017, and the summer season of 2018. The UDP treatment plots were managed exactly in the same way as other 7 treatments, except for the N input technique. A 2.7 g urea briquette was placed at 75 mm depth at a central position between four hills and between alternate row and column of plant hills. Thus, each group of four plant hills received one briquette centrally located between them at the rate of 77.6 kg/ N ha. This rate was recommended by the International Fertiliser Development Center (IFDC) and compares directly to the surface broadcast practice of the same rate in the T78 treatment (Table 5.1.3). The deep-placed urea briquettes were applied to the plots at 10 DAT as a single dose. For experimental purposes the urea briquettes were placed by hand instead of using the farmer's standard applicator. In addition, N-15 microplots were included in the UDP treatment to trace the fate of N applied in the urea briquette. The microplots were managed as described in 5.1.4.

5.1.7 Responses of maize to N fertiliser

Replicated field experiments of identical design were established at two locations to determine nitrogen fertiliser responses by maize grown in the monsoon season. The two sites were a farmer's field at Laythar in Zeyathiri and at the DAR research farm at Tatkon. The soils at both sites were heavier than those used for rice and exhibited vertic properties such as deep surface cracks when dry and self-mulching surface soils when moist. Some key properties of the surface soils of the two sites are presented in Table 5.1.5. Maize crops were grown in the monsoon seasons of 2017 and 2018, with a cover crop of black gram grown in the dry season in between the two maize crops. The main field activities and associated dates for 2017 and 2018 are presented in Table 5.1.6.

Table 5.1.5. Basic properties of the soils (0-10 cm) used for the maize field experiments.

Site	pHw	EC	TC	TN	Olsen P	eCEC	Texture	PSA (< 2 mm size fraction)			
								C	Z	S (f)	S (k)
	pH units	dS m^{-1}	%	%	mg kg^{-1}	cmol(+) kg^{-1}	class	%	%	%	%
Tatkon	7.3	0.08	1.18	0.11	36	25.7	ZCL	12.5	42	44.4	1.1
Laythar	6.5	0.07	1.17	0.10	31	24.4	ZCL	15.4	48.1	34.8	1.7

Table 5.1.6. Timeline for activities for the field experiment maize crops in the monsoon seasons at the Tatkon and Laythar sites in 2017 and 18.

Tatkon		
	Season	
Activity	**Monsoon 2017**	**Monsoon 2018**
Maize variety	'CP888'	'CP888'
Sowing seed + basal NPK fertiliser	21 May	20 May
2nd split Application N fertiliser (21 DAS)	11 June	10 June
3rd split application N fertiliser (35 DAS)	25 June	24 June
Harvest	18 Sept.	17 Sept.
Laythar		
	Season	
Activity	**Monsoon 2017**	**Monsoon 2018**
Maize variety	'CP888'	'CP888'

Sowing seed + basal NPK fertiliser	23 May	22 May
2nd split Application N fertiliser (21 DAS)	13 June	12 June
3rd split application N fertiliser (35 DAS)	27 June	26 June
Harvest	13 Sept.	12 Sept.

Field trial design: The experiments at both sites had an identical randomised complete block design with 7 treatments and 3 replications. The plots were 7.6 m × 7.6 m in size. There was a 1 m spacing between plots in each block and a 3 m spacing between blocks. Maize was planted in rows within the 3 m wide spaces between blocks and within the 4m buffer area, which surrounded the whole field experiment site. The 7 treatments included no external inputs (nil) and 6 rates of urea N fertiliser: 0 (T0), 30 (T30), 60 (T60), 120 (T120), 180 (T180) and 250 (T250) kg N/ha. For each N rate urea was applied in 3 split applications with 14% of the N just prior to planting (time zero), 43% of the N applied at 21 days after sowing (21 DAS ~ crop stage V2 – 2 leaves fully emerged) and 43% of the N applied at 35 days after sowing (35 DAS ~ crop stage V8 – 8 leaves fully emerged). These splitting proportions were based on those for local DAR farmer recommendations for N fertiliser for maize. The urea was surface applied down the line of seeds and then covered with soil using an ox-drawn plough tine adjacent to the plant line, according to local practice. Prior to sowing, all treatments received basal fertilisers (50 kg P/ha as triple P, 50 kg K/ha as KCl, and 25 kg S/ha as gypsum) as well as their basal time-zero split application of N, applied along the row and manually incorporated into the soil with hoes. Potassium (K) as KCl was also applied later at a rate of 25 kg K/ha at 25DAS and then again at a rate of 25 kg K/ha at 40 DAS.

The experiment fields were prepared by several passes with a traditional ox-drawn plough according to local practice. But due to variability in plant row spacing, plant lines had to be accurately re-measured at the 76.2 cm spacing and installed manually with hoes following accurately located string lines prior to fertiliser applications and sowing. The maize seeds were sown manually at 22.5 cm spacing along the plant line furrows, using a stick marked with 22.5 cm spacings as a guide. Therefore each 7.6 m × 7.6 m plot contained 10 rows of 33 plants.

The maize variety 'CP888' was selected for these field experiments because it was the most common variety grown by local farmers. 'Black gram' (*Vigna mungo*, mung bean) was grown as a cover crop in the dry season between the two maize crops. No N fertiliser was applied to the black gram crop, and all plant material was removed from the field trial sites so that the cover crop did not add any N to the soil.

The monsoon season maize crops were grown as rainfed crops with minimal irrigation as much as was possible. The one exception was the maize crop at the Tatkon site in the 2017 monsoon season which received irrigations on two occasions during dry conditions. The maize crop at the Laythar site experienced severe waterlogging across the entire field trial site as a result of a prolonged heavy rainfall, release of water from Yezin dam, and poor site drainage. This had an adverse effect on the subsequent growth of crop, especially for the lower N rate treatments.

Soil sampling of the main plots: At the start of the experiment prior to the application of basal fertilisers and sowing, composite soil samples were taken from each plot for the 0-10 cm depth from 7 randomly located sampling points within the plots (excluding the outer 1 m wide area around the edge of the plot). Following thorough mixing of the composite sample, a small subsample (~80g) was taken and placed on ice for mineral N analysis in the laboratory, and a larger subsample (~800g) was taken and air dried to constant mass and sieved to < 2mm for other analyses. To determine soil bulk density samples were taken from 4 randomly selected locations within each plot. Intact soil core samples (5 cm diameter × 5 cm high) were collected using a bulk density sampler at the 2-7 cm and 13-18 cm depths, to represent the 0-10 cm and 10-20 cm soil depths for later soil nutrient conversion calculations.

Sampling of crops at harvest: The central 2.5 m × 2.5 m of each treatment plot was designated as the harvest area. A total of 20 randomly selected plants were harvested from within the harvest area by cutting them at the soil surface level. The maize ears were separated from the rest of the plant. Total weights of plants and ears from each plot were determined before drying to a constant mass at 65 °C. Total dry weights of plant, husk, kernel and cob were determined for each plot and converted into t/ha. Dry weights were calculated for the stover (biomass of the plant minus the kernel grain) and the kernels. For each plot, the dried samples of plant (minus ears), husk, and cob were combined into a composite subsample (based on their relative proportion of dry biomass) to represent the 'whole plant minus the kernel grain' or 'stover' sample. These were ground to a fine powder (< 0.25 mm) for later analysis. Likewise, the dried grain kernel samples for each plot were ground (< 50 µm) for later analysis. Soil and plant samples were analysed as described in the section 5.1.2.

Micro-plots and N-15 urea tracing: The stable isotope (N-15) technique was applied to trace the fate of the N applied as urea fertiliser at each sites in the 2017 monsoon season. Non-enclosed micro-plot areas (0.76m x 0.91m) enclosing 4 plants in a single plant row were used for the application of N-15 enriched urea. The exact location of the micro-plots were carefully marked with pegs in each corner. The micro-plots were placed along a single plant row in a randomly selected location (only 2 plants away from the central harvest area of the plot) within each plot. The micro-plots were established and pegged out at the time of sowing. The micro-plots received the same rates of fertiliser applied in the same manner (surface applied down the plant line and then covered over with soil) and at the same time as the rest of the plot, the only differences being that the urea N fertiliser applied in the micro-plot was enriched with 10.1 atom% N-15. Micro-plots were installed into the plots of treatments T3 and T4 corresponding to 60 kg N/ha and 120 kg N/ha N fertiliser application rates. The urea for the micro-plot areas was carefully weighed to 4 decimal points to deliver the N rate for each application for each given treatment, and carefully applied to the area within the micro-plot.

At harvest, the crop plant material and the soil within each micro-plot area were sampled carefully immediately following the sampling of the harvest area of the main plots of all treatments at each experiment site. The crops were harvested at ground level and the ears separated from the rest of the plant biomass straw, and these samples were air dried and then dried to a constant mass at 65 °C, and weighed. The grain kernels were removed from the cobs for each ear. A representative subsample of the 'plant material minus the grain kernel' and the 'grain kernel' were then taken and ground down to a fine flour (< 50 µm) for later analysis.

Five randomly located slices of soil perpendicular to the plant line were taken from each micro-plot, each 76 cm long x 5 cm wide by 20 cm deep. Composite soil samples for the 0-10 cm and 10-20 cm depths taken for each micro-plot, by bulking the soil slice samples together for these two depths and then mixing and subsampling for the final sample for analysis. These soil samples were air dried to a constant mass and sieved to < 2mm and finely ground to a powder (<50 µm) for analysis. The soil bulk density results from the whole of plot soil bulk density sampling at harvest time were used for the nutrient conversion calculations for both the whole of plot and micro-plot soil sample analysis results. Soil and plant samples were analysed as described in the section 5.1.5.

5.1.8 Crop modelling methodology

The Water and Nutrient Management Model (WNMM) crop simulator (Li et al., 2007; Hu et al., 2010) was calibrated and validated for the project trial sites and then used to simulate crop yields and their response to N fertiliser.

Firstly, historic weather data (1997-2018) were prepared, in which the solar radiation was estimated using software of RadEst 3.0 (global solar radiation estimate, (http:/www.isci.it/tools/RadEst) with DOY, Rainfall, Tmax, Tmin as input parameters.

The WNMM model was calibrated with two-years (2017-2018) of field observation data for Laythar, Tatkon and Taungoo, and one year (2017) field observation data for Yezin.

Scenario simulations for crop rotations at different N rates at four sites were run for 1997-2018. For maize, the criterion for having a dynamic sowing date was when the available soil water in the topsoil (0-20 cm) was greater than 20 mm, otherwise the sowing date was shifted one day later until the condition was met. For summer rice, the previous year's annual rainfall was used to constrain the daily growth rate of summer rice.

5.1.9. Nitrogen losses from intensive vegetable production in Victoria

The original plan for the project included a research component in Victoria to complement research in Myanmar and to provide training opportunities for Myanmar collaborators on advanced methods of determining the fate of N applied to crops. However, the Australian component was reduced to allow greater than expected support to the research in Myanmar.

A field experiment was conducted to examine how alternative fertilisation strategies - reduced N fertiliser inputs and the use of nitrification inhibitor (DMPP) - affect crop yield, N use efficiency and N_2O emissions, compared to the grower practice, in an intensive celery production system in Victoria. Details are presented in Suter et al. (2021). The experiment was established at a commercial farm in Boneo, Victoria (38° 21’S, 144° 45’E). The soil in the area was classified as a Tenosol. The surface soil (0-15 cm) was a slightly alkaline pH (7.9, pHw 1:5) sandy (>91% sand) with 6.4 g organic carbon kg^{-1} and 0.8 g N kg^{-1}. We investigated N recovery by celery plants under existing standard grower practice (GP) in the region and compared this with alternative N fertilisation strategies. A 15-N tracer microplot study was used to determine N recovery from fertilisers at different growth stages of the celery, and N_2O emissions were determined in samples from gas collection chambers.

5.2 Assessment of Fertiliser Quality

The project focused on the quality of commercial inorganic fertilisers in the project areas near Pyinmana (19°74’43”N, 96°21’78”E ,Nay Pyi Taw Union Territory, including Laythar, Zeyathiri and Yezin), Tatkon (20°09’81”N, 96°19’41”E) and Taungoo (18°09’81”N, 96°19’40”E) Townships. Commercial fertiliser samples available in local markets were collected and tested for conformity with bag labels during the dry season. By January 2017 a total of 233 commercial fertiliser samples were taken at random from wholesalers, retailers and local distributors in the surveyed townships. Seventy-five dealers and ten fertiliser inspectors from DoA were interviewed. Extensive data were collected from each of the dealers interviewed to capture their perceptions of fertiliser quality, sales in 2016 and dealer training requirements. Interviews were held with the owners of shops who make the decision on bulk fertiliser purchasing and selling activities. The field investigations of fertiliser physical characteristics such as caking, impurity, and granular degradation involved site visits to dealers’ shops and warehouse locations. A second round of sampling was made in the wet season of 2017 with a focus on compound, high analysis P and potassium fertilisers. Thirty one samples were collected from 15 retailers and six separate wholesalers from Taungoo, Tatkon, Pyinmana and Zeyathiri townships.

Fertiliser samples collected in 2017 were sent to both the LUD laboratory in Yangon, and the University of Melbourne (UoM) soils laboratory in Melbourne, for total N, P and K analysis. The LUD laboratory used the following methods: Total N, Kjeldahl method (Horwitz et al., 1970); Total P and K, aqua regia digest (HCl and HNO_3) with colorimetric and flame photometer finish respectively. The UoM laboratory used the following methods: Total C/N, LECO combustion at 1350 ˚C in a stream of oxygen; Total P and K by digesting 0.1 g of fertiliser with 3 ml HNO_3 and 0.5 ml of HCl with ICP-OES finish. Additionally phosphorus containing fertilisers were analysed for cadmium by the UoM laboratory only using 0.3 g of fertiliser and digesting with 3 ml HNO_3 and 2 ml $HClO_4$ with an ICP-OES finish.

Descriptive analysis was used to analyse the data collected. Simple linear regression analysis was used to investigate possible relationships between laboratory results and bag label. This was conducted using the discrete sample data and the regression (REG) procedure in SAS (SAS Institution, 2002).

5.3 Economic aspects of fertiliser use

5.3.1 Introduction

The overall integration for this type of project is provided by the traditional agricultural economics and farm management economics sub-disciplines of economics, which have been developed specifically to address questions analysing decisions about the management of farm systems in both developed and developing countries. The agricultural economics (AE) framework for agricultural decision making is exemplified by texts such as Anderson et al. (1977) and Hardaker et al. (2004). The farm management economics (FME) framework for analysis of agricultural systems and farm decision making is described by Makeham and Malcolm (1986) and Malcolm (1990). AE and FME integrate information from bio-physical disciplines (soil science, crop science, agronomy, animal science) and other disciplines such as climate science and systems thinking, with economics as the core discipline (e.g., Dillon (1976) and McConnell and Dillon (1997)).

The AE and FME sub-disciplines provide an integrating framework for the project. The Production Economics Framework (part of AE and FME) is at the heart of agricultural economics methods and is comprised of three components (Anderson et al. (1977), Hardaker et al. (2004)):

- A farmer objective (initially profits, but this can be adjusted to incorporate risk aversion by farmers),
- A yield response function (called a production function in AE literature), and
- A set of prices, principally of the crop inputs (e.g., fertiliser) and crop outputs (sale price of products).

In applying the AE/FME framework to this project the following activities were conducted by the socio-economics sub-project:

- Focus Group Workshops (FGWs) with local smallholder farmers at the beginning of the project to gather their opinions, establish their goals and means, and build an inventory of their knowledge about issues affecting their production systems.
- Conducted a literature review of the use of Decision Support Tools (DSTs) in agricultural industries in developed and developing countries.

- Statistically analysed the farm survey results to explain likely adoption of DSTs by these farmers.
- Conducted a workshop on DSTs in Melbourne.
- Conducted two surveys of the local population of smallholders to determine their farm and family characteristics (cropping systems, soils information, farm area and resources, family size).
- Used the farm survey results to obtain a full picture of current nutrient management practices by farmers in the project area and compared their management to 'common management practice' and local Department of Agriculture (DoA) recommendations,
- Analysed the farm survey data to develop a typology of farmers in the sample.
- Conducted follow-up FGWs with farmers in each farm type to determine whether they were likely to be interested in using a predictive DST to inform their decisions about fertiliser.
- Used the field trial data for yield response of summer rice, monsoon season rice and maize, and economic information to determine an Economic Optimum N Rate for N use for each crop type and location and compared these N rates with DoA recommendations and actual farmer practices for N fertiliser use.
- Wrote a short description of historical and current government and finance policies in Myanmar relating to rice production, sale, and finance.
- Developed whole-farm models to assess the likely farm-level profit changes if improved N fertiliser management is implemented at the farm level, and assessed other changes in crop choices and use of family labour, and
- Integrated the essential outputs of sub-projects, developed a framework for discussion support on social media, which could be implemented to assist with fertiliser management decisions by individual smallholder farmers in Myanmar.

5.3.2 Focus Group Workshops 2017

In March 2017,18 focus group workshops (FGW) were conducted in 18 villages located within Tatkon, Zeyathiri and Taungoo townships (Fig. 5.1.1). The objectives were to elucidate the smallholder farmers' perceptions of their farming systems and family livelihood decisions, and to determine their knowledge, understanding and attitudes to crop production and fertiliser use. Other aspects of their production systems such as climate, water, livestock and labour/mechanisation were also investigated.

Villages were selected based on their proximity to the project trial sites and with the help of local DoA extension staff (Fig. 5.3.1). The names of the villages and total numbers of farmers attending FWGs are shown in Table 5.3.1. A total of 158 farmers attended the workshops, of whom 20 were female. The FGWs focused on discussing six main questions which were open-ended requiring qualitative responses:

1) Please describe your farm – crops (and varieties), livestock, cropping sequences and season types, including irrigated or rainfed agriculture, and crop sequences and patterns,
2) What are important issues with respect to your farms, we want to determine your perceptions about important issues. Who do you mainly talk to with respect to information for your farm decisions - other farmers, Government extension officers, Non-Government Organisations (NGO), or retailers/shops for fertiliser and seeds?
3) What are your objectives, motivations, and priorities?
4) Do you have any farm family members who work off the farm and send money back to the family? Or more generally, what about labour supply, wages, and challenges?
5) The climate, in your opinion is it getting worse or better (drier or wetter, hotter?). How many times in the last 10 years have you had a crop failure?

6) What is your knowledge about fertiliser concepts? Do you think that soil fertility must be replenished after you grow and harvest a crop?

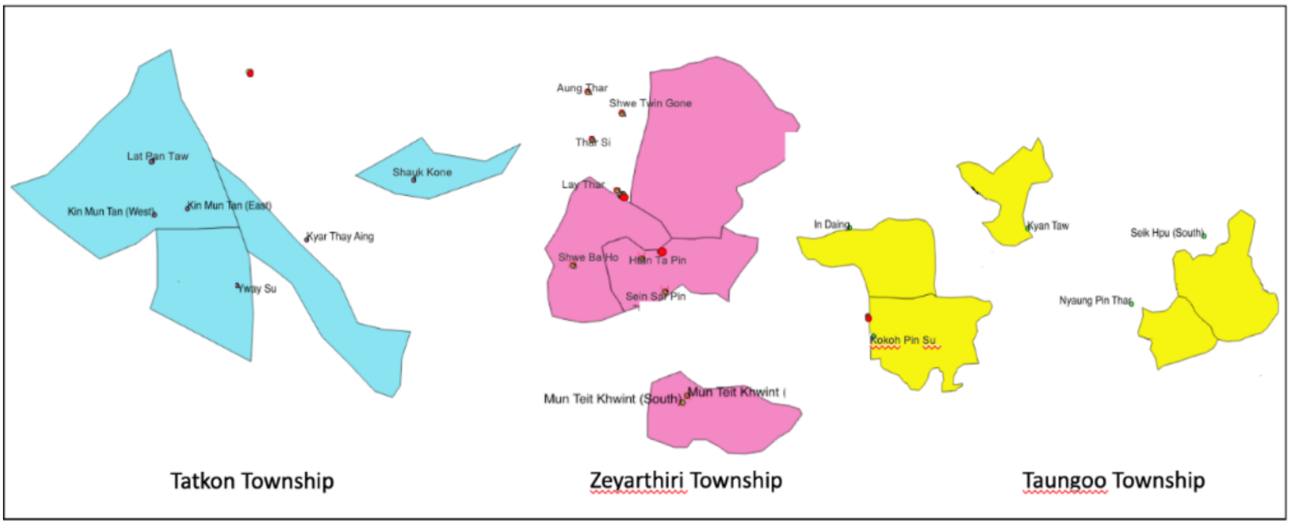


Figure 5.3.1. Selected villages for the survey
red dots represent the project trial sites

Table 5.3.1. Villages and the number of farmers participating in the FGWs.

Township	**Village Name**	**Interview Location**	**Population(estimated)**		**Farmer Group Size**		
			Household	***Farmers***	***Male***	***Female***	***Total***
Tatkon	Lat Pan Taw	KC*	250	200	12	0	12
	Kin Mun Tan	Farmer house	200	110	13	0	13
	Yway Su	KC	700	350	8	2	10
	Kyar Thay Aing	KC	500	250	5	0	5
	Shout Kone	KC	365	220	5	0	5
Zeyathiri	Sein Sar Pin	KC	500	350	10	0	10
	Shwe Ba Ho	KC	90	25	4	0	4
	Htan Ta Pin	Farmer house	100	35	6	0	6
	Lay Thar	Farmer house	400	100	6	0	6
	Mun Teit Khwint	Farmer house	213	55	3	2	5
	Aung Thar	Farmer house	210	100	3	3	6
	Thar Si	Farmer house	135	20	4	1	5
	Shwe Twin Gone	Farmer house	254	10	5	2	7

Taungoo	In Daing	Farmer house	340	300	10	5	15
	Kokoh Pin Su	Farmer house	100	24	7	3	10
	Kyan Taw	Farmer house	107	70	16	1	17
	Nyaung Pin Thar	Farmer house	300	70	16	1	17
	Seik Hpko	Farmer house	360	180	5	0	5
Total			5124	2469	138	20	158

***Knowledge Centres or Knowledge Transfer Centres.**

5.3.3 Surveys

Two field surveys were conducted to obtain information on the farming systems and on-farm management practices in central Myanmar. The surveys were also designed to understand how farmers make decisions about fertiliser use. The questionnaire contained questions relating to household demographics, farmland and crops, inputs including labour, outputs, and other sources of income. The questionnaire also included questions specific to farmers' fertiliser and water use and other factors that influence their decisions on fertiliser use. The surveys were carried out in the three project townships (Figs. 5.1.1, 5.3.2). Ethical approval for the research was obtained from the research ethics committee of the University of Melbourne (Ethics ID: 1851136).

Preliminary Survey 2017: A preliminary survey was conducted in May 2017. In total, 232 farm households were interviewed from 15 villages. The villages were selected at random with the help of local extension staff. Ten postgraduate students from Yezin Agricultural University were trained as enumerators to conduct farmer interviews. They were given two days of training on the use of the electronic questionnaires that had been uploaded onto the CommCare® application and downloaded to Android tablets. CommCare® is a customisable, open-source mobile platform that enables non-programmers to build mobile applications for data collection (see www.commcarehq.org). All enumerators were experienced with the use of Android mobile phones. The training covered familiarisation with the app, the questionnaire, how to take GPS coordinates, administration of informant consent, capturing digital images and pilot testing in the field with some volunteer farmers.

Detailed follow-up Survey 2018: Based on experience from the preliminary survey, a more extensive and comprehensive survey was conducted in May 2018.The questionnaire for this survey is included as an Appendix in Thar (2021). A buffer zone with a radius at 6 km was made and grids of 1000 m x 1000 m were overlaid on maps of each trial site. Ten villages were selected from each township (total 30 villages) that fell within the grid and containing the largest populations of farmers (Figure 5.3.2). The purpose of the grid was to generate samples of villages that provide diverse farming contexts. The GPS locations of the villages were obtained from the Myanmar Information Management Unit (MIMU) (www.themimu.info/gis-resources) and the farmer population data of the respective villages were obtained from the Department of Agriculture (DoA) Myanmar. The 2018 survey also included collection of information on farmers' access to mobile phones (smart phones) and usage (contributing to section 5.5, below).

A stratified systematic sampling technique was used to randomly select the farmers for each location from farmer population lists provided by the village chiefs and extension staff. Farmers were stratified by crop type and gender to ensure sufficient observations for each farm type covering a wide representative of farmer groups with different cropping systems. To generate a representative sample of the farmer populations in each township, 6% of the farmers from each township were randomly selected, providing a total of 600 respondents (258 respondents in Tatkon township, 196 respondents in Zeyathiri township and 146 respondents in Taungoo township). A ratio of 8:2 for male and female farmers was selected based on the gender ratio within the population in the study area. The same Android tablets with the CommCare® app used in the preliminary survey were used to collect this data. One day of training was given to the enumerators to refresh their CommCare data collection skills, and feedback from the previous survey was provided. In the detailed follow-up survey, each enumerator completed no more than 4 or 5 interviews per day. Reducing the number of enumerators to four, and limiting their numbers of the interviews each day, improved the quality and consistency of the data.

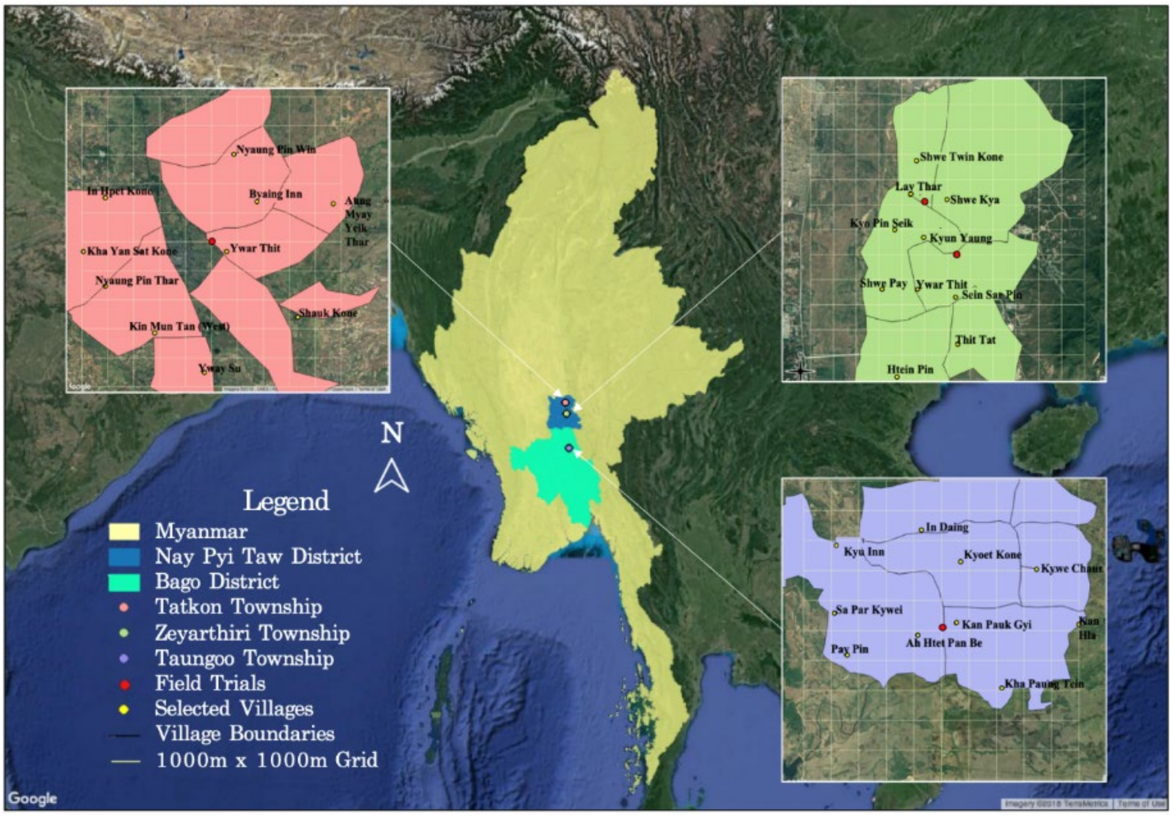


Figure 5.3.2. Map of Myanmar showing the study locations for the detailed follow up survey

5.3.4 Review and discussion of decision support tools

A literature review was conducted as part of the PhD thesis by Ms. So Pyay Thar (*Development of a Decision Support Framework to Assist with Fertilizer Decisions in Myanmar*) (Thar 2021). In addition, a workshop was held at the University of Melbourne in November 2019 (*Nitrogen fertiliser management for cereal crops in Central Myanmar: Farmer decisions and tools for decision support*) (Farquharson 2019). Eight people presented at the workshop and additional attendees participated in discussions.

Development of an interactive platform using social media (Facebook): One of the main challenges associated with DSTs is the limited on-going funding to maintain and update the tools (Gallardo et al. 2020). Studies have reported that most of the developed tools are no longer in use after project funding stops and there is no further financial

support (Hochman and Carberry 2011; Rose et al. 2016; Gallardo, et al. 2020). A study by Thar et al. (2020) found that incorporating useful information and decision support functions to social media platforms could have a more useful and sustainable impact, at the same time eliminating the issues of most DSTs such as lack of awareness, lack of use and long-term servicing and sustainability. According to their survey, most of the farmers in Myanmar were already familiar with information received through Facebook groups. Hence, a Facebook page for the project was created to instigate an interactive discussion platform. Useful video clips, simple budgeting functions, fertiliser yield response predictions are also to be incorporated into the platform for exchanging knowledge and networking among industry stakeholders and farmers.
The project Facebook profile was created under the name Nutriment Management Central Myanmar (https://m.facebook.com/Management-of-nutrients-in-Central-Myanmar-106653474866389/)

5.3.5 Analyses of data

Focus group responses from the focus group workshops were translated to English and analysed in NVivo Qualitative data analysis software (version 12.3.0). Typology Analysis (Gorton et al., 2008; Kobrich et al., 2003) was used to create farm household types based on socio-economic characteristics. Probit analysis (Greene, 2003) was employed to determine the socio-economic factors influencing the use of agricultural apps mobile apps by each farm type.

5.3.6 Focus group discussions

The focus group method (Krueger, 1988) was used to collect qualitative data. FGDs are designed to obtain participants' perceptions on a well-defined area of interest and are found to be a valuable way to obtain a range of perceptions, feelings, and opinions by interviewing groups of people (Yin, 2011). The objective of the FGDs was to introduce the concept of a mobile-based DST to Myanmar farmers and find out how they felt about using such tools in making their fertiliser decisions. In FGDs, opinions of individual participants are converted to a shared group opinion (Kraaijvanger et al., 2016). FGDs were conducted with farmers of six farm types in January 2020. At these discussion groups farmers were asked about their attitudes to DSTs and ideas for alternatives.

A total of 34 farmers participated in the FGDs. The list of farmers in each group was obtained from the household survey. Farmers from each group were selected at random and invited to group discussions with the help of the agricultural extension officers. The FGDs provided farmers with the opportunity to be involved and for researchers to better understand farmers' beliefs and attitudes towards mobile-based fertiliser DSTs.

5.3.7. Discussion of rice policy in Myanmar

A review of historical and current agricultural policies in Myanmar with respect to paddy rice production and marketing was conducted to develop an understanding of the framework and culture in which paddy rice has traditionally been produced. The review also included policies on land tenure (and tenancy rights) and finance/credit regulations. These policies have implications for fertiliser management since most smallholders must borrow money to buy fertiliser and the interest rate payable and terms of loan repayments have implications for crop fertility management.

5.3.8 Calculation of economic optimum N rate (EONR)

The production economics framework (section 5.3.1) method and the application of marginal thinking means that an economic optimum input rate can be determined.

Essential information for applying this framework is the yield response to the application of additional units of the limiting (fertiliser) input. The field trials (section 5.1) at the four locations provided field-level yield responses (or production functions, section 5.3.1) for this analysis.

The determination of 'economic optimum N rates' (EONR) must be considered in the context that farmers must borrow money to buy fertiliser. Borrowing capital from a bank or other finance source, and the requirement to repay of principal and interest, is at the forefront of many farmer's minds and has implications for smallholders in making crop fertiliser decisions.

The EONR determines the rate of N fertiliser application that a profit-oriented farmer would use to maximise profits if he or she was certain of attaining the predicted crop yield. The EONR is found where marginal revenue equals marginal cost for an incremental addition of fertiliser. However, because of variations in yield across soil types and landscapes, and between seasons (climatic variation), there is a distinct possibility of different yields obtaining from any given N application in any year. Hence farmers are often cautious (or risk averse) in deciding how much N fertiliser to apply due to the chance of crop failure or lower than expected yields. A crop failure associated with borrowed finance causes severe financial difficulty. Since farmers generally borrow money to buy fertiliser and pay interest on the loan, the risk of a crop failure is an important reason for caution in applying higher rates of fertiliser. The method of CIMMYT (1988) was followed in this analysis, where a target return on investment (ROI) was used for assessing marginal investments in fertiliser.

A 100% ROI target (termed EONR100) was applied to develop indicative N rates for on-farm use. It requires that for every 1,000 kyats invested in fertiliser, the farmers expect (or requires) 2,000 kyats return, based on their expected yield improvement. This is the '2 for 1' rule recommended by CIMMYT (1988). It is used to incorporate the likely risk aversion attributes of smallholder farmers in developing countries (Llewellyn and Brown 2020).

In any case it is not possible to be too precise about an EONR recommendation because of the well-known flatness of economic responses near the level of maximum yield (Pannell, 2006). The EONR100 is likely to be lower than the EONR.

Application of the production economics framework (section 5.3.1) to determine an EONR relies on smoothed (regression) lines being developed for sets of crop yield responses to added fertiliser. Visual inspection of these yield responses indicates diminishing-returns shapes (yields increasing at a decreasing rate leading to a yield plateau). Responses of the diminishing-returns type are common in biology and elsewhere (Thornley and France 2007). For more than one nutrient, the lack of substitutability between nutrients (based on von Liebig's 'law of the minimum') led to the development of a linear response and plateau (LRP) function. There has been debate about crop response functional forms between the agronomic (LRP) and economic (smooth concave functions) points of view. There are implications from this choice for the shape of the response function and the degree of substitutability between two or more nutrients. Berck and Helfand (1990) resolved the issue by illustrating that the effects of spatial variability in soil conditions (across the field) and temporal variability in crop planting and flowering dates resulted in a LRP form for individual plants and a concave response in the more general case.

A modified Mitscherlich-Baule functional form was used to estimate the smoothed responses for economic analyses of the project field trial crop yield responses. The relationship is crop yield (Y) depending on N applied, all other inputs held constant (or not limiting). This modified M-B functional form allows a yield intercept which may differ from zero, a concave shape, and an asymptote for the maximum crop yield.

5.3.9 Whole-farm models

Representative whole-farm models were developed to assess the likely impacts of improved fertiliser management on the farm family. The project research questions related to whether raising rice and maize yields by changed fertiliser practices could realistically increase farm profits. Can improved fertiliser use and associated crop management practices increase incomes and strengthen local food security for small-scale farmers?

Whole-farm models based on the farm typology analysis were developed to translate yield improvements on a per ha basis into likely whole-farm impacts. Information on average farm areas (upland and lowland), average family size, typical crop rotations and other resources was included. Three possible changes were evaluated to improve farm-family income:

1. An improvement in crop fertility management, or
2. A change in crop rotations by including higher-value crops, or
3. An increase in family labour being employed off-farm with extra money being remitted back to the farm family.

Optimising models can be developed based on the linear programming method (Pannell 1997; Paris 1991) to assess these possible changes.

An initial analysis using spreadsheet models with gross margin budgets was used to answer questions about the implications of possible farm-level changes.

5.4 Capacity building at YAU

Capacity building at YAU consisted mostly of on-the-job learning by doing research, and by mentoring of YAU staff by those from UoM, following the ACIAR model of project execution, supplemented by intensive courses presented by UoM staff at YAU. This applied to the work on socio-economics (presented on section 5.3.3), laboratory upgrade, planning and execution of field research with rice and maize, sample handling, data management and interpretation. Specific training activities are reported in Section 7.6 (below) including targeted presentations and laboratory demonstrations and a small project scheme. Capacity building also extended to LUD to a lesser extent in the form of data management and interpretation, and cross comparisons of their laboratory results with those of UoM.

5.5 Decision support development

Decision support tools were (DSTs) were appraised by the socio-economics subproject. A comprehensive literature review was included as a chapter of the PhD thesis (Thar 2021), published as Thar et al. (2020), and a workshop was held in November 2019 at the University of Melbourne (Farquharson 2019). The presentations and discussions at the workshop '*Nitrogen fertiliser management for cereal crops in Central Myanmar: Farmer decisions and tools for decision support*' workshop were aimed at developing an improved DST for farmers' fertiliser decisions by smallholders in the project areas or to develop something with a wider scope to include broader environmental impacts of N fertiliser use.

Development of a DST for central Myanmar was planned for the two platforms of internet webpage and a smart device app (e.g. Android smartphones).The core concept of the DST is to demonstrate optimised fertiliser N application rates based on the spatial variability of soil types in space.

The framework of the internet web based DST is shown in Figure 5.5.1, in which the soil type map is manipulated by a web GIS of Openlayers 3.0 and associated with a practice database based on the WNMM scenario simulations for a specific site. For this kind of web-based system, users can use internet browsers to explore its functions.

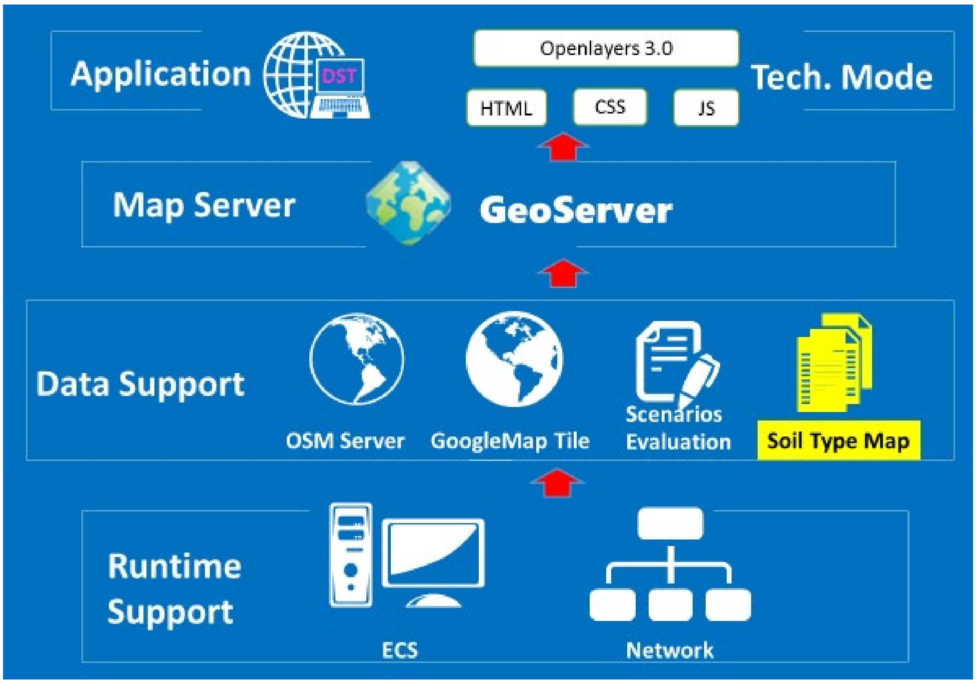


Figure 5.5.1. Web-based framework for DST.

Another way to develop a DST is to build an Android app with a public web GIS (e.g., MapBox). Again, the core is to demonstrate the optimised fertilisation regimes in the database of WNMM scenario simulations for a specific site, such as Laythar.

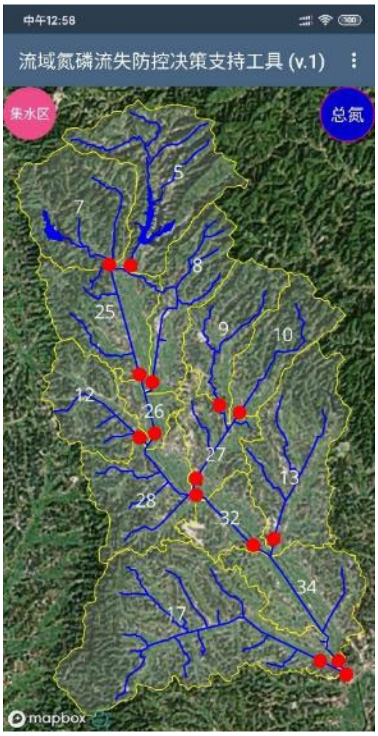


Figure 5.5.2. Android-based framework for DST.

6 Achievements against activities and outputs/milestones

Objective 1: Establish the biophysical basis for appropriate fertiliser use for rice and maize crops in central Myanmar.

No.	Activity	Outputs/ Milestones	Completion date	Comments
1.1	Determine the responses of rice and maize crops in central Myanmar to fertilisers and current fertiliser N efficiency. (YAU)	Detailed planning for field operations at inception meeting.	May 2016	Detailed plans were agreed by the research partners after the inception meeting. A participatory impact pathway analysis was made with support from external agencies, particularly IRRI.
		Work plans and protocols developed.	July 2016	Detailed plans and protocols for implementation of field trials of rice and maize were agreed by the research partners after the inception meeting.
		Sites selected and establish-ment of field trials.	Jan. 2017	Potential field sites were visited and choices between alternatives identified by YAU were made during visits by UoM staff. Fences and shelters were installed at the on-farm sites.
		Operation of field trials, field crop management.	Field trials were conducted with rice and maize in 2017, 2018 and 2019. Completed 2020.	Field trials were conducted with summer and monsoon rice and with maize, as detailed in sections 5 & 7. Field implementation was generally satisfactory, although one maize crop was affected by pests. The YAU rice site was flooded in 2017 and moved to a nearby farmer's field site for the following crop. The initial trials focussed on obtaining crop responses to urea fertiliser and sufficient data collection to support

				modelling. The plots were also used for research on the fate of N using N-15 labelled fertiliser and for evaluation of deep placed urea briquettes. Portable met stations were installed at the Laythar, Tatkon, and Taungoo sites, to supplement weather data.
		Yield responses as functions of fertiliser inputs for the two crops at 4 sites determined.	2020	Yield responses for summer rice, monsoon rice and maize were obtained. Summer rice and maize showed significant grain yield responses, but monsoon season rice showed no, or small responses to urea.
		Determine the recovery of fertiliser N and mechanisms for apparent high N efficiency	2019	N-15 fertiliser recoveries by plants for the surface broadcast urea treatments revealed the ineffectiveness of the first application at the start of the crop (i.e. 10DAT) with only around ~10% recovery, and higher recovery >40% for the second application at the PI crop stage.
1.2	Determine correct fertiliser formulations and crop nutrient needs. (YAU)	Detailed planning for field operations at inception meeting.	May 2016	Detailed plans and protocols for implementation of field trials of rice and maize were agreed by the research partners after the inception meeting.
		Soil sample survey of target crop systems for major and micro-nutrients	2020	Composite samples for characterisation of the surface soils of sites were taken and analysed. Soil pits for site characterisation were dug, and soils described and sampled in conjunction with Project LWR/2014/075. Major soil types were defined and mapped for the Zeyathiri area and used for rice and maize crop modelling and the DSS. Soils were described

				on or adjacent to the upland cropping areas. Rice growing soils were described but not mapped at Taungoo or Tatkon (Appendix 11.1.1, and 11.2.2).
		Omission trials established to determine the need for nutrients in addition to N.	n/a 2019	Item deleted (as reported in 2018), as the work was superseded by events. Subsequently undertaken by a Masters candidate at YAU. An omission pot trial with two soils revealed that N was the limiting nutrient at both sites. Sulphur was a limiting nutrient at a site at Tantabin. Each project field trial had a control with no nutrient additions, and indicated that PKS and Zn were not limiting at the field trial sites.
		Operation of field trials, field crop management.	2019	In general, for monsoon season rice there was no significant grain yield benefits from increasing N fertiliser above current low farmer application rates (~30 kg N/ha). Larger N inputs increased plant biomass but not grain yield. Fertiliser inputs were not the main driver of low yield for the monsoon season. Results for dry season 2019 rice at farmers' sites at Taungoo and Sein Sar Pin village (Yezin) showed little difference in yields in a comparison of farmers' practice, the project-derived most financially rewarding N rate, and the N rate of current DAR. The UDP treatment achieved a high crop recovery (up to 95%) of fertiliser 15-N compared to surface broadcast treatments and may potentially provide NUE

				and environmental benefits. However, in practice, the adoption of UDP technology depends on the development of mechanised application systems of large urea briquettes at planting. Rice produced using UDP may result in lower N pollution than surface broadcast urea.
		Recommendations made for fertiliser nutrient needs.		Recommendations concerning fertilisation of dry season rice and monsoon season rice and maize were developed. They were "road tested" and propagated by LUD with farmer scale trials after formal completion of the project
1.3	Assessment of existing fertiliser quality and suitability. (DoA)	Fertilisers collected from local markets and analysed for nutrient content.	Oct. 2017	For the samples collected from project locations in the dry season of 2017 all urea fertilisers were found to be pure and did not need analysis of additional elements. Sampling and surveys were repeated in 2017 wet season with a focus on compound fertilisers. In general the P fertilisers met their label specifications. Some compound fertilisers containing P were found to have high values of cadmium and this was communicated to MOALI. Comparison of the total N and P analytical results between LUD and UM showed that the LUD lab was accurate.
		Recommend-ations on fertiliser quality reported to DoA and others.		Ongoing as LUD extends its influence. Fertilisers imported at the Muse border crossing (Shan State) were not subject to QA/QC and the project's activities led the government to allocate budget from a

				World Bank Loan programme to establish a lab with trained staff at this border crossing.
1.4	Adapt the Water Nutrient Management Model (WNMM) to the 4 sites (YAU, UM)	Calibrate and validate WNMM based on the site trial results.		At Taungoo, WNMM was calibrated and validated well for the double rice rotation (summer and monsoon) for 2017 & 2018 (R^2=0.50-0.81). The low yield at the site was attributed to the low soil fertility (e.g. very low SOC of 0.5%). At Laythar, the model was calibrated and validated well for a maize-green gram rotation for 2017 & 2018 (R^2=0.67-0.89). The site had a problem of waterlogging for maize cropping. At Tatkon, WNMM was calibrated well for a maize-green gram rotation for 2017 (R^2=0.93). The site needs irrigation to maintain high maize yield. At the YAU research farm at Yezin, WNMM was calibrated for a summer rice season for 2017 (R^2=0.82). The soil at the site is very fertile and is not suitable for testing crop N responses.

Objective 2: To determine and address economic and policy related constraints to adoption of improved rice and maize production by fertilisation.

No.	Activity	Outputs/ Milestones	Completion date	Comments
2.1	Determine general socio-economic conditions of farms and farm families in central Myanmar at the 3 project	Detailed planning undertaken at inception meeting.	May 2016	General cropping patterns and general market conditions were identified for each field location and detailed plans for surveys were agreed by the research partners.

	locations. (YAU)			
		Literature review and provision of protocols.	2017	Published as a conference paper and in PhD thesis chapter (Thar 2021).
		Focus group meetings, small needs-based surveys.	May 2017	Published in Farquharson et al. (2017) as a project report and as a conference paper in Than et al. (2017)
		Socio-economic conditions reported and published.	2019	Published in Thar et al. (2020) and Thar et al. (2021a) and Thar et al. (2021b).
2.2	Determine current fertiliser use and crop yields by farmers in central Myanmar at the 3 project locations. (YAU)	Results reported from focus groups by gender, literature review and needs-based surveys.	2019	Completed and reported (Than et al. 2021b)
		Survey report including information of pre-project conditions.	2017	Completed and reported as a conference paper in Than et al. (2017).
2.3	Determine interest rates paid and typical indebtedness levels of farmers at the three project locations. (YAU)	Results reported from focus groups by gender and other information sources.	2019	Completed and reported (Thar et al. 2021b).
		Report on economic circumstances related to fertiliser use in rice and maize farming systems.	2019	Completed and reported (Thar et al. 2021a)
2.4	Produce marginal economic analysis for	Report and publications on economics of fertiliser use in	2021	Economic optimum nitrogen rates for rice and maize were determined (presented in Section 7.5.5).

	fertiliser use decisions from yield response functions determined in sub-project 1 and incorporate with DSS in Objective 4. (YAU, UM)	central Myanmar.		
2.5	Develop representative whole-farm models for the selected farming systems and farmer types at the 3 project locations and produce enterprise (gross margin) budgets. (UM, YAU)	Farm models to assess promising new technologies and assessments of risks of increased investment.	2019	Six typologies of farms were defined and whole farm models have been developed for an upland and a lowland farm based on the farm types and survey data.
2.6	Synthesise socio-economic research findings for policy implications of the promotion and adoption of improved fertiliser practices in central Myanmar. (YAU, DoA, UM)	Consult with a range of government agricultural policy makers and supply chain for fertiliser about project directions and outcomes.	2019	Initial consultations have been held with senior MOALI staff, and with international organisations. Consultations were maintained during the project but ceased at the end of Dec. 2019. A review of Myanmar Government policies relating to agriculture and finance was developed to help understand regulations and incentives about paddy rice production and finance available for loans for other crops (Farquharson et al. (2021)).
		Reports and policy briefs for senior agricultural officials.	2019	LUD has been communicating the project's results on fertiliser quality to policy makers and other DoA directorates with

				responsibilities for fertiliser use. The project's results were also presented at another workshop held by IFC. As a result of the project, DoA now prioritises investments in capacity building of inspectors who will contribute more effective knowledge transfer to dealers and farmers. DoA held training on fertiliser quality, and storage conditions with about 600 inspectors at the Central Agricultural Research Training Centre at Helgu. LUD will establish an official website of the product information and promote the project results of fertiliser quality control. LUD has continued farm-scale demonstrations beyond the duration of the project.
2.7	Determine short-term impacts of the project by surveys at the end of the project. (YAU, UM)	Report on short-term impacts of the project.	2021	Field survey work was not permitted in 2020 or 2021 and follow-up surveys were not made. Estimates of potential benefits were made from the available economics data (Appendix 11.2).

Objective 3: To build capacity for the long-term improved nutrient management at the farm level, through training of YAU staff

No.	Activity	Outputs/ Milestones	Completion date	Comments
3.1	Develop analytical capacity for soils and crops at	15 senior students and 4 staff trained.	2020	The YAU laboratory was successfully upgraded from a teaching facility with capacity for few soil

	YAU with protocols and ongoing systems to ensure sustained capacity in the future beyond the project. (YAU, UM)			and plant analyses and small numbers of samples, to one capable of supporting a large field programme. The project provided key equipment and chemicals, and emphasised improvement of safe working practices. It allowed utilisation of facilities already provided by JICA. Fewer YAU staff than expected were trained. Whilst the project has resulted in an effective lab, many fewer opportunities for training of YAU staff were taken than expected or offered, despite the project having capacity to train several more. This was partly due to YAU policy of moving junior staff to remote campuses resulting in trained individuals being moved to lesser equipped laboratories. In terms of sustaining capacity two YAU staff have sufficient skills now that the project-supported staff have departed. The lab in now able to determine pH, EC, total C, total N, mineral N, Olsen P CEC, and particle size. QC protocols including ASPAC and locally prepared reference samples that were introduced by the project.
3.2	Increase capacity in the interpretation of soil and plant tests in YAU. (YAU, UM).	15 senior students and 4 staff trained.	2020	Fewer than planned were trained (see 3.1). Training was mostly in the form of the ACIAR model of working together. Several formal presentations were made to larger groups of

				YAU senior students and junior staff.
3.3	Increase capacity of YAU in the conduct of nutrient deficiency and response processes and research. (YAU, UM)	15 senior students and 4 staff trained.	2020	As for 3.2.
3.4	Increase capacity in the use of economic frameworks and models in teaching and research for undergraduate and postgraduate students at YAU and UM. (YAU)	15 students and 2 Myanmar staff capable of economic fertiliser use and whole-farm economic modelling.	2020	Capacity building in digital data collection by field enumerators was achieved. Training provided enumerators with the ability to independently complete or explain a range of concepts related to the CommCare application, and to digital data collection.
3.5	Establishment and operation by YAU of small research grants scheme. (YAU)	18 student projects dramatically improved by mentoring and training by the project (6 per year for 3 years). Linkages built from YAU to relevant RD&E agencies.	2020	Ten small projects were completed. Principles of subject justification, planning, budgeting, and delivery were reinforced. There were fewer than expected due to delays caused by changes in YAU staff and difficulties with UoM agreeing budgetary practices with YAU. The small projects were popular in YAU as they were a good fit with the need for student projects in some of their higher degrees. The scheme did not develop as UoM had originally planned, but was integrated with YAU activities.
3.6	Enhance YAU's curriculum and teaching	Improved soil science and agricultural	2020	Ms Pan Ei Ei Kyaw, John Allwright Fellow, has continued to make

	approaches related to soil science, agricultural economics, and university management, through staff exchange. (YAU)	economics curricula at YAU.		progress with her PhD research at UoM. The PhD research is aligned with subproject 4. Ms So Pyay Thar was awarded a UoM scholarship. Her work supplemented that of the project in socio-economics, and she has been awarded a PhD.
3.7	Specific DSS training activities for YAU staff and senior students. (YAU, UM)	Training support for: DSS development.	Not achieved	We were unable to identify a staff member or students at YAU to work on modelling, GIS or DSS. A possible staff member at YAU was identified but was absent for long periods.

PC = partner country, A = Australia

Objective 4: To develop decision support systems for Myanmar rice and maize crops and for intensive vegetable production in Victoria, Australia

No.	Activity	Outputs/ Milestones	Completion date	Comments
4.1	Conduct a comprehensive review of current N fertiliser DSSs in Australia and worldwide. (UM)	Report of the review, and selection of most suitable DSSs for Myanmar rice and maize systems and for intensive vegetable production systems near Melbourne.	2020	Completed and reported. (Thar 2021, Thar et al. 2020)
4.2	Modification and calibration of the selected DSS model(s) using new and existing experimental	Report of the review, and selection of a model for Australian vegetable	2018	As reported in earlier annual reports, the proposed Australian component of the project was reduced to allow greater than expected

	data for new fertiliser technologies for intensive vegetable production in Victoria, including an economic framework. (UM)	production systems. Simple N rate experiments for vegetables in Victoria Updated N models capable of simulating the financial and environmental effects of N fertilisation technologies for vegetable systems in Australia.		support of research by YAU, particularly for implementation of the Myanmar crop field trials. DSS for Victoria were not expected as part of the project. A field experiment was conducted to determine the effects of reduced N fertiliser inputs and the use of nitrification inhibitor (DMPP) on crop yield, N use efficiency and N_2O emissions as compared to the grower practice, in an intensive celery production system in Victoria. Intensive-vegetable growing on these sandy soils with high N input leads to large N losses, including N_2O emissions. N inputs can be reduced without compromising yield. Published by Suter et al. 2021. Ms Pan Ei Ei Kyaw, with supervision by A/Prof Helen Suter, is undertaking related work in Victoria for her PhD research. Models for Victorian crops were not expected as part of the project.
4.3	Modification and calibration of the	A practical decision	DSS incomplete	DSS for central Myanmar was developed and was

	selected DSS for rice and maize production in Myanmar, including an economic framework. (UM, YAU)	support system for making fertiliser recommend-ations for rice and maize systems in Myanmar.		given priority over that for Victoria. Two types of DSS with soil-type (or –variation) specification have been developed: web-based and Android app-based. The web-based DSS can be accessed through any platform via the internet. Currently, only a small area in Laythar was tested for the application of the web-based DST due to lack of soil type maps in the study area. In response to consultations with farmers a Facebook page was developed in both English and Burmese to initiate discussion about soil type among farmers. It is proposed that future extension activities take the form of meetings of groups of farmers with extension officers for discussions of their aspirations and that Facebook be used as support materials. This is more likely to be attractive to farmers than a new smartphone app. Crop modelling, and a more developed DS tool could form the scientific basis for material presented by Facebook.
4.4	Develop, promote and transfer DSS for private sector, NGOs and DoA extension staff. (YAU, DoA)	Consultative meeting with farmer groups, DoA, private sector fertiliser companies, NGOs to determine appropriate extension	2020	Consultations were held with private companies in Australia, and with IFDC and IRRI. Farmer group workshops provided guidance on how farmers want to receive information. Dr Farquharson presented

		approaches and materials.		a seminar: 'Economics of fertiliser' at Yezin Agricultural University Wider consultative meetings have been ongoing throughout the project. Over the last year (pre-COVID-19 lockdowns) three large-scale farmer field days were led by YAU and another by LUD. Farmer consultation workshops were conducted in 21 Townships of Nay Pyi Taw, Mandalay, and Bago Regions during September 2019 by LUD. This benefitted 1050 collaborating farmers. Large field demos are currently (Feb. 2021) underway with summer rice. LUD are targeting the poorest farmers in Laeway and Oattaya Thiri Townships, Nay Phy Taw Region, and Taungoo, Oat Twin and Yay Tar Shay Townships, Bago Region. This is an LUD initiative stemming from the project.

7 Key results and discussion

7.1 Introduction

The project is a unique investigation of smallholder farmers in central Myanmar in terms of rice and maize crop fertiliser management. The results are presented by each major objective, covering (1) the biophysical responses of rice and maize to N fertiliser, (2) economic aspects of fertiliser use, (3) capacity building at YAU, and (4) the development of a decision support system.

7.2 Myanmar field crops

7.2.1 Response of rice to N fertiliser in field experiments

The project conducted rice field trials at 2 main locations – Yezin, Zeyathiri Township, Nay Pyi Taw Union Territory, and Taungoo, northern Bago Region (Fig 5.1.1) – to investigate the effects of incremental N applications on rice yields where other nutrients were not limiting. The treatments used of the initial field trials is shown in Table 5.1.3, and site information and cropping systems are shown in Table 5.1.2.

Summer irrigated (dry) season rice responded strongly to N applications and the response was stronger at Taungoo than at Yezin, although there was considerable variability (Figures 7.2.1 and 7.2.2). Rice was much less responsive to N fertiliser in the monsoon (wet) season than the summer season. The results showed that there is limited potential for N fertiliser to raise yields in the monsoon season, but that yields can be increased from approx. 4 t/ha to 8 t/ha in the irrigated summer season.

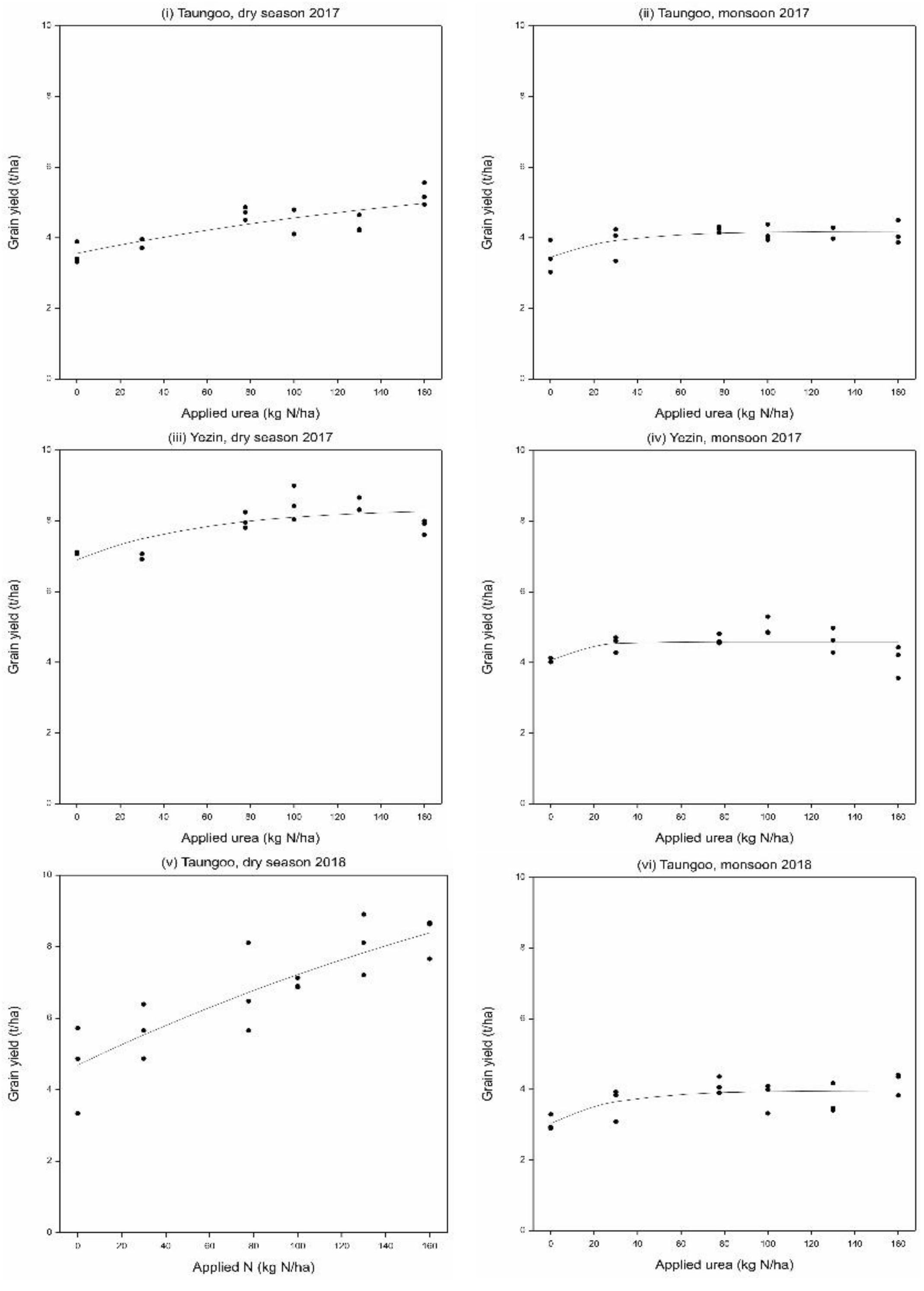


Figure 7.2.1. Responses of rice to N fertiliser applications

Crop grain yield (adjusted to 14% moisture content) responses to N fertiliser application rate (surface broadcast) for the rice crops at the two experimental sites with a response curve fitted with an exponential functional form (Yield = α + β(ρ^N) for each data set for ; (I) Taungoo site summer (dry) season 2017 crop [Y =6.26 – 2.70 (0.9954 ^{X}) , P<0.001, R^2 = 0.636]; (II) Taungoo site monsoon season 2017 crop [Y =4.18 – 0.73 (0.9661 ^{X}) , P=0.007, R^2 = 0.419]; (III) Yezin site summer season 2017 crop [Y=8.36 – 1.46 (0.9826 ^{X}) , P=0.004, R^2 = 0.498]; (IV) Yezin site monsoon season 2017 crop [Y =4.59 – 0.46 (0.924 ^{X}) , P=0.226 (n.s), R^2 = 0.071]; (V) Taungoo site summer season 2018 crop [Y =13.9 – 9.2 (0.9968 ^{X}) , P<0.001, R^2 = 0.718]; and (VI) Taungoo site monsoon season 2018 crop [Y =3.96 – 0.93 (0.9642 ^{X}) , P=0.007, R^2 = 0.418].

Although there was variability in rice grain yields between replicates at all the sites, statistically significant differences were obtained between treatments. Generally, there was a lack of grain yield responses to N fertiliser input in monsoon seasons, barely increasing yield by 0.5 t/ha compared to the unfertilised treatment (Figure 7.2.3). There is lower solar radiation index during wet seasons due to more cloudier days compared to the summer seasons, which leads to low grain yield (Dobermann et al., 2003). This is a common phenomenon in rice crops where low solar index reduces the grain to biomass ratio in cloudy seasons (van der Gon et al., 2002). It should be noted that the selection of the rice cultivars in this study was based on their being commonly grown varieties with local farmers, so they

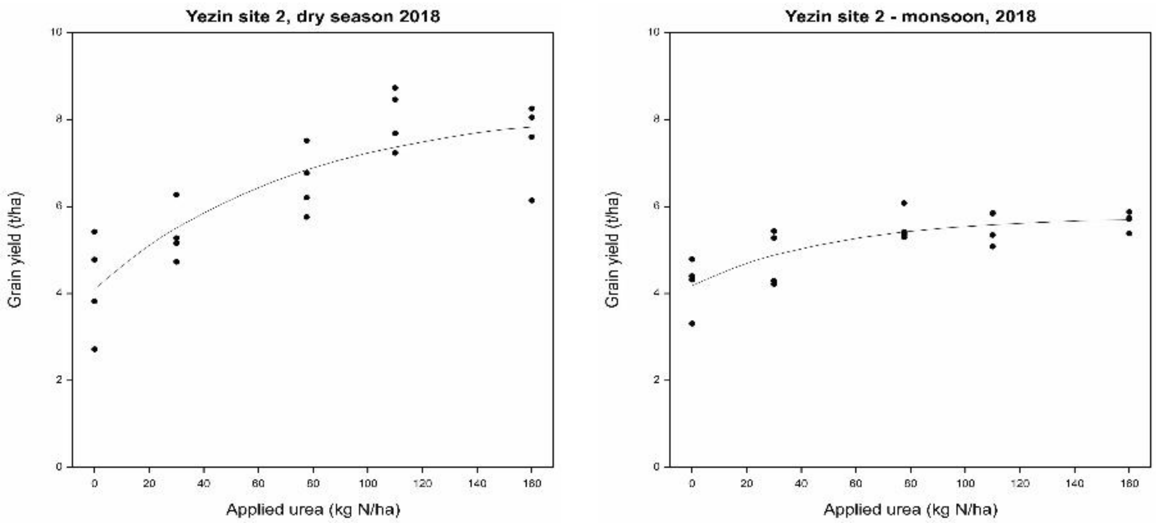


Figure 7.2.2. Responses of rice to N fertiliser in a farmer's field in Yezin in 2018

Crop grain yield (adjusted to 14% moisture content) responses to N fertiliser application rate (surface broadcast) for the rice crops at the Sein Sar Bin village site fitted with response curves with an exponential functional form (Yield = α + β(ρN) for each data set for ; (A) summer season 2018 crop [Y =8.31 – 4.21 (0.9865 X) , P<0.001, R^2 = 0.694]; (B) monsoon season 2018 crop [[Y =5.76 – 1.58 (0.9806 X) , P<0.001, R^2 = 0.60].

may not be as responsive to N input as some high yielding varieties grown elsewhere. With existing varieties, the N fertiliser input in the wet season should be limited to 30 kg N ha and the input could be increased to 77 kg/ha during the dry season.

Significant grain yield responses to nitrogen inputs were demonstrated in rice grown in the summer season. However, the application of more than 77 kg N/ha did not provide any yield benefits in the dry summer season crops. Only in one dry season and at one location, did raising N fertiliser to 160 kg N/ha lead to significantly higher grain yield compared to grain obtained from an N input of 77.6 kg/ha.

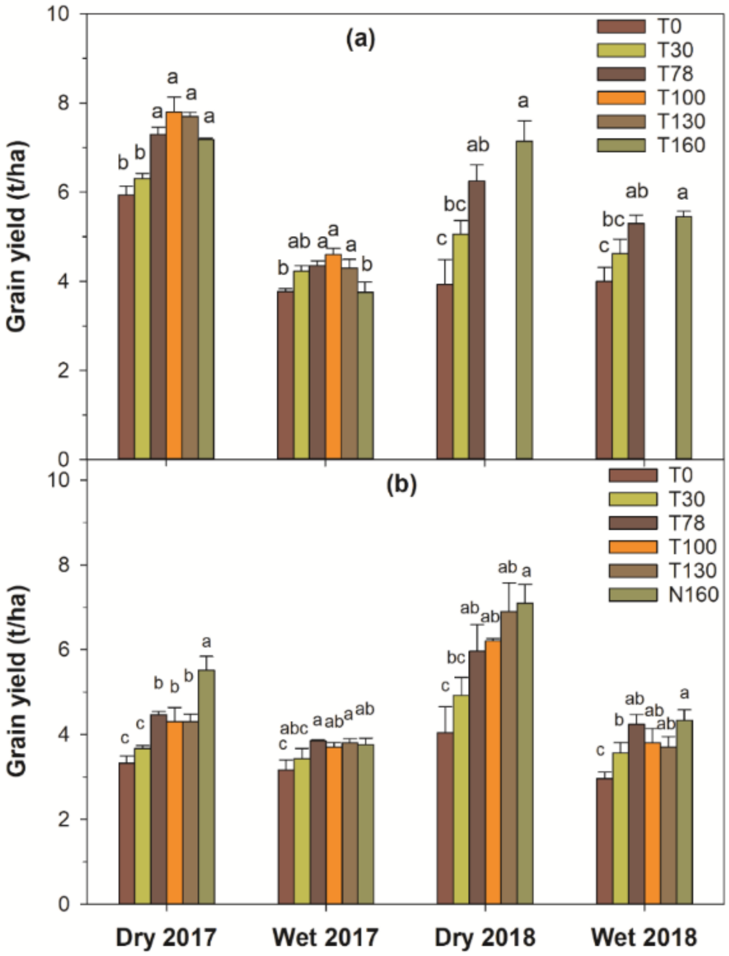


Figure 7.2.3. Rice grain yield at Yezin (a) and Taungoo (b) in the summer and monsoon seasons of 2017 and 2018.

Column bars with different letters within a season are significantly different (p <0.05). Error bars represents ±1 standard error of mean.

Nitrogen recovery and effects of urea deep placement: The use of N-15 labelled urea to trace the fate of applied N fertiliser showed that the plant use of N applied as urea rarely exceeded 30%, and the majority of N in plants was derived from indigenous soil nitrogen. Total recovery of applied N fertiliser in plants and soil was below 60%, so the remaining 40% of the applied N fertiliser was unaccounted for, or lost from the system. This observation is not unique to our experiment sites and is consistent with global trends of nitrogen fertiliser recovery in rice paddies (Yan et al., 2020).

The results for the recovery of N from split applications of urea at 10 days after transplanting (DAT) and panicle initiation (PI) stage showed that the current farmers' practice of applying N fertiliser in two equal split doses is inefficient. Less than 21% of the applied N fertiliser at 10 DAT was recovered in rice plants while the total recovery (plant+soil) was less than 43%. Between 41 and 54% of the N fertiliser applied at the PI stage was recovered in plants and the total recovery (plant+soil) was up to 67%. This shows that the first application of N fertiliser at 10 DAT should be reduced to 1/3 of the total and application of the remaining 2/3 of the N dose around active tillering stage (35 DAT) may prove beneficial.

Urea briquette deep placement (UDP) at the rate of 77.6 kg N/ha in rice paddies showed similar or higher grain yields than those where it was surface broadcast at 77.6 kg N/ ha and 160 kg N/ha (Figure 7.2.4). However, the total dry biomass yield (Table 7.2.1) resulting from the UDP was generally higher (p <0.05) than in the surface broadcast of 77.6 kg N/ha, and always similar to urea surface broadcast at 160 kg N/ha.

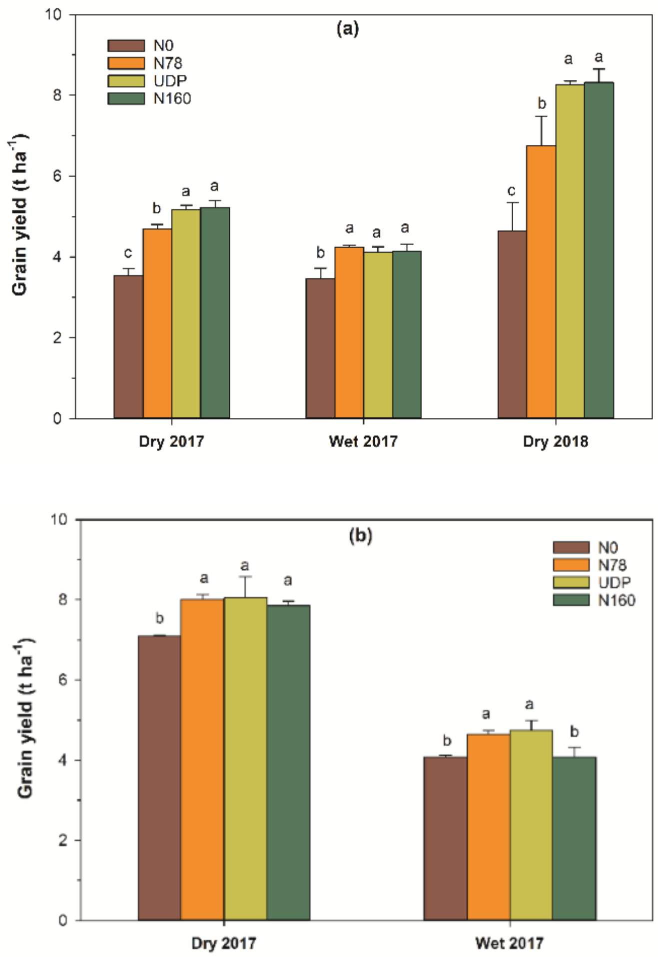


Figure 7.2.4. Effects of urea deep placement on rice grain yield at Taungoo (a) and Yezin (b) in the summer and monsoon seasons of 2017 and 2018.

N0, without N input; N78, surface broadcast at 77.6 kg N/ha; UDP, urea briquette deep placement at 77.6 kg/N ha; N160, surface broadcast at 160 kg N/ha. Column bars with different letters within a season are significantly different (*p* <0.05). Error bars represents ±1 standard error of means.

Table 7.2.1. Effect of urea deep placement on total dry biomass yield of rice at Taungoo and Yezin in summer and monsoon seasons of 2017 and the summer season of 2018. (t /ha)

Location & Treatments*	Summer 2017	Monsoon 2017	Summer 2018
Taungoo			
N0	8 c	8.5 b	8.8 d
N78	11.1 b	10.6 a	12.1 b
UDP	13.6 a	10.7 a	14.8 a
N160	13.1 a	**11.3 a**	**14.7 a**
Yezin			
N0	14.1 c	16.2 b	
N78	17 b	18.5 a	
UDP	18.5 a	18.4 a	
N160	16.9 ab	17.1 a	

*** N0, without N input; N78, surface broadcast at 77.6 kg N/ha; UDP, urea briquette deep placement at 77.6 kg/N ha; N160, surface broadcast at 160 kg N/ha. Values followed by different letters within a column and location are significantly different (p <0.05).**

Encouraging results for the use of UDP were obtained by the results for N-15 recovery (Figure 7.2.5). The recovery of the labelled urea (%NFR_p) in the plant (grain + straw) in the UDP treatment was the highest (p <0.05) regardless of the seasons and locations. Total N uptake by plants in the UDP treatment was lower or equal to the T78 and T160 treatments. This indicates that the UDP treatments had greater N recovery from applied N fertiliser and smaller exploitation of the indigenous soil N. The recovery of fertiliser-N in plants ranged between 47 and 61% in the UDP treatment, whereas that surface broadcast at rates of 77.6 and 160 kg N/ha had N recoveries of 30-37% and 29-39%, respectively. The recovery of applied fertiliser-N in the top 20 cm soil (%NFR_s) in the UDP technique was also the highest (p <0.05) among the fertiliser treatments, except in the 2018 summer season at Taungoo. Soil recovery of the applied fertiliser-N ranged between 24 and 40% at harvest in the UDP treatment, leading to total (plant+soil) recoveries (%NFR_t) of 77-95%. In contrast, the comparable 77.6 kg N ha^{-1} surface broadcast treatment had soil recoveries of N between 10 and 22% and total recovery between 41 and 60%. The soil recovery of fertiliser-N in the 160 kg N ha^{-1} treatment was 6-13%, resulting in a total recovery of 40-54%.

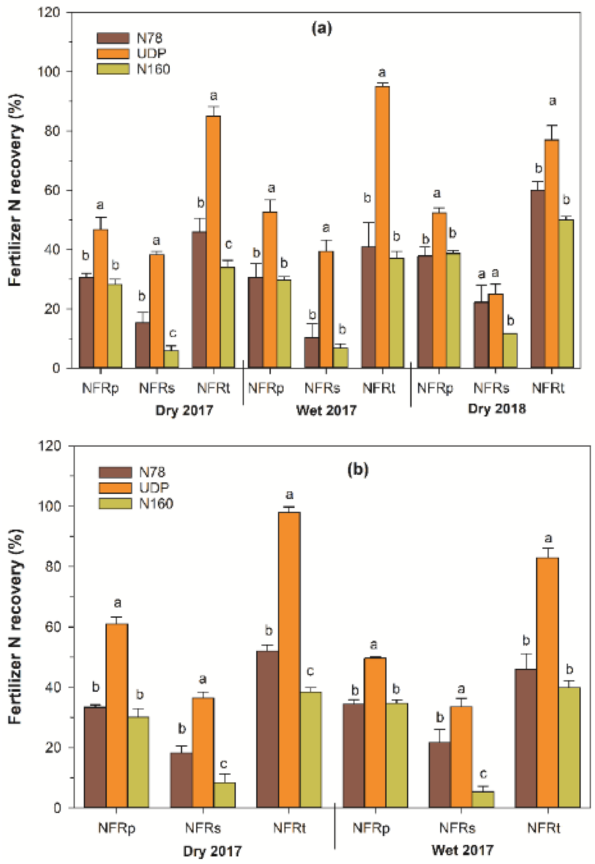


Figure 7.2.5. Fertiliser-N recovered (%) at (a) Taungoo and (b) Yezin in summer and monsoon seasons of 2017 (Dry 2017 and Wet 2017) and summer season of 2018 (Dry 2018).

NFR_p, fertiliser-N recovered in plant; NFR_s, fertiliser-N recovered in soil; NFR_t total fertiliser-N recovery (plant+soil); N78, surface broadcast at 77.6 kg N ha^{-1}; UDP, urea briquette deep placement at 77.6 kg N ha^{-1}, N160, surface broadcast at 160 kg N ha^{-1}. Column bars with different letters within a season are significantly different (p <0.05). Error bars represents ±1 standard error of mean.

7.2.2 Results of on-farm trials on application methods

N fertiliser increased rice grain yield by more than 75% compared to the control at Sein Sar Bin (Yezin, Table 7.2.3). All the treatments receiving N fertiliser, namely farmer practice, puddled urea, urea deep placement and 3-split surface broadcast, showed statistically similar rice grain yields at Sein Sar Bin. At Taungoo, the UDP treatment produced significantly higher grain yield than any other treatment. Farmer practice, puddled urea and 3-split broadcast produced similar grain yields, whereas grain yield in the control treatment was significantly lower than any of the N treatments.

Table 7.2.3. Rice grain yield at Yezin and Taungoo in 2019 summer rice

Treatment	Urea (kg N ha^{-1})	Grain yield Yezin (t ha^{-1})	Grain yield Taungoo (t ha^{-1})
Zero N	0	3.22b	3.46c
Farmer Practice	70	5.64a	4.43b
Puddled in std urea	70	5.91a	4.51b
Urea deep placement	70	5.71a	5.53a
3-split broadcast	70	5.68a	4.39b

The values followed by different letters are significantly different ($p < 0.05$).

In general UDP was promising allowing reductions of the total rate of urea application, with potential financial and environmental benefits. However, the results were inconsistent between sites. Further research would be worthwhile if feasible and adoptable on-farm mechanisation of deep placement becomes available.

7.2.3 Rice production with small fertiliser inputs

Pandey et al. (2019, 2020) reported how dissimilatory nitrate reduction to ammonium (DNRA) and biological N_2 fixation contributed to N supply in rice paddies, and compared these with N losses through denitrification. DNRA transforms nitrate to ammonium, which is less prone to losses than nitrate, and reduces losses as nitrous oxide or N_2 through denitrification. Biological N_2 fixation contributes to N nutrition of rice paddies by fixing inert N_2 to plant available ammonium.

Continuous N fertilisation in rice paddies is known to increase denitrification and reduce biological N_2 fixation, however little is known about its effect on DNRA and the NO_3^- partitioning between DNRA and denitrification. It was shown that DNRA exceeded denitrification by a factor of eight in low N fertilised rice paddies, while DNRA was almost half of the denitrification rate of highly N fertilised rice paddies. These findings highlight the self-regulated microbial N cycling in low N input paddy systems which maintain long-term paddy soil N nutrition.

Diazotrophs can fix N_2 in excess of 60 kg N/ha in unfertilised paddies (Pandey et al. (2019), Pandey et al. (2020), which is enough to produce moderate grain yields (~ 3 t ha^{-1}). Also, microbes in unfertilised paddies are efficient in retaining nitrogen, thus minimising losses. For example, more than 60% of nitrate produced in rice paddies can be reduced to ammonium through dissimilatory nitrate reduction to ammonium, preventing nitrate loss through denitrification (Pandey et al. 2019;, Pandey et al. 2020). This unique microbial N-cycling strategies in resource-limited paddies enable N nutrition of the paddy system and maintain moderate levels of grain yield (Pandey et al., 2020)

Figure 7.2.6 illustrates N pathways in low and high N input paddy systems. Solid arrows with different colours represent different N pathways. The thickness of the solid arrows represents the relative magnitude of the N pathways. DNRA and N_2 fixation dominate N transformations in low N input paddies allowing for minimal N loss, whereas denitrification dominates in high N input paddies.

These findings, and the observed results from N response trials in rice paddies in central Myanmar, indicate that unnecessarily high N fertilisation does not provide yield benefit but rather promotes native soil N mining and high N losses, where ~50% of fertiliser N applied is lost unaccounted for. Biological N_2 fixation, more or less, compensates for moderate yield levels in monsoon seasons, so fertiliser rates exceeding 30 kg N/ha are not advisable.

Residue return could be one way to promote DNRA and minimise native N loss in rice paddies with high N input.

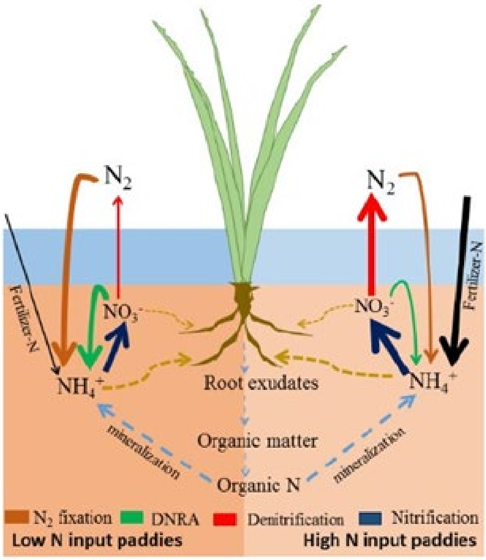


Figure 7.2.6. Illustration of N pathways in low N input (left) and high N input (right) paddy systems

7.2.4 Rice crop simulation results

The Water and Nutrient Management Model (WNMM) crop simulator (Li et al., 2007; Hu et al., 2010) was calibrated and validated for the project trial sites. Calibration was achieved by running weather data for 2017-2018 and 1997-2018 then used to simulate rice crop yields responding to N fertiliser as practice scenarios.

WNMM was calibrated for a summer rice season at the YAU research farm at Yezin, for 2017. The soil at the site was very fertile and is not well suitable for testing crop N responses. WNMM was calibrated for a summer rice season for 2017 and WNMM's prediction was acceptable (R^2=0.82, Figure 7.2.7).

WNMM was also calibrated for Taungoo, and validated for the double rice rotation (summer and monsoon) for 2017 and 2018 (R^2=0.70 Figure 7.2.8). The low yield at the site was attributed to the low soil fertility (e.g. very low SOC of 0.5%).

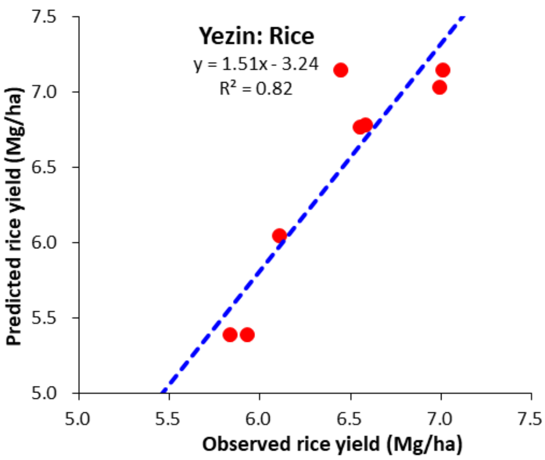


Figure 7.2.7. Observed vs. WNMM predicted rice yield at Yezin.

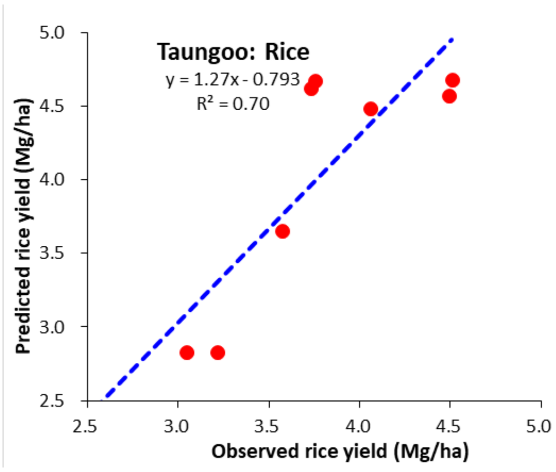


Figure 7.2.8. Observed vs. WNMM predicted rice yield at Taungoo

WNMM was also applied to simulations of the response of summer and monsoon season rice crops to N using historic weather data of 1997-2018 (22 years) at Taungoo. The simulation results are shown in Figures 7.2.9, and 7.2.10, respectively. There was acceptable agreement between the responses found in the field (Fig. 7.2.1) and the simulated results for responses. The simulation results indicated that the summer season rice is much more sensitive to climate than the monsoon season crop, even though both crops responded to N applications.

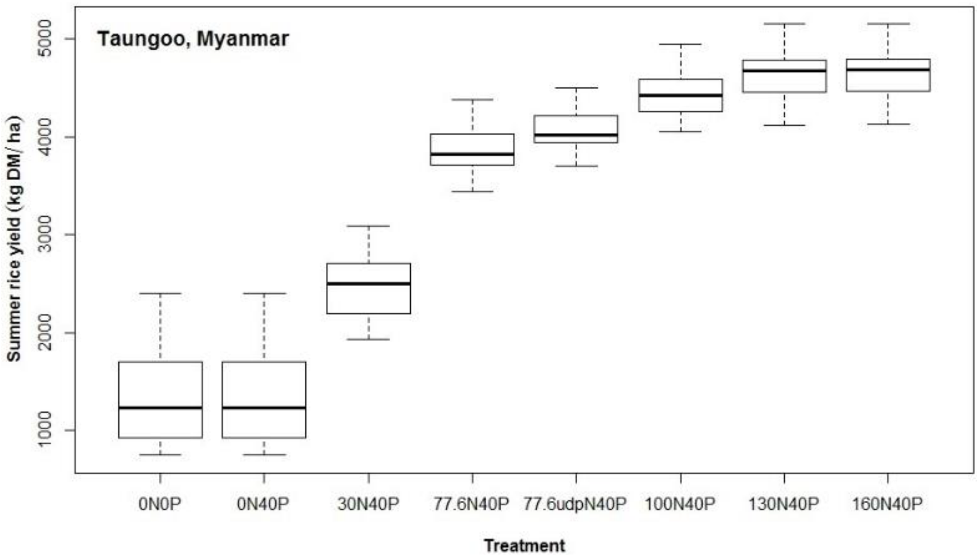


Figure 7.2.9. Simulated summer rice yield response to N rates at Taungoo

X axis label refer to rates (kg/ha) of applications on N and P. The boxes represent 50% confidence and the bars represent those for 95% confidence.

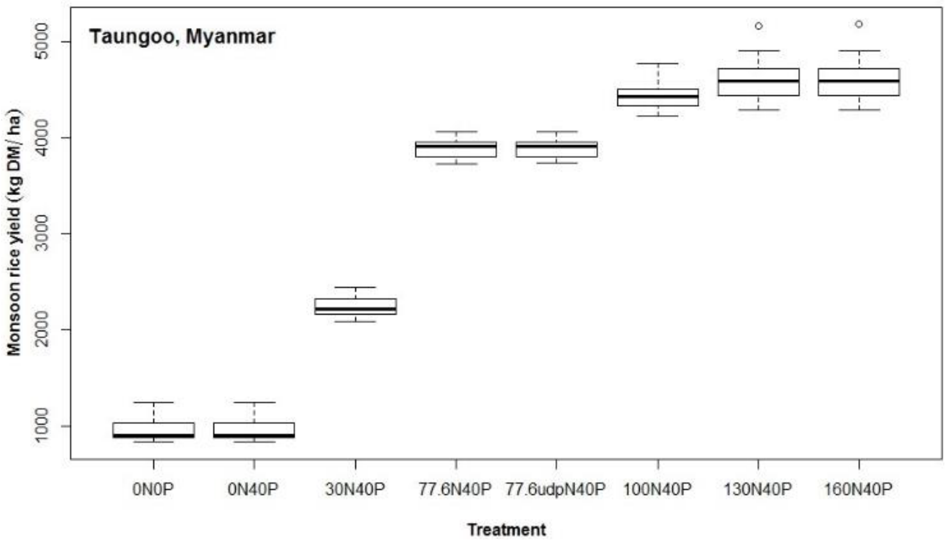


Figure 7.2.10. Simulated monsoon rice yield response to N rates at Taungoo

X axis label refer to rates (kg/ha) of applications on N and P. The boxes represent 50% confidence and the bars represent those for 95% confidence.

Successful application of WNMM to the rice yields allows the application of the model to the development of a decision support tool for the study area, allows “what if” scenarios to be illustrated, and can be utilised by a discussion-based decision support approach proposed in Section 7.6.1.

7.2.5 Responses of maize to nitrogen

Maize grain yield and crop above-ground biomass responded strongly to fertiliser N inputs at both locations in 2017 (Figure 7.2.11). The yield responses to N inputs were stronger at Tatkon than at Laythar. There was higher variability in yield and crop biomass within a treatment at the farmer’s field at Laythar compared to the research station field at Tatkon.

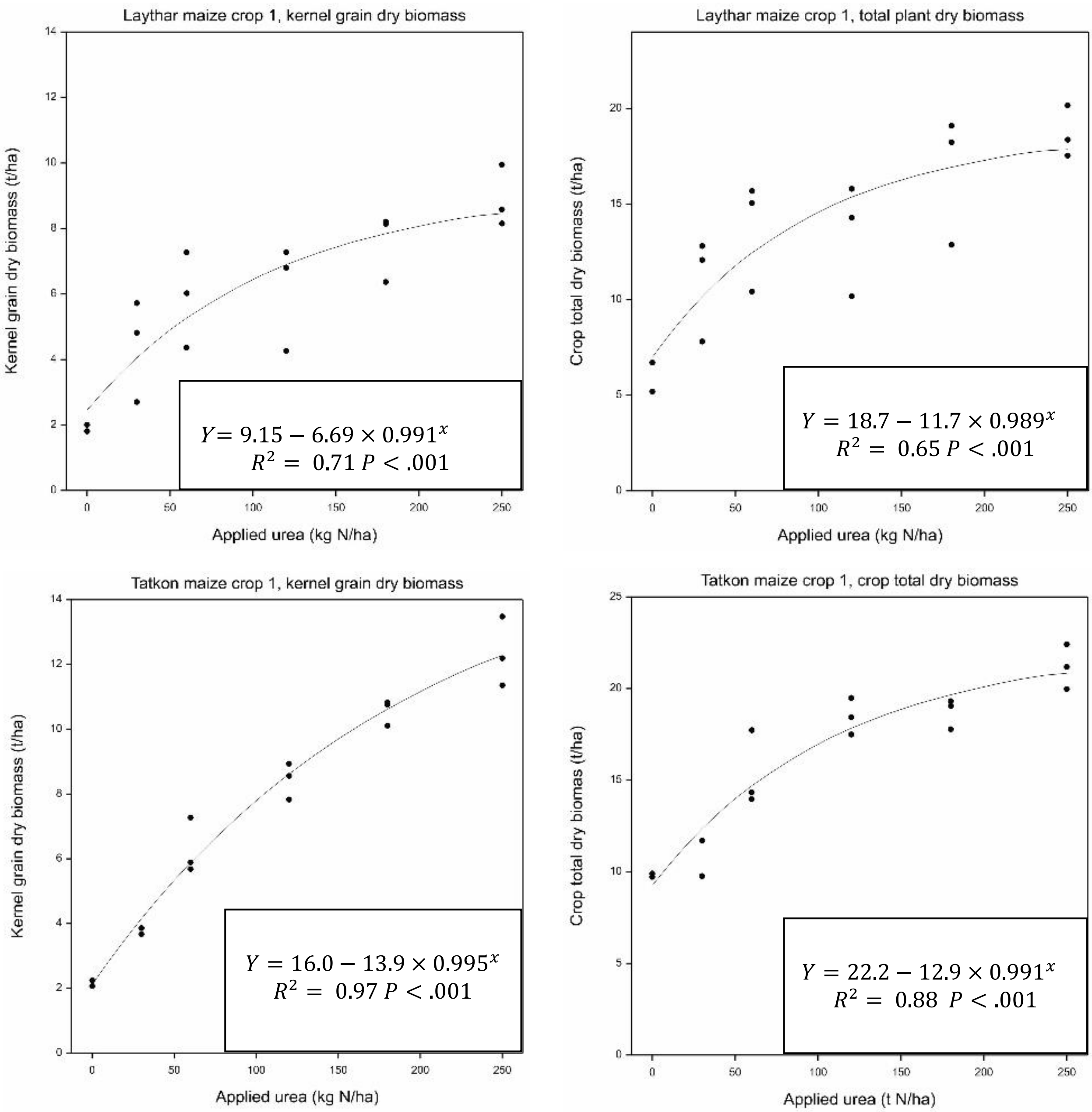


Figure 7.2.11. Responses of maize to fertiliser N inputs in 2017.

Crop grain yield and biomass response to N fertiliser application rate for the maize crops at the Laythar and Tatkon sites in the monsoon season of 2017. The response curves are an exponential functional form (Yield = α + β(ρN) fitted to each data set.

There was large seasonal variation in grain yield at Laythar in 2018 (Figure 7.2.12) and this was due to an extended period of flooding following heavy rain and the release of water from Yezin dam, leading to lower yields in 2018 than in 2017. There was a marked increase in grain yields with fertiliser N inputs, from ~2 t/ha with zero fertiliser N input to more than 8.5 t/ha with 250 N/ha, in 2017 (Figure 7.2.12a). A yield response to N was apparent in the 2018 monsoon but with smaller yields due to the flooding. Crop total N uptake followed very similar trends to crop yields in both 2017 and 2018 seasons (Figure 7.2.12b). Crop yield and crop N uptake increased from zero to 180 kg N/ha fertiliser inputs but there was no significant increase in crop yield or N uptake above that, indicating that 180 kg N/ha was likely to be the maximum N rate for maize at Laythar.

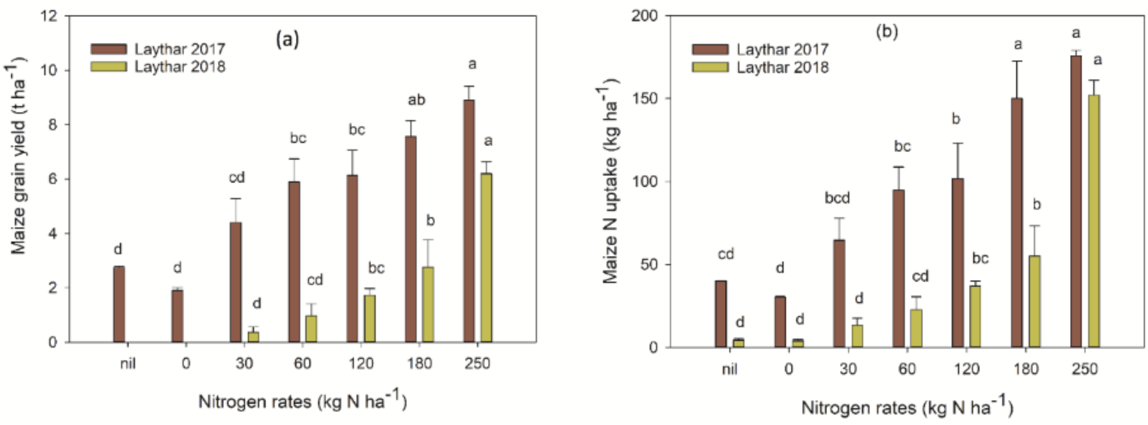
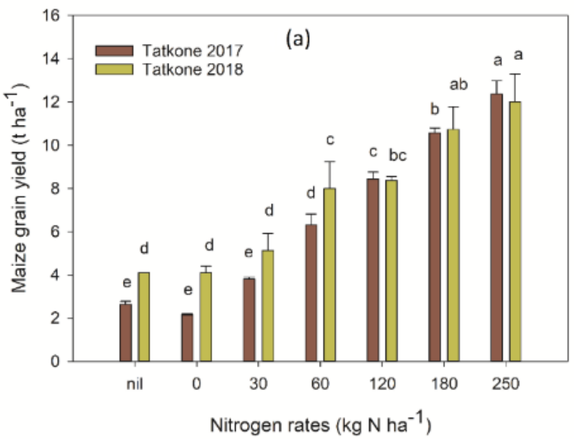


Figure 7.2.12. Responses of maize grain yield (a) and N uptake (b) in the monsoon seasons of 2017 and 2018 to N fertiliser at Laythar.

Column bars with different letters within a season/year are significantly different (p <0.05). Error bars represents ±1 standard error of mean.

Similar strong responses of maize grain yields to N input were observed at Tatkon (Figure 7.2.13a). The yield of the control treatment in the 2018 monsoon season was twice as high as that in the 2017 monsoon, but the difference in yields between the two seasons became less marked when fertiliser N was applied; the highest yield (~12 t/ha) observed in the 250 kg N/ha treatment was similar in both seasons. This suggests that fertiliser N input may help overcome any other edaphic and climatic constraints negatively affecting yields (Shapiro and Wortmann, 2006). Total crop N uptake also increased with fertiliser N input, with crop uptake of more than 200 kg N/ha in the treatment receiving 250 kg N/ha (Figure 7.2.13b). Even though the grain yields were similar between the seasons there was a trend of smaller crop N uptake in the 2018 season compared to the 2017 season. Depending on the season, 180 kg N/ha or 250 kg N/ha resulted in the highest yields of monsoon maize at Tatkon.



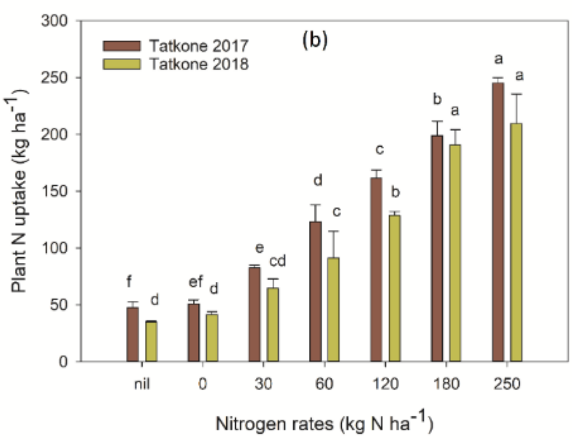


Figure 7.2.13. Maize grain yield (a) and N uptake (b) in the monsoon seasons of 2017 and 2018 at Tatkon.

Column bars with different letters within a season/year are significantly different (p <0.05). Error bars represents ±1 standard error of mean.

There was no significant difference (*p* <0.05) in the recovery of N-15 labelled fertiliser between the treatments receiving 60 and 120 kg N/ha at any of the locations in 2017 monsoon season (Figure 7.2.14). Total recovery of N from the treatment receiving 60 kg N/ha was more than 70% at both locations. Total N recovered from 160 kg N/ha was ~50% at Laythar, whereas it was 75% at Tatkon. The results for grain yields with higher N inputs (>60 kg N/ha) and fertiliser N recovery showed that Tatkon is better suited for monsoon maize than Laythar.

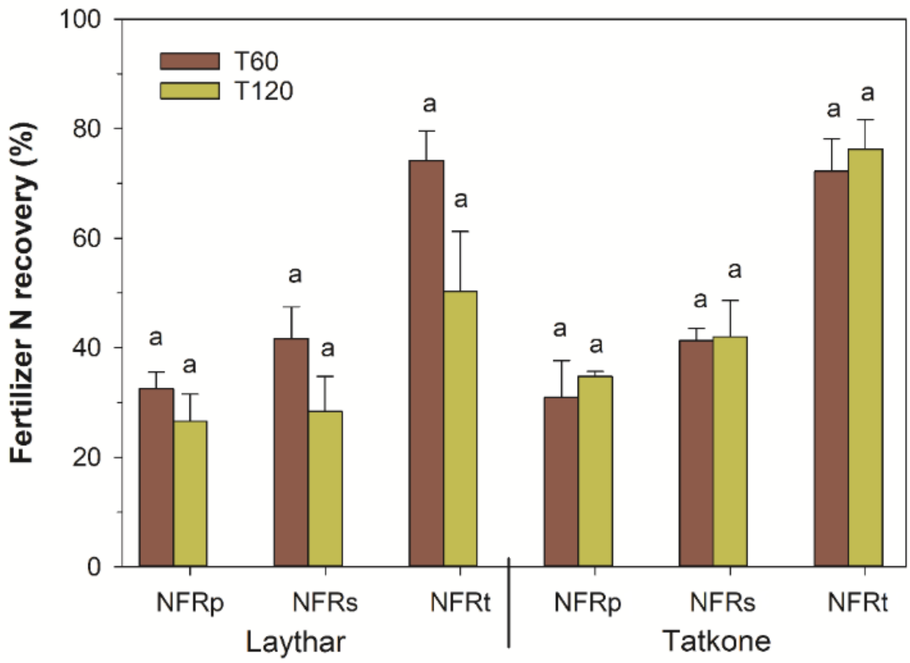


Figure 7.2.14. Fertiliser-N recovered (%) at Laythar and Tatkon monsoon maize in 2017.

NFR_p, fertiliser-N recovered in plant; NFR_s, fertiliser-N recovered in soil; NFR_t total fertiliser-N recovery (plant+soil); T60, surface broadcast at 60 kg N ha^{-1}; T120, surface broadcast at 160 kg N ha^{-1}. Column bars with different letters for a parameter are significantly different (*p* <0.05). Error bars represents ±1 standard error of mean.

7.2.6 Maize crop simulation results

At Laythar, the model was calibrated and validated well for a maize grown in rotation with green gram for the 2018 season (R^2=0.94, Figure 7.2.15), although the site had problems of waterlogging during the maize cropping. At Tatkon, WNMM calibrated well for maize for 2018 (R^2=0.93, Figure 7.2.15). As irrigation was applied on time the maize yield was higher; the WNMM predictions and field observations suggested that the site needs irrigation to produce high maize yield.

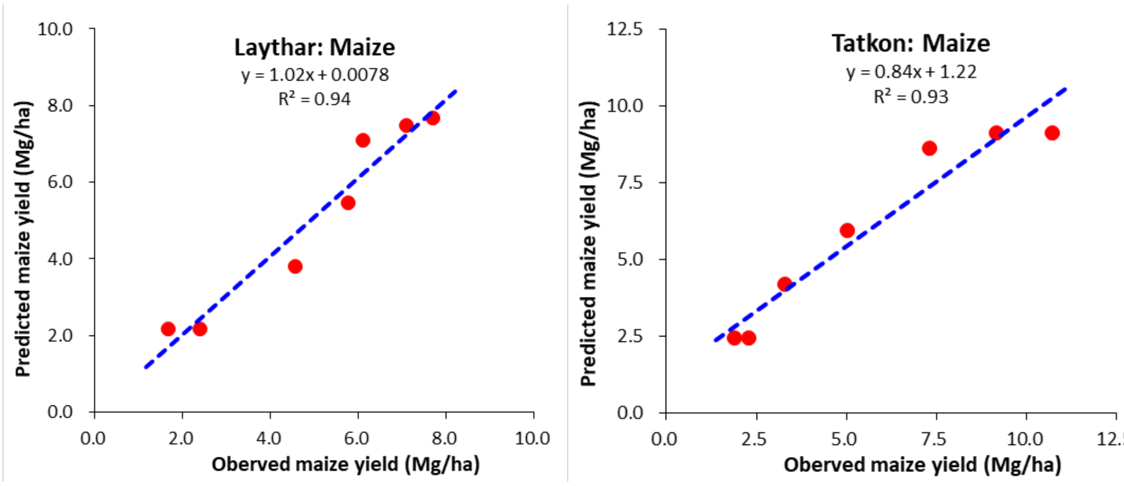


Figure 7.2.15. Observed vs. WNMM predicted maize yield at Laythar and Tatkon.

Simulations of the response of maize to N fertiliser are shown for Laythar in Fig. 7.2.16 and Taungoo in Fig. 7.2.17. As shown in the two figures, maize yield is more sensitive to high N rates at Laythar than at Tatkon, indicating the importance of irrigation practice in maize production in the central Myanmar region.

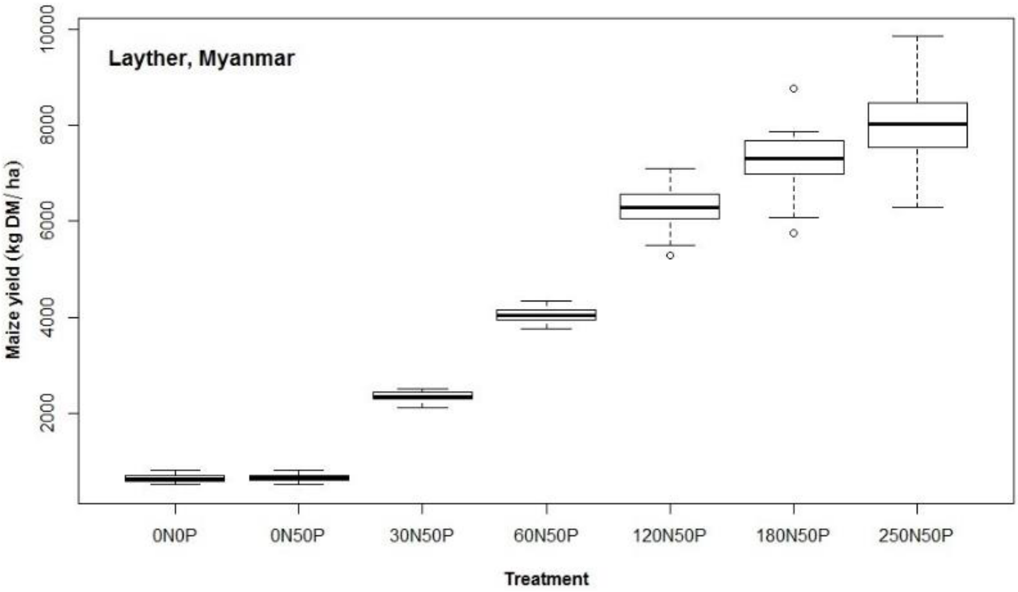


Figure 7.2.16. Simulated maize yield response to N rates at Laythar

X axis label refer to rates (kg/ha) of applications on N and P. The boxes represent 50% confidence and the bars represent those for 95% confidence.

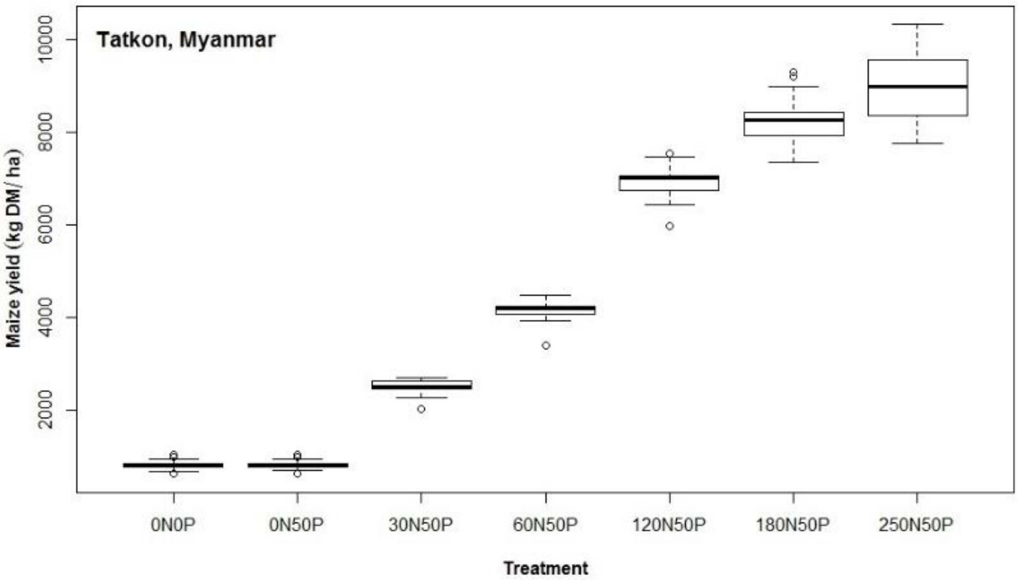


Figure 7.2.17. Simulated maize yield response to N rates at Tatkon

X axis label refer to rates (kg/ha) of applications on N and P. The boxes represent 50% confidence and the bars represent those for 95% confidence.

7.3 Fertilisation strategies to reduce N losses from intensive vegetable production in Victoria

A field experiment was conducted to determine the effects of reduced N fertiliser inputs and the use of nitrification inhibitor (DMPP) on crop yield, N use efficiency and N_2O emissions as compared to the grower practice (GP), in an intensive celery production system in Victoria. Details are presented in Suter et al. (2021).

Using only manure as the N source significantly reduced celery yield compared to the GP treatment (Figures 7.3.1 and 7.3.2). Reducing N input by 1/3 did not affect celery yield or apparent N use efficiency (ANUE). The use of DMPP did not improve celery yield but there was a trend of positive effects on ANUE in some of the treatments.

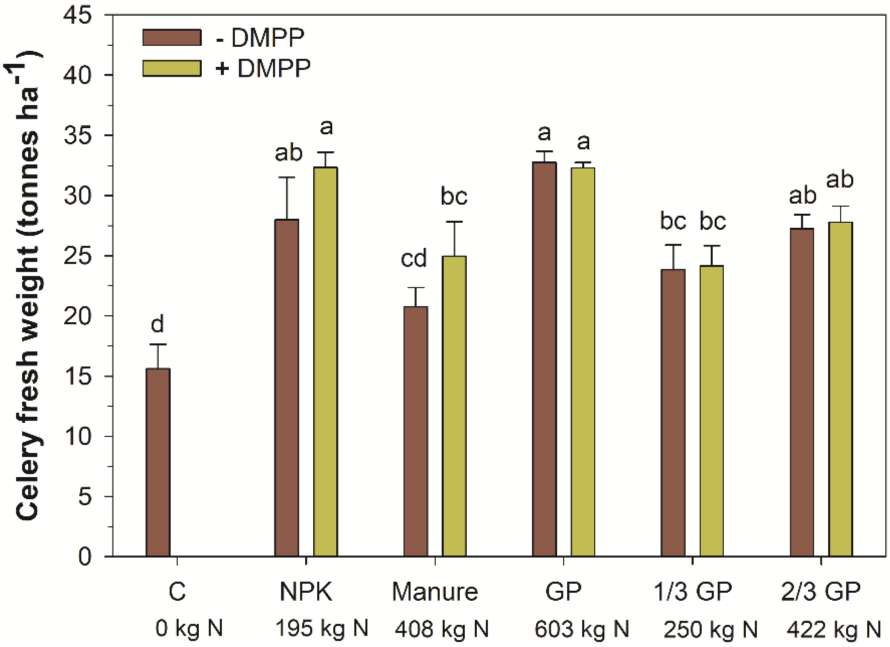


Figure 7.3.1. Effects of alternative N fertiliser practices on celery yield

C, Control; M, Manure; GP, Grower Practice. Columns with different letters were significantly different ($p < 0.05$). N rates in different treatments are indicated alongside the treatment names on the X axis. Error bars represent ±1 standard error of the mean (n = 5).

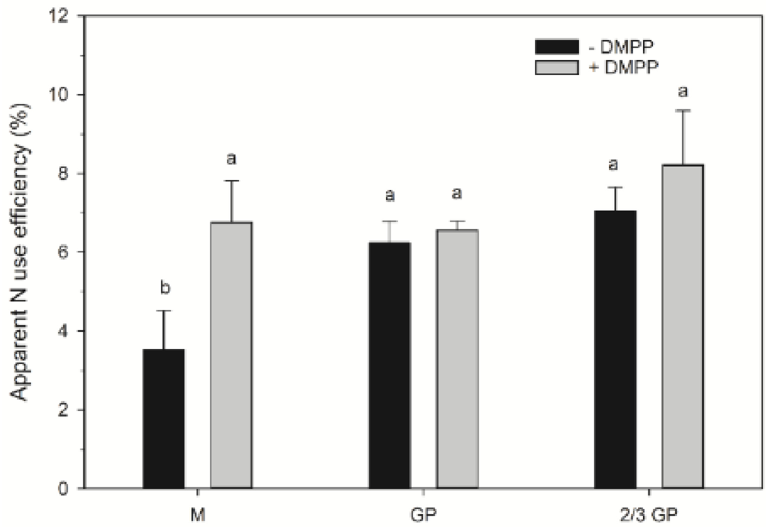


Figure 7.3.2. Effects of alternative N fertiliser practices on apparent N use efficiency C, Control; M, Manure; GP, Grower Practice. Columns with different letters are significantly different ($p < 0.05$). Error bars represent ±1 standard error of the mean (n = 5).

The recovery of the N fertiliser applied during the earlier plant stages was very low (<10%), whereas the recovery of N fertiliser applied during the later growth stages of celery plants was more than 40% (Figure 7.3.3). More than 50 % of the applied N in the GP treatment was unaccounted for, indicating a significant loss to the environment.

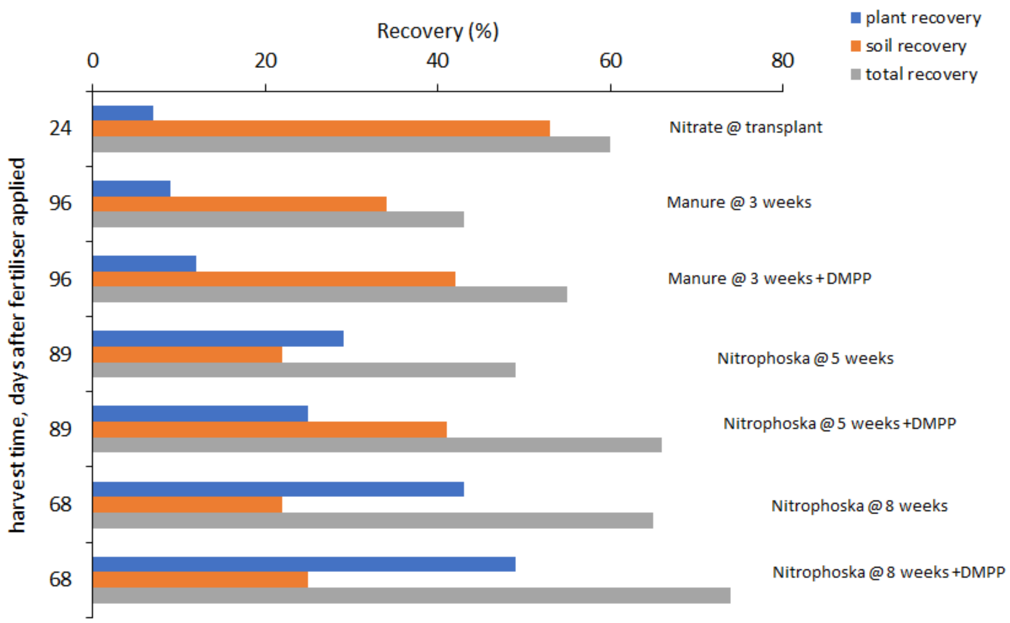


Figure 7.3.3. Recovery of 15-N labelled fertilisers applied under standard growers' practice

It was demonstrated that a reduction in N input by 1/3 from the existing grower practice did not reduce celery yield. The application of DMPP was ineffective in improving yield and ANUE, except in the manure-only treatment. Around 50% of the applied N in the grower practice was lost to the environment. Almost 10 kg N/ha was lost as N_2O from the grower practice over the two months of the celery growing period, which is 67 times greater than the control treatment. The application of N-fertiliser shortly after manure application led to the highest N_2O flux. Reducing N input in the grower practice by 1/3 reduced N_2O emissions by 4.5 times. Our study suggests that intensive vegetable growing on these sandy soils with high N input leads to high N loss, including considerable N_2O emissions, and that N inputs can be reduced without compromising yield.

7.4 Composition of commercial fertilisers in central Myanmar

7.4.1 Urea and compound fertilisers used in the dry season

From the survey analysis of fertiliser sales in 2016, 12 wholesalers, 15 retailers and 11 local distributors each sold about 1,614, 4,009 and 173 tonnes, respectively, in the surveyed area. Nitrogen fertilisers were the highest proportion of total nutrients sold (from 55 to 70% of the total). The N content of fertilisers found in the local markets is shown in Figure 7.4.1.

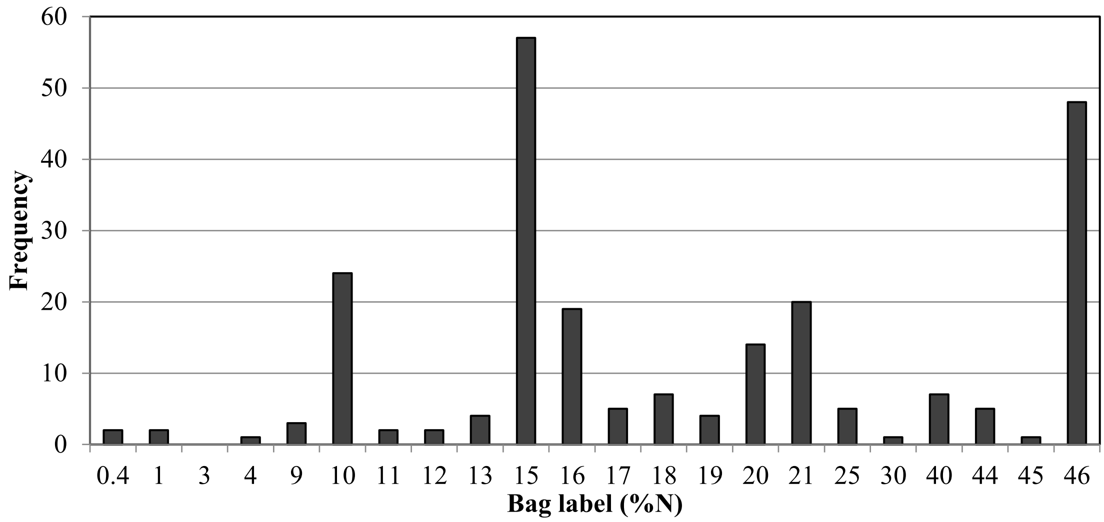


Figure 7.4.1. The stated N content (%) of fertilisers obtained in the 2017 dry season
Total n= 233 samples

Compound fertilisers containing 15% N were the most common type that were sold in the surveyed area, followed by urea (46% N) and compound fertilisers with 10% N (Fig. 7.4.1). This is in accord with the perception of interviewed dealers who stated that most farmers buy 15:15:15 NPK compound fertilisers, urea, and 10:10:5 NPK compound fertilisers for their crops.

There was a strong correlation between the N content labelled on the bag and %N content of fertiliser determined by University of Melbourne (UoM) (R^2=0.97, P<0.001) and LUD (R^2=0.99, P P<0.001) laboratories (Figure 7.4.2)

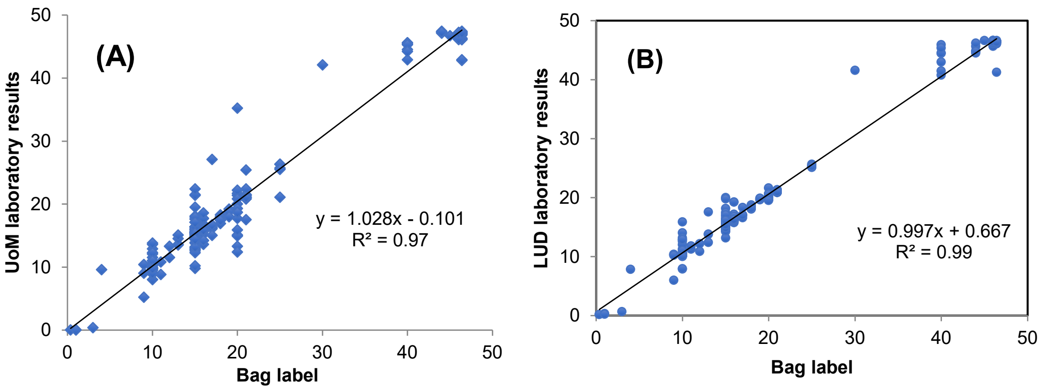


Figure 7.4.2. Relationship between % N figures for the UoM (A) and LUD (B) laboratories and bag label for commercial fertilisers obtained in the survey region

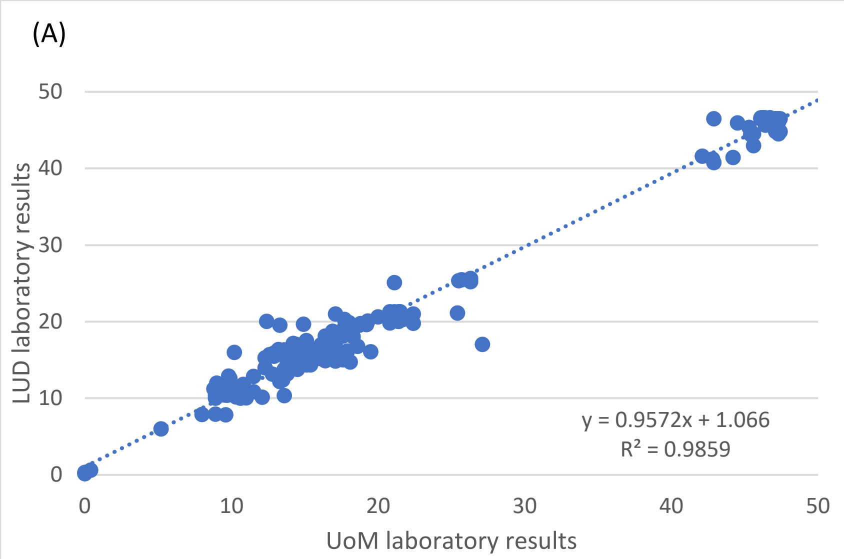
The slope of the regression line was close to one in both cases and suggests adequate labelling of the N content of the local fertiliser products. Only a few samples (14 out of total 233 samples) were deficient in comparison with the labelled value of N. Eleven of the 14 samples were imported from China and a disproportionate number of samples were unregistered products (five in all) suggesting that restrictions on the sale of unregistered fertilisers into the local market would be beneficial.

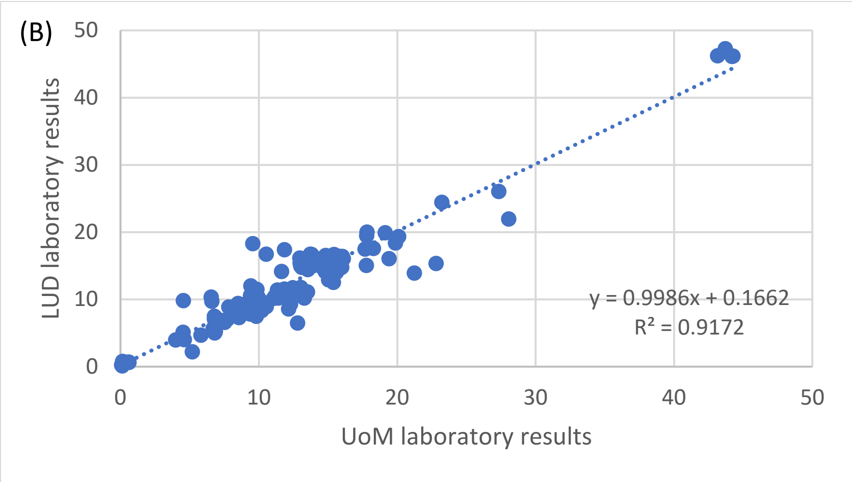
All urea (60 samples), ammonium sulphate (19 samples) and diammonium phosphate (4 samples) contained at least the designated levels of N, with the exception of one urea sample, which was 41.4% N. Almost 1 in 10 of NPK compound samples were N deficient.

The IFDC (unpublished report) also found that commercial mineral fertilisers collected from the Central Dry Zone, Ayeyarwady, Mandalay and Northern Shan State areas were also unadulterated, but details have not been published or released to the public.

Regression analysis of total N content determined by the LUD and UoM laboratories showed a strong linear relationship between %N and %P_2O_5 content of fertiliser samples for the UoM and LUD laboratories (Figure 7.4.3a and 7.4.3a). However the relationship between %K_2O for the LUD and UoM laboratories was poor ((Figure 7.4.3c). The results indicate that the LUD laboratory is at least as reliable as the UoM for analysis of total N and P content of fertiliser samples. The reasons for the differences in total K are less clear. Clearly the LUD laboratory is competent for monitoring and regulation of fertiliser quality.

Analysis of the P containing fertilisers revealed that of the 149 samples, 19 contained elevated levels of Cd and of those 15 had high Cd concentrations. One sample from Pyinmana contained 45 mg Cd/kg fertiliser and another from Taungoo contained 22 mg Cd/kg fertiliser. The suggested EU limit for Cd in fertilisers is 26 mg Cd/kg fertiliser or 60 mg Cd/ kg P_2O_5.





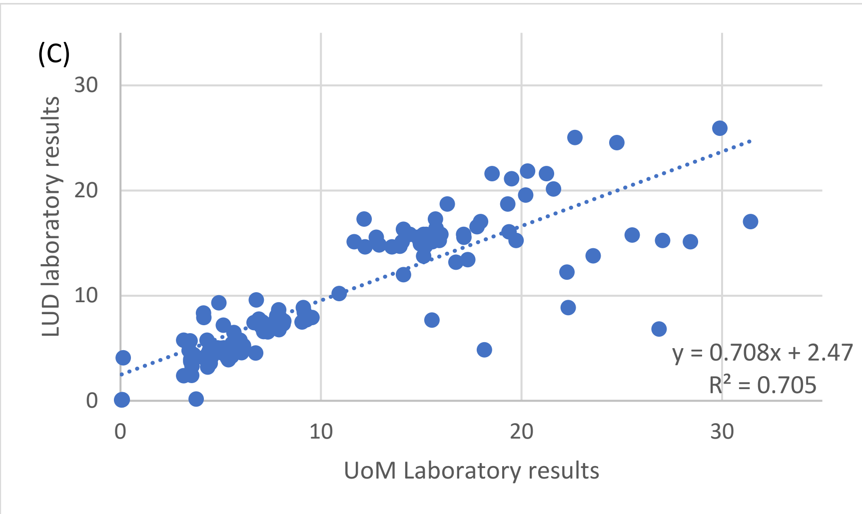


Figure 7.4.3. Comparison of total a). % N, b) %P_2O_5 and c). %K_2O values obtained by the UoM and LUD laboratories for dry season 2017 fertiliser survey samples.

Dealers were asked how many times government fertiliser inspectors visited their shops annually and how many fertiliser samples were taken. On average there was one inspector visit a year with around one third of the dealers' shops in Pyinmana and Tatkon townships visited and around two thirds of dealers' shops visited in Taungoo township. On average, two fertiliser samples per shop per year were taken in Pyinmana and Taungoo townships. In Tatkon township inspectors took one sample per shop per year. The inspectors mainly check sale licences, packing, and labelling. They also verify the products' registration. There are three inspectors per township. None of the dealers surveyed had attended training for fertiliser quality control, either from the government institutes or INGOs/NGOs. All fertiliser inspectors indicated that they were unable to properly train dealers about how to control fertiliser quality in their shops, mostly owing to time constraints. On average, one agricultural extension officer covers between 1,500 and 1,600 farmers in central Myanmar. Visits to dealers and product sampling are secondary to the extension service activities.

There are weak border controls for imported fertiliser due to the lack of facilities for checking fertiliser quality, especially those entering through the border crossing at Muse in Shan State. According to data from the Ministry of Commerce, Department of Trade, commercial fertilisers are mainly imported from the border area, which was about 77% of total fertiliser imported in 2015-2016. Gregory et al. (2014) reported that improperly labelled bags without Burmese language were found with Chinese imported products. About 80% of the respondent inspectors stated that imported products should be sampled and analysed at the border as a first line of defence. Controlling of fertiliser quality at township and village levels will be more efficient if there are effectively fertiliser quality control standards at the border.

About 70% of the inspectors interviewed claimed that one of the constraints to control fertiliser quality includes delay in providing up to date information of fertiliser products to dealers and farmers. This information should be provided in a timely way after the meetings of fertiliser committees, (which are responsible for product registration approval, registration of fertiliser business licences and product import licenses, brand and bag/label specification approval and sampling and analysis of fertiliser imports and in retail stores), because retailers and local distributors mostly stock commercial fertilisers one month before the growing season and one month during the growing season. Supporting booklets of fertiliser information such as the registered and cancelled product list is limited due to budget constraints. Many dealers (38 out of 75) also complained that verification was time consuming with over 3000 registered products on the lists. Consequently, they sometimes stock unregistered products in their shops.

According to the survey results, most of the dealers in the surveyed area have limited knowledge of fertiliser quality control owing to the lack of training. For instance, the actual nutrient content of the products are never questioned by wholesalers as this is beyond their capacity. Verification of quality was limited to the inspection of the physical characteristics of fertiliser such as caking, obvious impurity and condition of the bag. Further, most retailers and all local distributors do not check the quality of the products as they only sell them based on famers' order. It was noted that there was no balance to verify the weight of fertiliser bags at most of the dealer shops in the surveyed area. Farmers have to pay based on the weight of fertiliser mentioned on the bag in local market. About 87% of dealers answered that they were interested to attend the training on fertiliser quality control in their own township.

There are no regional laboratories at the Pyinmana and Tatkon townships and inspectors have to send the collected samples to the main laboratory at LUD headquarters in Yangon. Turnaround times are at least one month since the analysis of regular inspected samples is the low priority for the main laboratory service. Consequently, 40% of inspectors mentioned that little could be done to control substandard fertilisers for the current growing season.

The following recommendations are made as a way forward to maintain fertiliser quality at the township level:

1. In terms of N fertiliser quality control, fertiliser inspectors should concentrate their monitoring effort on NPK compound fertilisers and blended fertilisers;

2. Stringent import agreements should be entered into with neighbouring countries. Fertilisers without appropriate certification should be denied entry.

3. Since the number of fertiliser inspectors and their budget are limited, policy makers should assign more inspectors at township level and provide additional budget for increasing dealer visit and product sampling;

4. Regional laboratories should be established to provide quick feedback to the dealers;

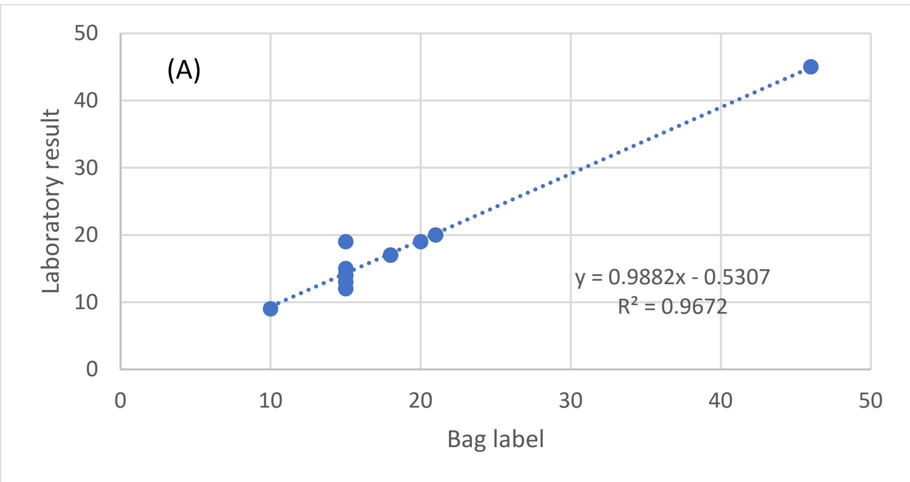
5. The training of dealers in product characteristics, physical and fertiliser quality control, storage conditions and efficient use of fertiliser for sustainable crop production in conjunction with farmers should be provided; and

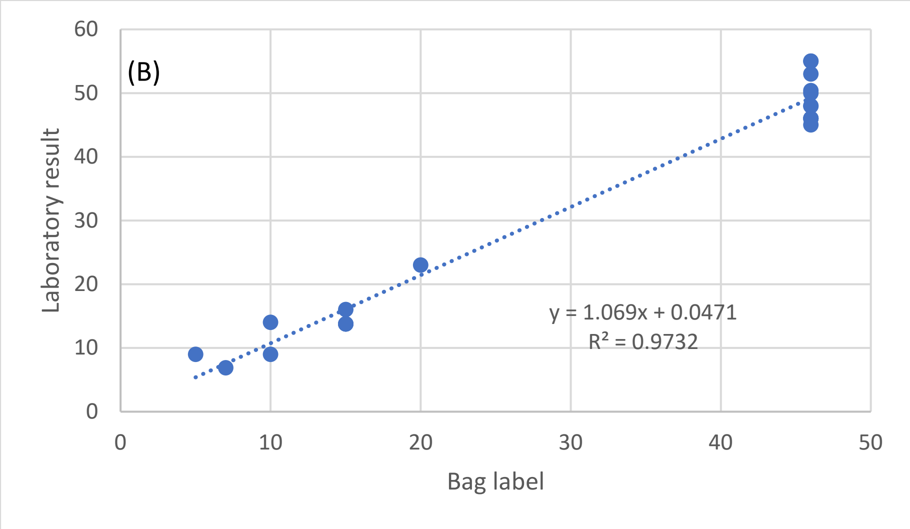
6. To update the commercial fertiliser information immediately after the meetings of the fertiliser committee, the concerned institute should establish an official website of the product information. This will be very efficient and convenient to assess the information of the products not only for the fertiliser inspectors but also for the dealers.

7.4.2 Fertilisers sampled during the wet season 2017

A smaller survey of fertiliser dealers was conducted in the wet season of 2017. On this occasion samples were only analysed by the UoM laboratory. Fertilisers analysed and number of samples were: N,P, K compound (8); muriate of potash (8); TSP (10); DAP (2); ammonium sulphate (1) and urea (1). There was a good relationship between bag label and measured N, P and K (Figure 7.4.4), however N containing fertilisers were generally slightly less than that claimed on the bag; P in P containing fertilisers were generally over the stated claim and; KCl fertilisers significantly under the claim on the bag, by 5-10%. This latter finding adds to list of fertilisers that should be tested routinely.

As with the dry season results, many (16/20) of the phosphatic fertilisers contained measurable amounts of Cd (> 2 mg Cd/kg fertiliser) and two (DAP and compound) contained concerning levels of Cd (10 and 22 mg Cd/kg fertiliser).





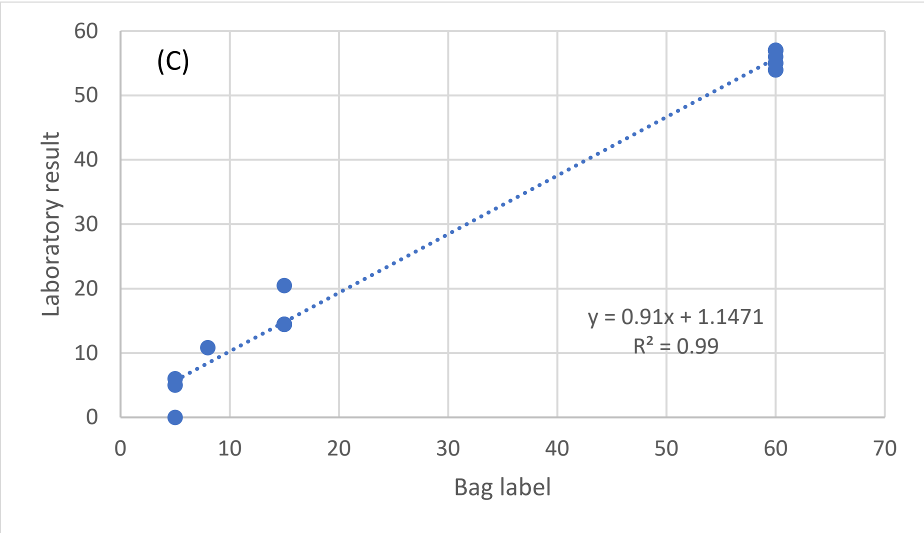


Figure 7.4.4 Relationships between bag label and laboratory analysis for: a). % N, b). %P_2O_5 and c). %K_2O values, for commercial fertilisers obtained in the survey region during the wet season 2017.

7.5 Economic and policy key findings

7.5.1 Focus Group Workshops

The focus group workshops conducted with local smallholder farmers at the beginning of the project gathered their opinions about their farms and farming systems, established their goals and means, and revealed their perceptions about several other important issues. Smallholders in the study area stated that their farm objectives were to make profit, sustain livelihoods, meet the needs of family consumption, and continue their farming heritage.

Important information about their cropping patterns is that they are now extending beyond the traditional rice, maize, and black gram crops to a range of other legumes (lablab, groundnut, green gram, and chickpea), vegetables (onion, chilli, tomato, potato, cabbage, sweet corn, eggplant, and radish), fruits (banana, watermelon) and other crops (sesame, sugar cane). These are higher value crops, and the smallholders appear to be expanding their cropping options beyond rice and maize. However, monsoon-season paddy rice is still the major crop grown.

In considering farming systems the decision to use more fertiliser on cereal crops is complicated by issues such as the crop varieties used (whether they can fully express the yield potential of added fertility), other bio-physical constraints (weed, pest and disease control), and the economics of borrowing money by risk-averse farmers. The cereal crop varieties used were mainly high-yielding varieties (HYVs) for rice and (older) hybrid varieties for maize.

An emerging trend is for some farm-family members to engage in off-farm activities and remit money back to their households to improve family livelihoods. This alternative use of labour corresponds with increasing mechanisation (4- and 2- wheel tractors in the villages, owned or hired) to replace draft cattle (oxen) and human labour for crop establishment. There are now small-scale mechanised harvesters available as contracted services to replace family or hired labour (see Figure 7.5.1). The observations of labour being used for higher value off-farm work rather than on-farm labour, and the substitution of capital for labour in the form of tractors and harvesters instead of family labour and draft cattle, are consistent with a more economic approach to crop production in central Myanmar. Indeed, some farmers expressed in the Focus Group Workshops the basic tenets of economics, in terms of the need for costs to not exceed revenues and for an acceptable return on investment in inputs such as fertiliser.

Figure 7.5.1. A contracted rice harvester operating in central Myanmar

The smallholders are beset by several complicating factors as they make farm management decisions. They are very concerned about climate change, which they observe firsthand as rising temperatures, unseasonal rainfall, and changed monsoon patterns, which are experienced as yield uncertainty and decline. They are also concerned for themselves working in the fields in hotter conditions. Apart from a changing monsoon rain pattern, some of them are also receiving less irrigation water from Yezin Dam and experiencing falling ground water levels in their tube wells.

With respect to fertiliser and crop yields they generally understand that fertiliser is required to replace nutrients removed with crop harvests. They already apply urea and compound fertilisers and seem to understand that nutrients in addition to N must be replenished.

But the question of using more fertiliser to improve crop yields is clouded by lack of clear advice on how much to apply, by concern for fake or adulterated fertiliser, and by the need to borrow money to buy the fertiliser and the terms of repayment. These uncertainties are a friction on using more fertiliser in their cropping systems.

7.5.2 Large-scale farmer survey of fertiliser practices

The 600-farmer survey (Thar et al. 2021a) documented typical smallholder fertiliser management practices. Fertiliser practices were classified in terms of both the quantity and timing of urea and compound (NPK, usually 15:15:15) fertiliser applications. The splitting of applications of fertiliser based on types of crop and fertiliser are shown in Figure 7.5.2.

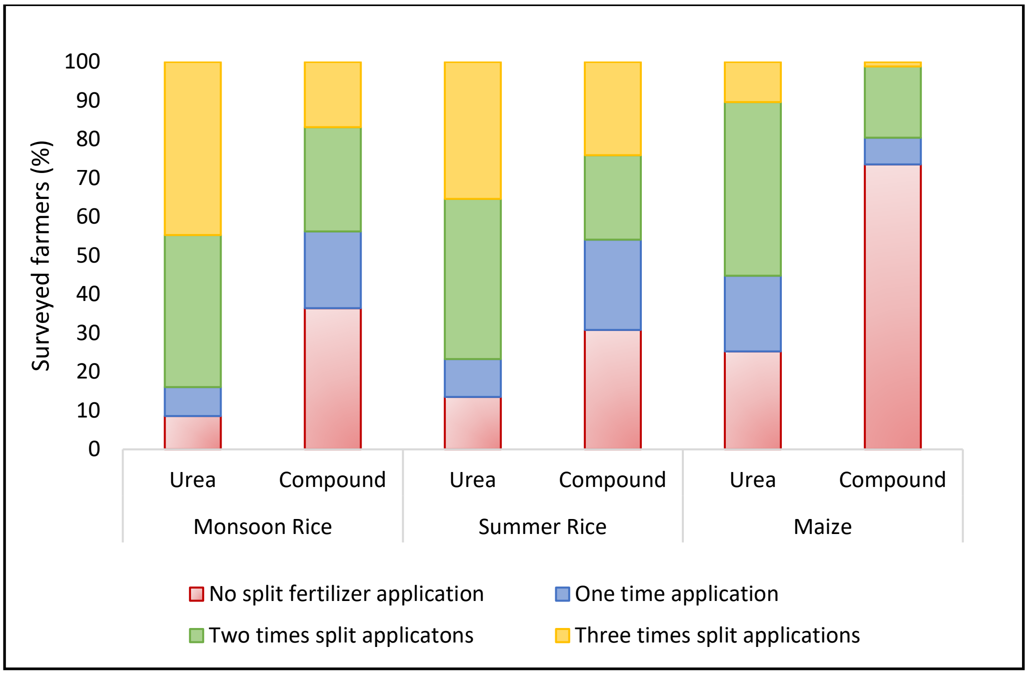


Figure 7.5.2. Splitting of applications of fertiliser based on the type of crop and fertiliser

'No split fertiliser application' refers to farmers who do not apply any type of fertiliser after sowing or transplanting. These farmers may or may not apply fertiliser as basal application prior to sowing or transplanting. 'One time application' refers to farmers applying fertiliser only once after the plants are established.

For monsoon-season rice, most farmers applied urea two or three times after sowing or transplanting. Compound fertiliser was used by 64% of the surveyed smallholders growing monsoon rice and more than half applied it as split applications. For summer rice, 86% of farmers used urea and 69% used compound as split applications. For maize, most smallholders split applications of urea, but very few farmers practised split application of compound fertiliser as most of the smallholders applied it as a basal application.

The rates of urea fertiliser applied to rice by the surveyed farmers are compared to the national recommendations from DOA and MoALI in Figure 7.5.3. Monsoon-season rice was cultivated by 89% of the smallholders in the survey sample. Twenty-three percent of farmers were applying N within the range of 69 to 92 kg N/ha, while 47% of the farmers were applying smaller rates, and 30% of the farmers applying higher than the recommended rates. Nine percent of farmers applied no urea fertiliser. Dry season (irrigated summer) rice was cultivated by 22% of the farmers in the survey due to limited access to irrigation. Only 20% of them applied urea fertiliser within the recommended range, while 49% of the farmers were applying lower, and 31% higher, than recommended rates. Maize was cultivated by only 15% of farmers surveyed. With respect to urea fertiliser application, 25% of the maize farmers did not apply any urea fertiliser and 95% applied less than the recommended rate.

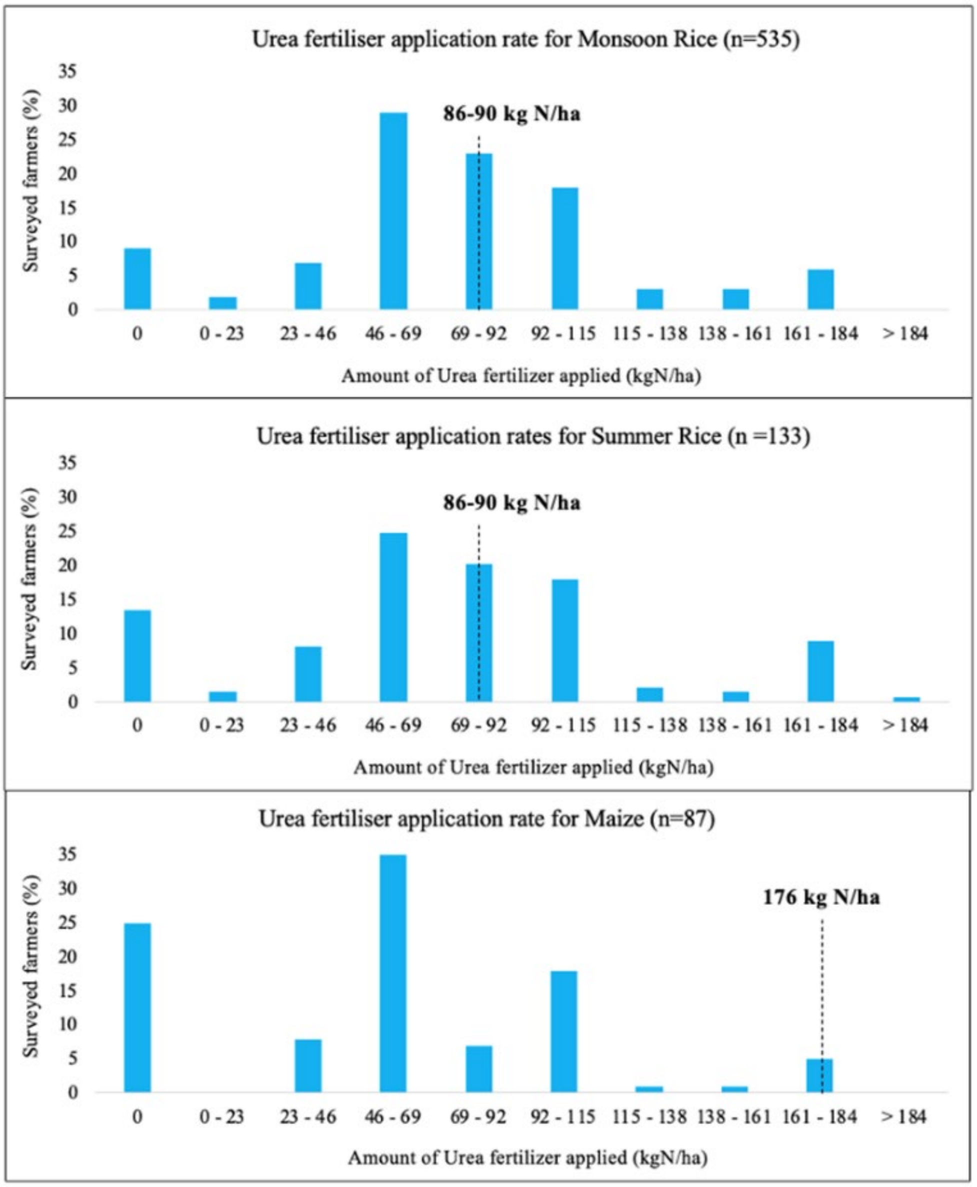
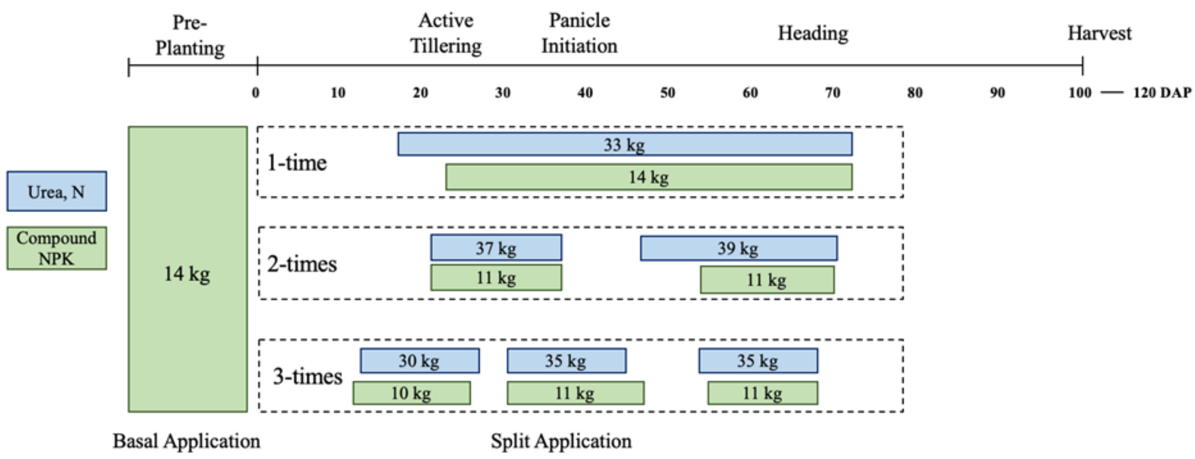


Figure 7.5.3. Distribution of urea fertiliser application rates by surveyed farmers compared with national recommendation

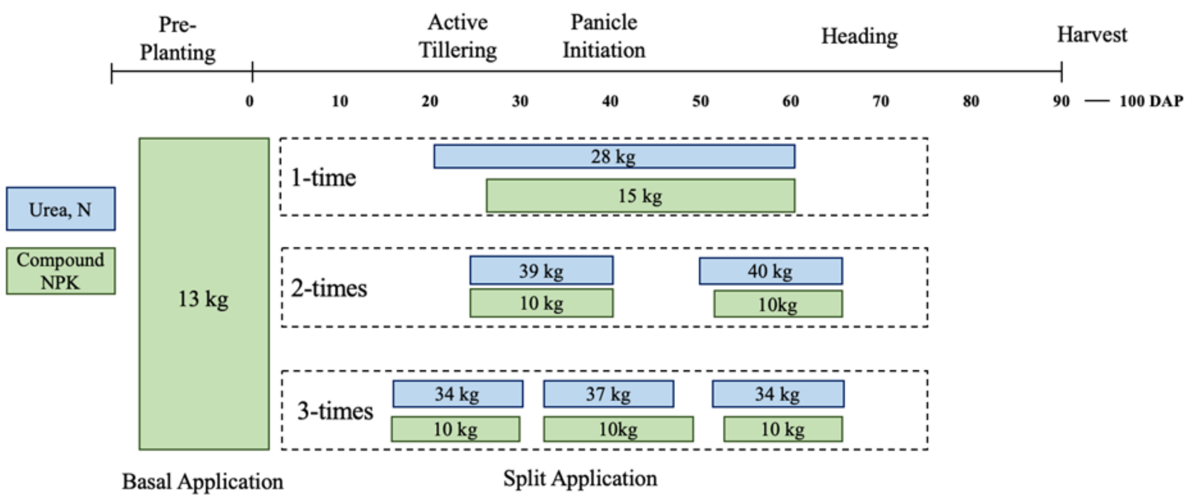
(--- represents the national recommended urea fertiliser application rates from DoA and MoALI)

While there were smallholders applying substantial amounts of fertiliser in the study area, there were also some farmers applying none, or less than the recommended rates, as well as some who were applying urea at higher rates to their rice crops. When asked “How do you make decisions on how much or how often to apply fertiliser?”, the farmers' responses were: personal decisions due to socio-economic conditions and risks (42%), suggestions from other farmers (24%), recommendation from fertiliser companies (15%), recommendations from extension officers (17%), and information on fertiliser package labels (2%). Assuming that the national recommendations are correct there is scope for improving fertilisation practices in the surveyed area. The use of inadequate rates of N fertilisers may decrease overall crop production whilst excessive applications of N fertilisers represents losses to farmers and may contribute to degradation of air and water quality.

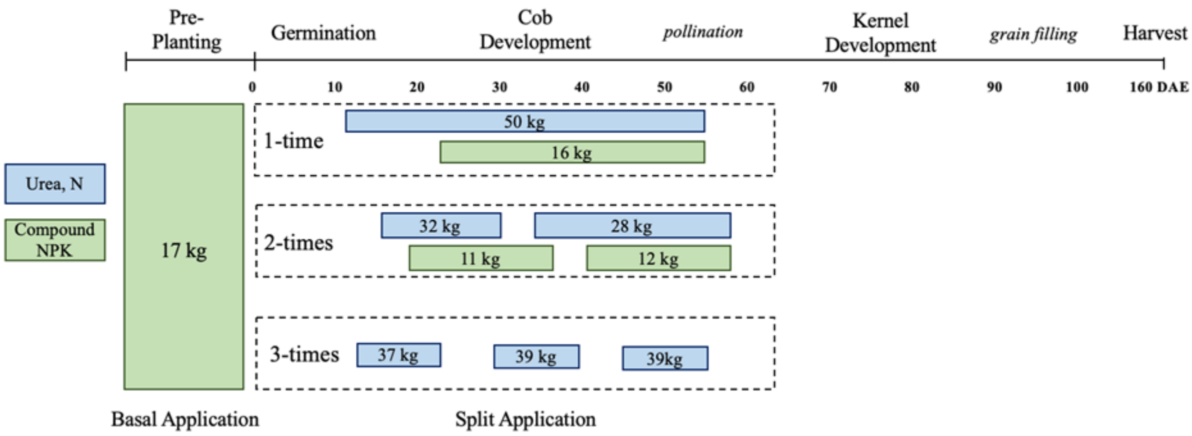
The average fertiliser application rates for each number of split applications are shown in Figure 7.5.4.



A. Monsoon season rice



B. Summer Rice



C. Maize

Figure 7.5.4. Average fertiliser application rates for each number of split applications at different times for Monsoon Rice (A), Summer Rice (B) and Maize (C); DAP = Days after planting; DAE = Days after emergence

An analysis was conducted of the timing of fertiliser applications by the surveyed farmers compared to good management practices (GMP) shown in Table 7.5.1.

Table 7.5.1. Generalised 'good management practices' for rice fertiliser amounts and timing.

'Good practice'	Threshold	Supporting references
1. Limit early N applications	Apply <1 third of applied N before 21 days (if direct seeded) or 14 days (if transplanted) after planting.	(Sharma *et al.* 2007; Peng *et al.* 2010; Haden *et al.* 2011; Qi *et al.* 2012; Saito *et al.* 2015; Silva *et al.* 2017; Banayo *et al.* 2018a; Buresh *et al.* 2019)
2. Avoid late N applications	Apply <5% of N <55 days before crop maturity for non-hybrid variety.	(Fairhurst *et al.* 2007; Banayo, et al. 2018b)
3. Split apply N	Apply N at least three times (including basal application).	(Fairhurst, Witt et al. 2007; Saito, Diack et al. 2015; Silva, Reidsma et al. 2017; Banayo, 2018b; Buresh, Castillo et al. 2019)
4. Apply N at panicle initiation	Apply 20 to 60% of applied N between 55 to 65 days before crop maturity.	(Banayo, et al. 2018a; Banayo *et al.* 2018b)
5. Apply P early	Apply all P within 14 days of transplanting or 21 days of direct seeding	(MOAI 2006; Fairhurst, Witt et al. 2007)
6. Apply P once	Apply P once (including basal application)	(MOAI 2006; Fairhurst, Witt et al. 2007)

The use of GMPs for N applications by the surveyed farmers are shown in panels A to D, and for P in panels E and F of Figure 7.5.5. There has been no comparable study in Myanmar considering the fertiliser application timing of cereal crops. Most farmers' practices were aligned with the first three GMPs concerning the timing of N fertiliser shown in Table 7.5.1. More than 75% of the farmers avoided excess early application of N (Panel A), approximately 90% of farmers avoided late applications of N fertiliser (Panel B), and approximately 85% of farmers applied N fertiliser at least three times (including basal applications) (Panel C) (Figure 7.5.5). The large number of N splits is mainly due to the number of compound fertiliser applications. Nearly half of the surveyed farmers' practices did not align with the fourth GMP practice of applying N at panicle initiation (PI,) between 55 to 65 days before crop maturity (Panel D).

In the case of P fertiliser, the farmers' practices generally did not align with the recommended GMP of applying P during the early growth stages of rice when it supports flower, root, and stem development. Only 18% of the farmers applied total P early (within 21 days after seeding or 14 days after transplanting) (Panel E). Most farmers (82%) applied P throughout the growth period when it may have been needed earlier. It is also recommended to apply P only once as it is relatively immobile and the cost of labour for its application can be reduced. Only 34% of the farmers were found to be applying P once (Panel F).

It can be concluded that the surveyed farmers were applying substantial amounts of fertiliser to rice, that they are applying both urea and compound fertiliser (as basal and in-crop), and that they are splitting the fertiliser applications up to three times during the crop growth period. The results imply relatively sophisticated fertiliser management by the smallholders and a willingness to apply fertiliser at different times during the growing season. With respect to timing, nearly half of the surveyed smallholders were not applying N to rice at the panicle initiation stage, which is often crucial to increase yield, and the majority (82%) of smallholders were applying P throughout the growth stages, when earlier applications are desirable. There is clearly scope for improving the timing of urea and compound fertilisers to rice in the study area. It should be restated here that we found that urea applications to monsoon season rice should be minimal, if at all, as it may be unnecessary (section 7.2.1) and could inhibit natural N fixation (section 7.2.3).

Smallholders may be able to reduce the cost of labour by reducing the number of P applications and avoiding late applications. It is not yet clear if the applications of compound fertiliser during the growing season results in beneficial effects of applying K. If that is the case, the use of potassium chloride (better known locally as muriate of potash, MOP) rather than compound NPK fertiliser, would be preferable. However, in general, studies of crop responses to P and K (and Zn) applications to rice in central Myanmar (including the Central Dry Zone, CDZ) have been inconsistent.

In the case of maize, it was found that the rates of N were well below current government recommendations, and well below those suggested by our trials (section 7.2.5). Appropriate basal applications of compound fertilisers were being used for maize crops. In general, the agronomic results (section 7.2) and survey results presented here suggest there is scope to improve farmers' practices for rice and maize production. Key results in a nutshell, without consideration of financial returns to farmers, are:

i. Apply basal NPK fertiliser at the final land preparation stage for rice,

ii. Apply no, or no more than than 30 kg N/ha, of urea to monsoon season rice,

iii. Apply 77 kg N/ha as urea to summer rice and split so that none is applied after the panicle initiation stage, and

iv. Increase the rates of urea applied to maize crops

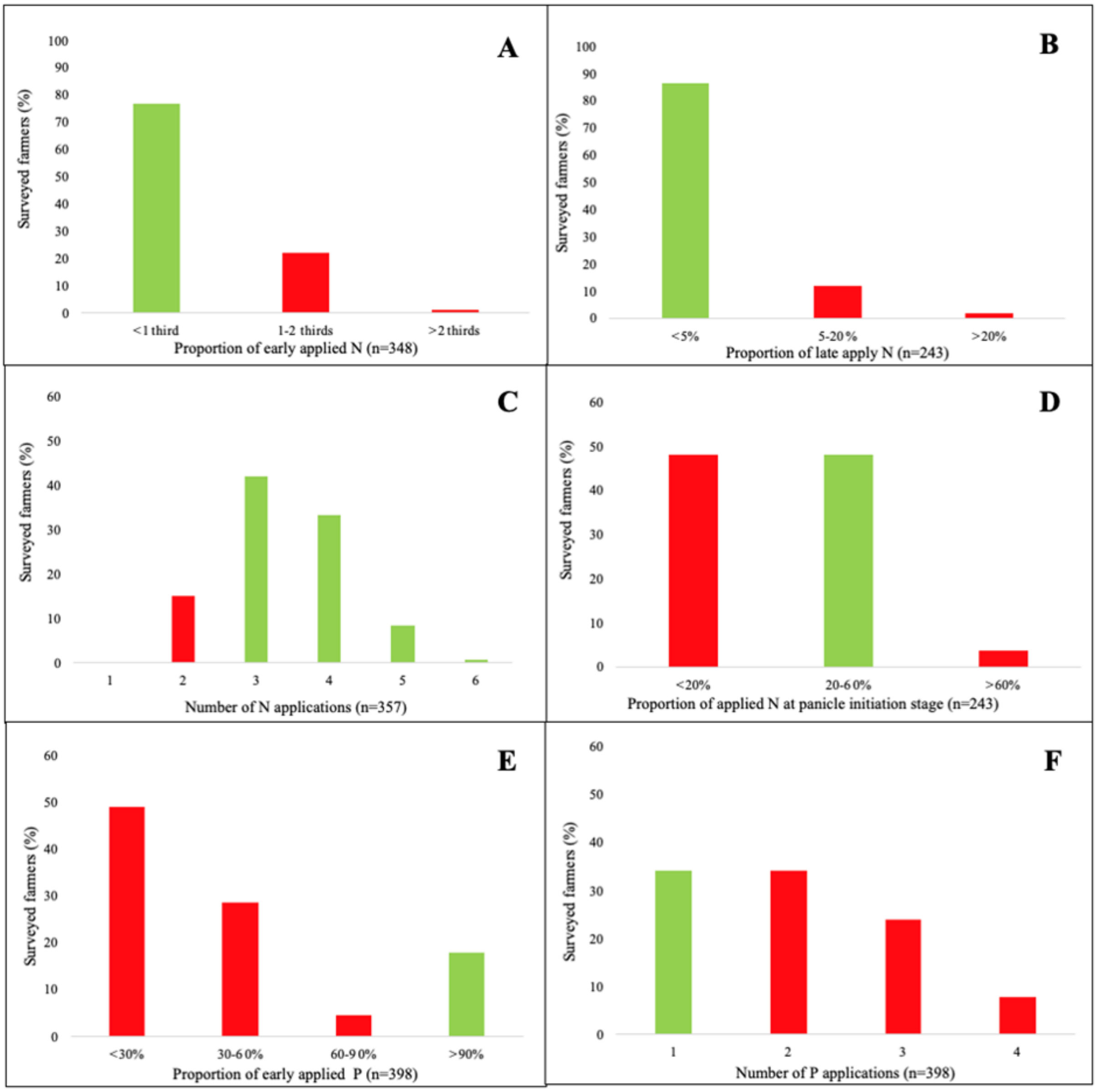


Figure 7.5.5. Timing of fertiliser application practices by surveyed farmers compared to 'good management practices'

The green columns represent practices that are aligned with the generalised 'good management practices' and red columns represent those not aligned

7.5.3 Typology analysis

Smallholder farming systems are heterogeneous in terms of socio-economic and agro-ecological characteristics (Llewelyn and Brown 2020). It is important to consider the heterogeneity of the farming systems so that any DST can be designed to reflect farmers' needs and target appropriate end users.

Farm typology studies are useful for understanding factors explaining the adoption or rejection of new technologies. From a practical point of view, identifying the reasons for farmers' adoption or rejection of new technologies such as DSTs is important for the agricultural society, policy makers and related value chain sectors. In particular, the typology of farmers' management, along with their opinions on DSTs, can provide useful policy insights on whether and how such tools can contribute to adoption of innovations and rural development.

Six types of farm systems were identified with distinct characteristics in the study area of central Myanmar (Thar et al. 2021b):

1. Small and subsistence
2. Large and semi-intensive on-farm income
3. Small and intensive
4. Diversified with off-farm income
5. Small and subsistence female farm
6. Commercial farm

Participatory research through focus group discussions validated the farm typologies and provided evidence that farmers belonging to only one type considered that DSTs could be useful in gaining more information and knowledge. The six systems were used for gauging farmers' interests, attitudes, and preferences for DSTs. Farmers interested in the fertiliser technology indicated that discussion groups are better tools for learning and preferred a learning-based approach rather than a prescriptive tool. Farmers preferred video clips and infographics integrated into existing familiar digital platforms. The study contributes by identifying heterogeneity among farmers in a statically robust manner and developing a deeper understanding of fertiliser decisions as well as knowledge and intentions related to use DSTs/Apps via the follow-up Focus Group Discussions. Incorporating a participatory research framework with typology identification may have a beneficial role in direct interactions with smallholders which may increase their acceptance of DSTs.

Arising from the focus group discussions, farmers in Type 2 (Large and semi-intensive on-farm income) were more optimistic and thought that DSTs may be useful in allowing then to gain more information and knowledge. They were more likely to adopt a fertiliser DST than farmers in other farm types.

7.5.4 Fertiliser policy Implications

Background: With the current (2021) extensive civil unrest after the military coup it seems academic and unrealistic to be considering how agricultural policy can be assessed to improve crop fertility management to reduce poverty in central Myanmar. A brief review (Farquharson et al. 2021) of agricultural policy extended the discussion of Kurosaki (2008), who showed how restrictive agricultural policy had a real cost of income foregone by not using Myanmar's substantial natural agricultural resources to their fullest capacity. The "Road to Socialism" and restrictive agricultural policies were associated with substantial opportunity costs.

Rice is the staple food of Myanmar and rice consumption per capita was estimated to be 178 kg per person in 2016. A large share of Myanmar's agricultural land is used for paddy rice cultivation, amounting to 70% of total arable land, and constituting 30% of agricultural output and 95% of total cereal output. During the British Administration before 1948, Myanmar was considered as the "Rice Bowl of Asia" due to export-oriented, commercialised agriculture. However, in 1963 the rice market was nationalised by the Myanmar government to implement a national food security policy. The government shifted its priority focus to domestic distribution and monopolising the rice marketing system, with farmers prohibited from making any decisions about selling their products. In 1987, during the first liberalisation of the market, the government lifted restrictions on agricultural exports, except rice, to maintain stability in the country. In 2001, farmers were obliged to grow paddy in designated paddy fields of the lowlands and a government procurement quota of approximately 20% of gross product was established.

The Myanmar government also enforced cropping pattern plans and farmers were threatened with their tillage rights (see below) if they deviated from the government's crop plans, especially with respect to paddy. To retain their tillage rights, farmers were pressured to grow paddy rice crops on lowland fields. In 2008 the procurement system was abolished, and the private sector could trade rice freely in the domestic market. However, some restrictions remained such as a government-imposed restriction on rice exports (10% of total production) and a rice export quota for the private sector.

Generally, the Myanmar government's agricultural policy throughout the regimes has regarded rice as the staple food and a tool to maintain political stability. The market was not liberalised until the end of the long-term military regime. A study by Kurosaki (2008) found that there was loss in rural income because of government's policies that forced farmers to grow paddy with an income per acre that was lower than other crops. In 2016 the democratic government lifted restrictions on the choice of field crops that could be grown on paddy lowlands allowing farmers the freedom to grow any crop.

Land tenure and finance: In Myanmar farmland historically belonged to the state, and farmers were only given tillage rights (Kurosaki 2008). Farmers did not have the right to exchange, transfer, lease, inherit, or mortgage their paddy land, although children were usually given the right to cultivate their parent's land and unofficial transfers of tillage rights were not uncommon. Kurosaki (2008) reported that, in 2008, land use rights for plantations, orchards and non-paddy could not be sold, leased, or transferred.

This system was inherited from previous periods. Before the military government overthrew the elected government in 1962, the 1948 Constitution stipulated that:

(i) The State is the ultimate owner of all lands,

(ii) The State will have the right to regulate, alter or abolish land tenures or resume possession of any land and distribute the same for collective or cooperative farming or to agricultural tenants, and

(iii) There can be no large land holdings on any basis whatsoever.

Under "Burmese Socialism," a tenancy law was enacted, by which the rights of tenants were vested solely in the State in the form of Agrarian Committees, and another law was enacted to protect cultivators' rights so that no one could confiscate or seize any of a farmer's means of production, such as land, livestock, farm implements, and agricultural produce as payments for debts. The 1974 Constitution confirmed that all lands belong to the State. Although the present regime suspended both constitutions of 1948 and 1974, it continued to follow the land policies adopted in both cases.

Recent changes allow farmers to own their land with the right to buy and sell farmland. Leasing of farmland was also permitted. Despite these changes, and the lifting of restrictions on the choice of crops, most farmers continue to grow paddy as they consider that rice is their most important crop (see their expressed objective of farming heritage, section 7.5.1). It is the only crop that they have cultivated from generation to generation and is likely to be the best suited crop for lowlands under monsoonal climates.

In Myanmar, the Myanma Agricultural Development Bank (MADB) is the largest financial institution and finances agriculture activities at a subsidised interest rate. However, finance is only available to farmers with formalised land tenure (i.e., tillage rights) and who produce certain crops. Loans are specified by crop type. The total loan size is specified as the loan value per land area unit. Two aspects of this are that: (1) the loans for paddy and sugar cane are much higher than for other crops, and (2) the sizes of loans for all crops have increased over time. For paddy, the loan rate is AUD 370 per ha, and for other crops it is AUD 125 per ha. The maximum loan per farmer is AUD 1500 for any farm size. Hence, the amount of finance for the crops other than paddy is much lower than for rice and may encourage paddy rice production at the expense of other crops.

An illustration of the implications of loan size restrictions for farm-level fertility management is as follows. A 50-kg bag of urea (containing 23 kg N) currently costs 25,000 MMK (AUD 25) at the farm gate. The loan size limit of AUD 370/ha for paddy allows up to 15 bags/ha of urea to be purchased for rice fertility management. In contrast, the farm loan size limit of AUD 125/ha for maize allows the purchase of only 5 bags of urea for maize. Although this example assumes, unrealistically, that the loan limit is only used to purchase fertiliser and no other crop inputs, it strongly shifts the use of urea to rice rather than maize. This contrasts sharply with the agronomic results (section 7.5.2) indicating that that maize has a greater potential yield response to urea than rice (particularly during the monsoon season when maize is grown in the project area), and with recommendations for N fertiliser rates provided by DoA (Table 7.5.1).

The regulations for loan applications, in addition to establishing tillage rights, can act as a barrier to obtaining loans. To apply for a loan, farmers are required to:

(i) Submit a loan application to the loan screening committee at village level,

(ii) Submit their farmer registration book issued by the village authorities to verify the farmer's right over the land leased from the government year by year, and

(iii) have a good credit history and join a 5-10 farmer group to mutually guarantee their loans.

Interest rates (currently 8%) are a substantial cost for smallholders in financing farm input purchases. In addition, females are only permitted to apply for loans if they are the principal farmer.

From the survey in the project area (Thar, 2021) seventy-two percent of surveyed farmers borrowed money to purchase fertilisers. The primary lending source was MADB, with 90% of the farmers taking up loans from this bank. Other sources include financial institutions (15%), individual money lenders (5%), fertiliser company (Awba) (3%), and family and friends (1%). Nearly all smallholder purchases of fertiliser were financed by loans, so the terms and conditions of the loans have important implications for fertility management and crop choices. The uncoordinated nature of agricultural finance policy and DoA agronomic recommendations is an example of agricultural policies constraining 'best management practice' for fertility management in maize. Farms generally have both lowland and upland areas, and loan regulations for fertilisers favour lowlands, even though our results show that monsoon-season rice has small, if any, requirement for N fertiliser. Economic gains from re-directing the application of N fertiliser to crops other than monsoon-season rice of the lowlands, to more responsive, and higher value, crops, may be possible. This is consistent with our findings that farmers in the surveyed areas are interested in expanding their range of crops, including high value vegetables (section 7.5.1).

7.5.5 Calculation of economic optimum nitrogen rates for rice and maize

Rice: Economic analyses of the crop yield data from the project trial sites, the regressed yield responses and proposed economic N rates based on a target ROI of 100% (EONR100) are shown in Figures 7.5.5, 7.5.6 and 7.5.7. Comparisons of the DoA recommended N rates and the EONR100 rates from our results are given the Table 7.5.2.

Table 7.5.2. Economic analysis of project trial results and DoA recommended rates for rice and maize

Location, crop, and season	EONR with 100% ROI	DoA recommendations
Taungoo		
- Monsoon rice	30	90
- Dry season (irrigated) rice	120	90
Yezin		
- Monsoon rice	30	90
Tatkon		
- Monsoon maize	250	176
Laythar		
- Monsoon maize	200	176

These results show that for monsoon-season (paddy) rice at Taungoo and Yezin, with the shapes of yield responses and with the current prices of N and rice, that the EONR100 is only 30 kg N/ha (Figures 7.5.5 and 7.5.6). Furthermore, our results (section 7.2.3) show that unnecessarily high N fertilisation rates not only did not provide yield benefit but rather promoted native soil N mining and high N losses, where ~50% of fertiliser N applied was lost or unaccounted for. Biological N_2 fixation compensates for moderate yield levels in monsoon seasons, so fertiliser rates exceeding 30 kg N/ha are not advisable. It can be concluded that N applications above that applied in compound fertiliser before transplanting should not be applied to rice grown in the monsoon season, or at least limited to a maximum of 30 kg N/ha. In the context of farmers' current practices (section 7.5.2) recommendations to farmers should include reducing urea applications to monsoon-season rice.

For dry season irrigated rice at Taungoo the EONR100 was much higher (120 kg N/ha) because of the much greater potential yield response to N fertiliser (Fig. 7.5.5). The agronomic results in section 7.2.1 showed that yields can be increased from approx. 4 t/ha to 6-8 t/ha in the irrigated dry season with the existing varieties. For dry season (irrigated) rice it was shown that statistically significant yield increases were obtained up to 77.6 kg/ha. In one dry season and at one location, raising N fertiliser application to 160 kg N/ha led to significantly higher grain yield compared to grain obtained from an N input of 77.6 kg/ha. The economic results show a (risk adjusted) recommended N rate of 120 kg N/ha. There is clearly scope for increasing rice production in the dry season where irrigation is available, both from agronomic and financial points of view. In contrast to monsoon season rice farmers are currently using too little N on summer rice (section 7.5.2) and recommendations should be for increasing urea use.

Maize: For maize at Taungoo and Laythar the yield responses to N fertiliser were substantial and the calculated EONR100 values were very high at 200 to 250 kg N/ha. These rates are higher than the DoA recommendation of 176 kg N/ha (Table 7.5.2). From Figure 7.5.7 the actual farmer applications for maize were shown to be generally well below the DoA recommended rate. A possible explanation is the regulations in Myanmar relating to farm finance and credit limits for loans available to famers to purchase urea.

The agronomic trials (section 7.2.5) showed marked increases in grain yields with fertiliser N inputs, from ~2 t/ha with zero fertiliser N input to more than 8.5 t/ha with 250 N/ha, in 2017. A yield response to N was apparent in the 2018 monsoon season but yields were limited by flooding. Crop yields increased from zero to 180 kg N/ha fertiliser inputs but there was no significant increase in crop yield or N uptake above that, indicating that 180 kg N/ha was likely to be the maximum agronomic N rate for maize at Laythar.

Depending on the season, 200 kg N/ha or 250 kg N/ha resulted in the best economic decisions about N fertiliser for monsoon-season maize at Tatkon and Laythar. It can be concluded that N fertiliser use on maize is insufficient for increasing grain production or for optimising farmers' incomes, and that N application rates can be increased to around 200 kg N/ha. However, the existing Government policy restricting loans for farm inputs to crops other than paddy rice has implications for whether farmers can change their crop rotations to incorporate higher-value crops if such crops require N fertiliser.

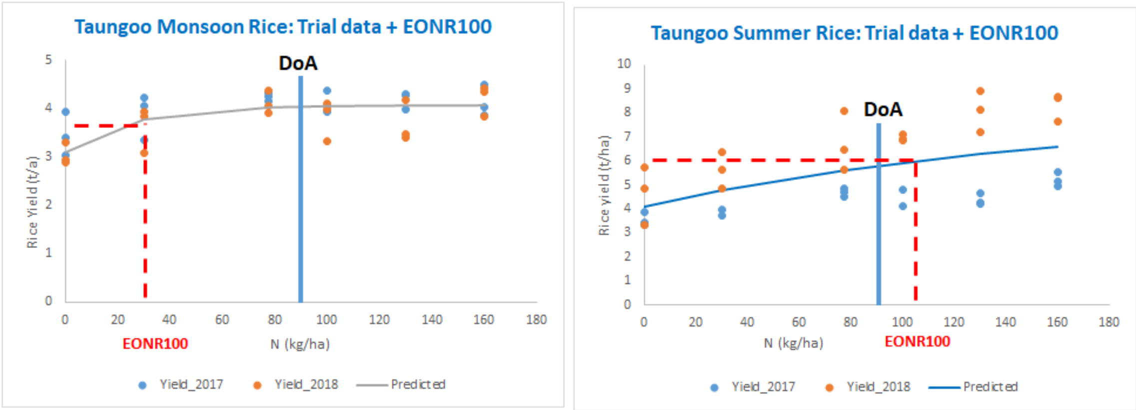


Figure 7.5.5. Economic analysis: Rice at Taungoo

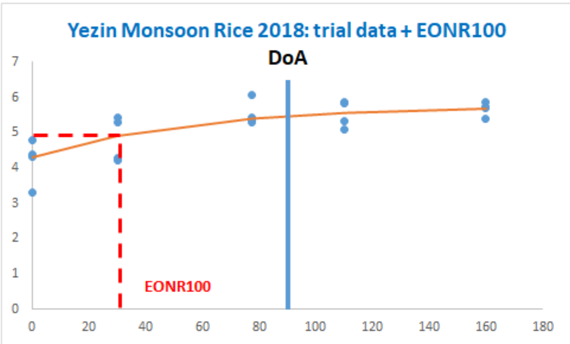


Figure 7.5.6. Economic analysis: Rice at Yezin

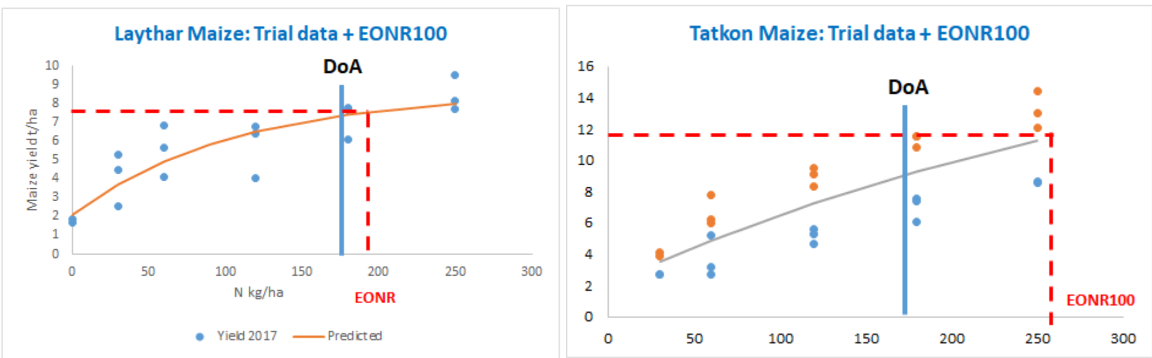


Figure 7.5.7. Economic analysis: Maize at Laythar and Tatkon

7.5.6. Whole farm models

Whole farm models of representative lowland and upland areas were developed and used to analyse questions about potential financial benefits from changed fertiliser practices and other farm and family management. The analysis shows that, on average, there is no benefit from an increase in N fertiliser rates applied to monsoon (paddy) rice. There is a potential benefit from increased N fertiliser applied to maize crops. Financial restrictions imposed by Myanmar Government policy on the MADB (limits in loan levels for non-rice crops) may be a reason for the lower than optimal N fertiliser rates applied to maize.

Figure 7.5.3 (top graph) shows the N fertiliser application rates of surveyed farmers for monsoon rice. Given the EONR100 estimate of 30 kg N/ha, there are many farmers who appear to be over fertilising N. A substantial cost saving, in terms of N not wasted, is possible if these farmer behaviours were to change. Using information from Figure 7.5.3, an applied fertiliser cost of AU$1.10/kg N and estimates of the population of farmers in the project region in each N application category, an estimate of farm-level benefits (as excessive N costs avoided) is over AU$1.8 million in one year. If only 60% of farmers who over fertiliser their paddy was to reduce these applications, the estimated benefit is still AU$1.1 million.

If higher-value crops such as sweet corn and sesame are considered as substitutes for black and green gram crops in the dry season there are potential whole-farm financial benefits. However, this result must be tempered by agronomic and crop management issues of whether such substitutes are feasible. If an extra 0.5 d/month of family labour is employed off the farm (at an indicative wage rate of AU$170/month), an additional AU$1,020 per year could be earned by the family.

7.5.7. Creation of a social media page for discussion groups

Using the project Facebook Profile (section 5.3.4), a project page was developed (Figure 7.5.8). An example post has been created in both English and Burmese to initiate discussion about soil type among farmers:

https://m.facebook.com/Management-of-nutrients-in-Central-Myanmar-106653474866389/.

It is proposed that future extension activities take the form of meetings of groups of farmers with extension officers for discussions of their aspirations and that Facebook be used for support materials. This is more likely to be attractive to farmers than a new smartphone app (section 7.7.1), although the crop modelling and decision support tool introduced by the project could form the basis of biophysical information presented by the Facebook page.

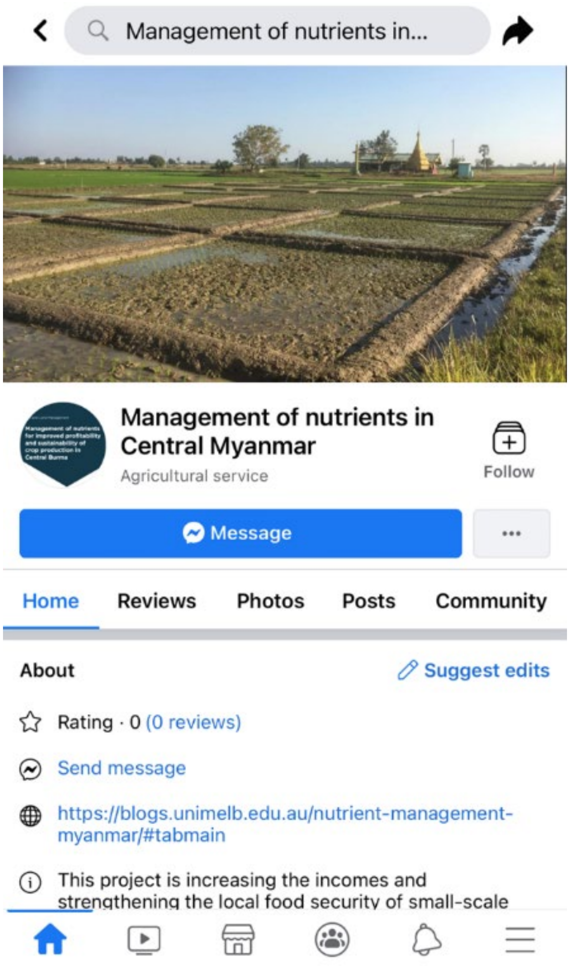


Figure 7.5.8. Project page on Facebook

7.6 Capacity building

The project had explicit but limited capacity building objectives directed at the biophysical and economic aspects of nitrogen fertiliser use, the conduct of research, its interpretation and reporting. This was mostly achieved by on-the-job training and mentoring. More specific capacity building took the form of developing YAU's analytical laboratory to support field-based research.

7.6.1 Key achievements

***3.1** Develop analytical capacity for soils and crops at YAU with protocols and ongoing systems to ensure sustained capacity in the future beyond the project.*

Although the YAU plant and soil laboratory had been very well equipped by Japanese aid (JICA), the analytical capacity at YAU was much weaker than expected. Much of the equipment was in its original wrapping and some equipment had never been turned on. Some instruments had not been installed correctly and this was rectified by UoM staff where possible. An automated steam distillation unit (Gerhardt VAP450) was provided by the project for nitrogen analyses. A systematic assessment of the analytical capacity and constraints was made, including identification of an urgent need to improve safe working practices.

The laboratory was mostly used as a classroom and only postgraduate students were allowed to use the equipment. There were no staff specifically assigned to the running of the laboratory and the (mostly junior) permanent staff of YAU with an interest in the laboratory were frequently moved to other campuses of YAU. The requirement for dedicated staff was emphasised to more senior staff in initial project meetings and as a result two bachelor degree holders were employed by the project and trained in soil and plant analyses, laboratory safety, and calculation and reporting of results. The correct installation and operation of existing and new equipment was demonstrated. By mid-2018 they were able to reliably determine soil pH, EC, total C, total N, mineral N and Olsen P. QC protocols including ASPAC reference samples were successfully introduced.

Laboratory staff were also trained in the correct identification of laboratory chemicals through the reading of labels. In many cases the laboratory chemicals had bogus labels. Examples included, photocopied labels, incorrect spelling of the chemical name, incorrect chemical formulae, no CAS number, and defunct companies. In an effort to get around this, some specialised chemicals were shipped from Australia and purchases were made from other reputable ASEAN suppliers. A cache of high quality chemicals ordered early in the project were only discovered in an academic's office two years after the initial order was placed.

By 2019 CEC, particle size analysis were added to the repertoire at YAU. Laboratory reference materials were prepared and standardised against certified reference material (ASPAC) to decrease reliance on external samples.

The project-funded research assistant, U Zoong Te Mang, developed good capacity to oversee the laboratory work and to do some minor repairs. Unfortunately the two well-trained laboratory staff and U Zoong were temporary project employees and departed YAU at the end of the project. Despite often repeated requests, YAU did not appoint tenured staff for sufficient periods of time to entrench capacity until late in the project. As reported to ACIAR early in the project, it was clear that the training of 15 students (as originally envisaged during project planning) was unrealistic. Senior students could not use the laboratory before 2019 as basic capacity and safety issues had not yet been addressed. Moreover, very few YAU staff or students were allocated sufficient time to develop laboratory skills but were rotated to other duties.

By 2019 regular support from UoM was still required as the number of analyses for the project increased markedly, mostly as a result of soil samples from the soil survey work. Regular follow up was provided for the correct installation and operation of instruments. Two permanent YAU staff were then allocated to work in the laboratory. The laboratory facilities (that were only made operational by the project) were by then being used for training of large classes of undergraduates, masters' projects, and by individual staff members for particular projects. The project transformed the laboratory from one focused on teaching with very little capacity in terms of the types of analyses and the numbers that could be processed, to one capable of a full range of soil and plant analyses in numbers sufficient for research work. The project achieved utilisation of extensive JICA facilities that were otherwise little used or inoperable.

Whilst the project has resulted in an effective laboratory, many fewer opportunities for training of YAU staff were taken than expected or offered by UoM, despite the project having capacity to train several more. This was partly due to YAU policy of moving junior staff to remote campuses resulting in partly trained individuals being moved to lesser equipped laboratories or other duties.

***3.2** Increase capacity in the interpretation of soil and plant tests in YAU*

Most of the laboratory training and interpretation was done “on- the-job” by participation and mentoring by UoM staff during country visits. The process generally involved the progressive introduction of methodologies for soil and plant analysis and the compilation of a methods book for the laboratory. In the case of soil analysis, an abridged version of the ‘Soil Chemical Methods - Australasia (2010)’ was used. Formal training sessions included:

“Ensuring quality analytical output’. A one-day training session was conducted in the JICA soil laboratory. Twenty-seven MAgSc, technical and academic staff attended.

“Soil profile description”. This two-day training session involved a lecture programme, laboratory practical session for essential field skills and a field excursion for soil profile description at three contrasting sites

Some YAU and UoM staff participated in project SMCN/2014/075’s selective ion training for potassium analysis, although salt concentrations in extracting solutions limited the utility of this equipment.

A half-day training session was conducted in the JICA soil laboratory on the use of N-15 in field experimentation, with an introduction on ‘Nitrogen dynamics’ by Professor Deli Chen. Simon Eldridge followed on with discussions on using microplots in field experiments, procedures for handling N-15, analytical methods, and working up N-15 data for calculation of N use efficiency. Seven YAU technical and academic staff, six DoA, LUD staff and 11 postgraduate students attended this session.

***3.3** Increase capacity of YAU in the conduct of nutrient deficiency and response processes and research.*

This took the form of on-the-job training for a wider range of staff. Such capacity was increased by the small project scheme (below) in addition to the primary project activities. Approximately 20 staff and students benefited

***3.4** Increase capacity in the use of economic frameworks and models in teaching and research for undergraduate and postgraduate students at YAU and UoM.*

By May 2017, capacity building in digital data collection by field enumerators was achieved with 10 Masters students from YAU and staff trained and deployed in field surveys. Training provided enumerators with the ability to independently complete or explain a range of concepts related to the CommCare® application, and to digital data collection. They were given two days of training on the use of the electronic questionnaires that had been uploaded onto the CommCare application and downloaded to Android tablets. The training covered familiarisation with the app, the questionnaire, how to take GPS coordinates, administration of informant consent, capturing digital images and pilot testing in the field with some volunteer farmers.

In July 2018, 12 additional Master students and staff from YAU were given basic training on the design and deployment of questionnaires using CommCare HQ. This training provided them with a basis to build questionnaires relevant to their research and to utilise mobile data collection. Various materials including videos and links for independent learning were also provided during the training.

Ms So Pyay Thar was granted a UoM PhD scholarship to oversee and analyse data from surveys and farmer group meetings, and has recently been awarded a PhD.

Bob Farquharson presented a seminar on *'Economics of fertiliser decisions'* to a large group of staff and students at Yezin Agricultural University, 29 July 2019.

By 2018 capacity building in digital data collection by field enumerators was achieved with 4 staff provided refresher sessions before being deployed in field surveys.

3.5 *Establishment and operation by YAU of small research grants scheme.*

Ten small projects were implemented by YAU during 2018 and 2019 with support from the project (Table 7.6.1). There were fewer than expected due to delays caused by changes in YAU staff and difficulties with YAU and UoM agreeing budgetary practices. It was originally envisaged that the scheme would be operated to familiarise YAU personnel with competitive funding applications, including proposal preparation on the lines of problem definition, proposed solutions, methodology, results and data analyses and reporting. The scheme did not develop as UoM had planned, but was integrated with YAU practical teaching courses. However, the principles of subject justification, planning, budgeting, and delivery were reinforced.

Table 7.6.1. Small Research Grants Projects

Titles	Scientists	Reporting	Output
Effect of cropping pattern and farmer practices on soil properties in selected areas under the ACIAR project 2014/044	Kaung Htet Lwin Oo (Assist. Lecturer), Kyaw Ngwe (Professor), Kyi Kyi Shwe (Lecturer)	Poster presentation was presented in the 13th Agricultural Research Conference, Nay Pyi Taw, in January 2020. Writing second paper	One paper published n the Proceedings of the 13th Agricultural Research Conference, Nay Pyi Taw Journal publication
Monitoring nitrogen status at different growth stages in rice and maize crops using remote sensing technology	Aung Naing Oo (Professor), Kyaw Ngwe (Professor), Kyi Kyi Shwe (Lecturer)	First paper was presented in the Myanmar Universities' Research Conference (MURC 2019), Yangon. Writing second paper	One paper publication in the Proceedings of the Myanmar Universities' Research Conference (MURC 2019), Vol. 1, issue 1.
Timing and rates of nitrogenous fertilisers application on rice production in Yezin area	Chaw Su Lwin (Lecturer), Kyaw Ngwe (Professor), Ei Ei Khaine (Master student) 4th Year students (30 students)	Thesis Poster presentation was made at the 13th Agricultural Research Conference, Nay Pyi Taw, January 2020	One paper publication in the Proceedings of the 13th Agricultural Research Conference, Nay Pyi Taw MSc Thesis in

			2020 Undergraduate research report to YAU
Evaluation of balanced fertiliser applications in rice cultivation	Toe Toe Maw (Lecturer), Aung Kyaw Swe (diploma student) Aung Naing Oo (Professor)	Thesis Paper was submitted to the 14th Agricultural Research Conference, Nay Pyi Taw	Postgraduate Diploma Thesis 2020, Journal publication
Potential for yield and profit improvements by proper application of N fertiliser in Rice and Maize cultivation in Tatkon Township	Shwe Mar Than (Deputy Director), Ay Mi Mi Zin (master student)	Data analysis Writing paper	MSc Thesis Journal publication
Assessment of the different sources of fertiliser utilization in Nay Pyi Taw area	Kyi Kyi Shwe (Lecturer), Swe Swe Mar (Lecturer), Theingi Win (Demonstrator)	Paper was submitted to the 14th Agricultural Research Conference, Nay Pyi Taw	Journal publication
Effect of Different Fertiliser Application on Yield and Yield Components of Rice and Nutrient Use Efficiency under Two Different Soil Types	Lwin Lwin Aung (Postgraduate student), Kyi Kyi Shwe (Lecturer), Kyaw Ngwe (Professor)	Pot experiment; rice yield was harvested in June 2020.	Postgraduate Diploma Thesis Journal publication
Mineralization rates of paddy soils from Zeyathiri and Taungoo	Win Yu Hlaing, Hsu Myat Thwin Khaing Nwe Oo Kyaw Ngwe (Professor)	N mineralisation was measured in all T=0 soils from the rice experiments and soil survey surface soils	Journal publication
Nitrogen Mineralization in Soil as Affected by Cropping System in Central Dry Zone, Myanmar	Win Yu Hlaing Hsu Myat Thwin Kyaw Ngwe (Professor)	A comparison of N mineralization in soils with or without incubation in laboratory under rice and maize	Submitted to Climate Smart Agriculture. March 2021
Spatial Variability and Mapping of Soil Properties Using GIS-Based Geostatistics in Myanmar	Tun Tun Hlaing Swe Swe Mar Chaw Su Lwin Htay Htay Oo	Study of the spatial variability of soil chemical properties of the study site at Yezin Agricultural University, Myanmar using geostatistics	MSc Thesis in 2020 Presented to the12th International Conference on

	Kyaw Ngwe (Professor)		Environmental and Rural Development on-line conference. March, 2021. International Society of Environmental and Rural Development.

3.6 *Enhance YAU's curriculum and teaching approaches related to soil science, agricultural economics, and university management, through staff exchange*.

Four YAU staff were sponsored for visits to Australia in December 2016. Four participated in the International Nitrogen Initiative Conference, "Solutions to improve nitrogen use efficiency for the world" in Melbourne and two attended the 61st Annual Conference of the Australian Agricultural and Resource Economics Society in Brisbane.

Ms Pan Ei Ei Kyaw, was awarded a John Allwright Fellowships and continues to make progress with her PhD research at UoM. Ms So Pyay Thar was awarded a PhD for her research in the project on socio-economics. Dr Arjun Pandey was awarded a PhD that included some Myanmar project sites. Dr Swe Swe Mar, undertook a John Dillon Fellowship and returned to YAU to oversee the laboratory. In addition, Dr Thandar Nyi, of LUD, also received a John Dillon Fellowship (with an allied project), and was awarded a prestigious Meryl Williams Fellowship for rising science managers, with the project's support.

Prof. Deli Chen and Dr Willett visited the National Education Policy Commission (NEPC) as arranged with its chairman (and former YAU Rector), Dr Myo Kyaw in December 2018. Deli made a presentation on university governance and management, emphasising autonomy, to members of NEPC, Yangon and other local universities. In common with other issues, the Myanmar academics were well aware of their difficulties, but are unable to make changes. Chen and Willett also visited Yangon University's Universities' Research Centre (URC) and central library. The URC hosts major analytical instruments such as SEM, HPLC, and AAS, and makes them available to researchers from Yangon and other universities, and Dr Willett tried to increase awareness in YAU of in-country capacity to advise on the operation of a service-orientated laboratory.

In general, there were fewer visits by Myanmar participants to Australia than planned, largely due to frequent changes in YAU project staff, and latterly because of COVID-19 travel restrictions.

3.7 *Specific DSS training activities for YAU staff and senior students.*

Preparatory training on WNMM and GIS was carried out in YAU in January 2017. Fifteen YAU staff received training, but because of software compatibility problems due to unlicensed operating systems only one laptop was able to instal the model and run WNMM. The project was unable to retain a suitable YAU staff member or student for sufficient time to transfer capacity in modelling, GIS, or DSS development.

7.6.2 Discussion

The project successfully transformed a teaching laboratory to one capable of high-quality analyses of a range of soil and plant properties in numbers sufficient to support field research. The project unlocked JICA's investment in modern instruments that otherwise were little used or inoperable. Significant progress was made in increasing safe laboratory operations, managing data, and problem solving. Three project-funded staff were trained and successfully operated the laboratory but few tenured YAU staff were permitted to stay for sufficient time to receive thorough training. Two permanent YAU staff received some sustained training toward the end of the project. YAU is focussed on teaching and appears to assign little priority to laboratory development for research purposes. Examples of what is possible are available at the nearby Department of Agricultural Research and Land Use Division in Yangon (both within the same Ministry as YAU), and Yangon University. In general, we found that successful interventions could be achieved by adapting, rather making marked changes, to YAU's practices.

Transforming the university from one almost wholly focussed on teaching to one that can deliver research has been shown to be possible with ongoing support and the employment of dedicated project staff.

7.7 Decision support systems

7.7.1 Development of DSS for rice and maize in central Myanmar

A web-based DST was developed to demonstrate the optimised N applications for the Laythar site (http://121.199.166.25/AFT/) as shown in Figure 7.7.1.1.

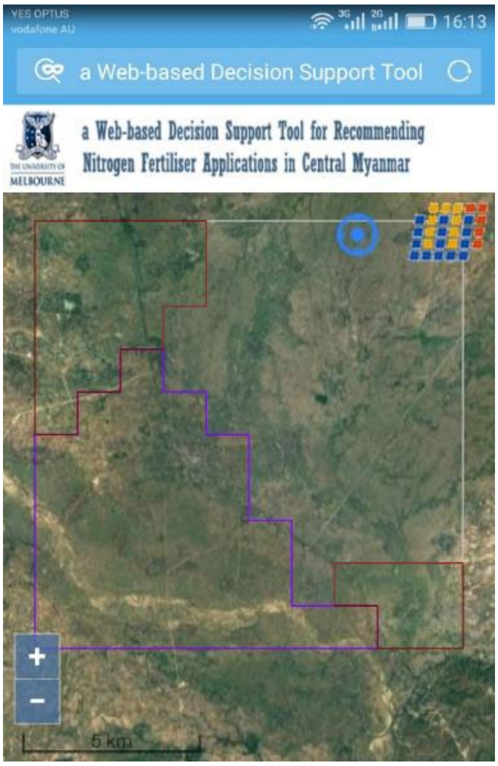


Figure 7.7.1.1 Framework of the DST for N applications at Laythar

The first display of this system is the soil type map. Once a click on the soil map is triggered the soil properties are displayed for the specific soil type, as shown in Figure 7.7.1.2.

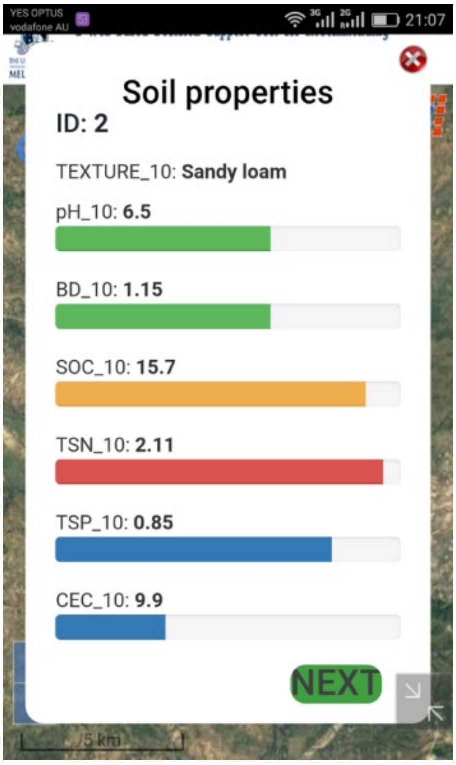


Figure 7.7.1.2 Soil property display.

A crop selection display (Fig. 7.7.1.3) is then shown after clicking the NEXT button in the soil property display. Users may choose crop rotations (e.g., mono crop or multiple crops) at this step.

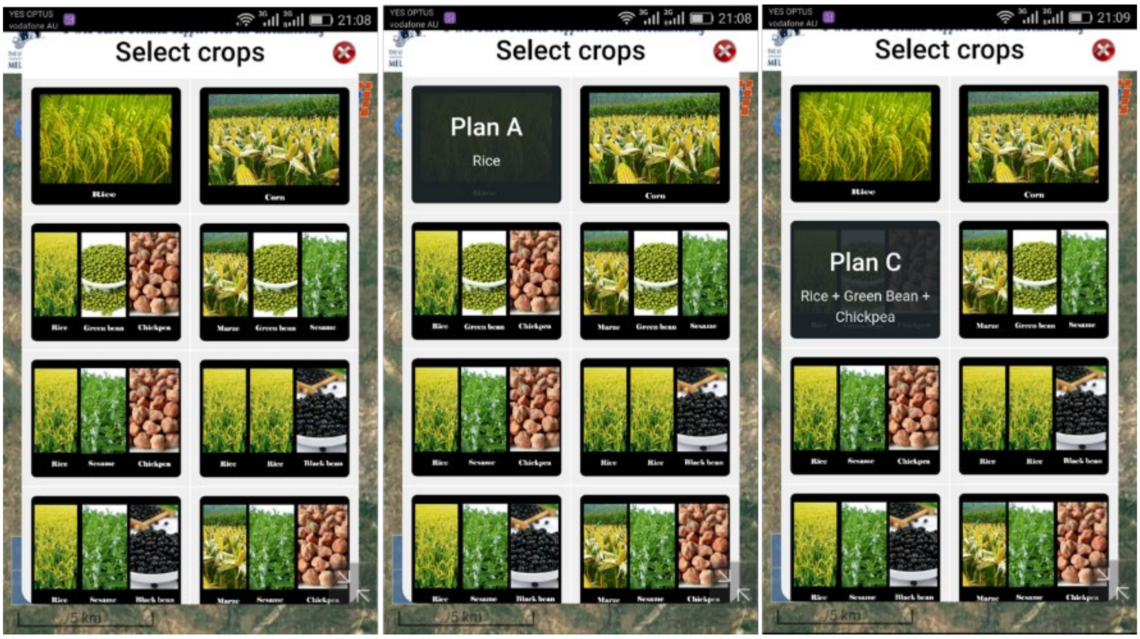
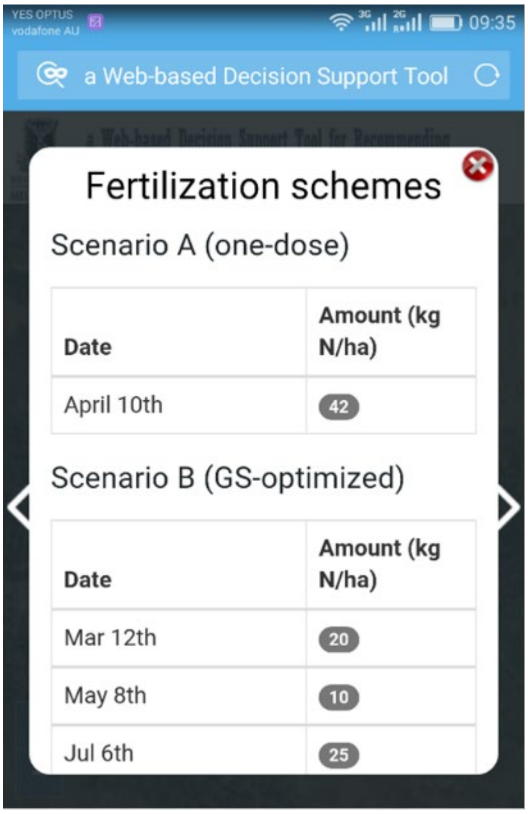


Figure 7.7.1.3 Crop selection display

The optimised N application regimes for the selected crop rotations are then recommended in the N fertiliser application display (Figure 7.7.1.4). By default, the system always gives two options: one-dose and crop growth stage-optimised doses.



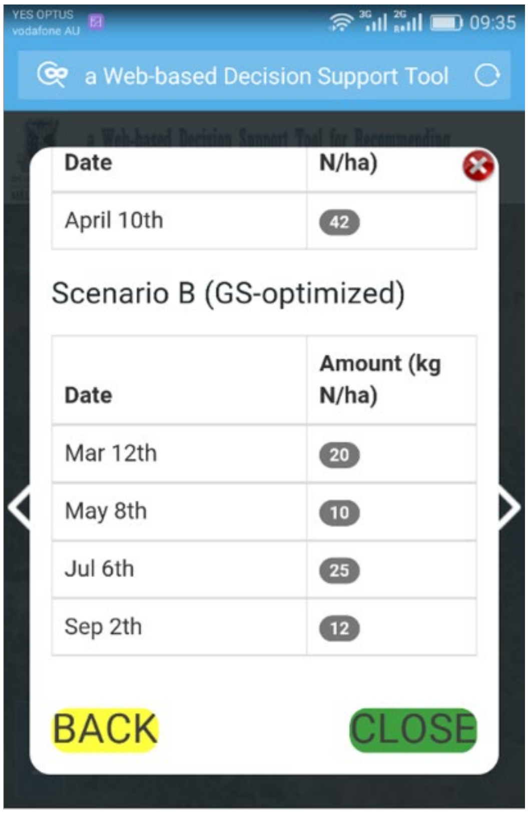


Figure 7.7.1.4. Recommended N applications display

In general the system is a very early version of a DST for recommending N applications for the central region of Myanmar. Its ability to perform this function depends on a detailed knowledge of soil distribution in the landscape. However, such maps are not available for central Myanmar, and the project's limited mapping of the Zeyathiri area (including Laythar, Appendix 11.1.1) shows considerable short range variability of soils in a complex prior stream topography, indicating that the DST cannot rely entirely on the soil mapping for fertiliser recommendations in a farmer's field. An alternative approach could be based on farmers identifying their soils from information provided via a DST app that contained common soil types such as that presented in Appendix 11.1.2 Using such detailed soil information, WNMM can be calibrated more intensively and a DST that is meaningful and useful to local farmers could be developed on the framework shown in Figs. 5.5.2 and 5.5.3.

7.7.2 Review of decision support tools for fertiliser management.

Integration of socioeconomic data with geospatial and biophysical information enhances the ability and scaling-up potential of decision support systems. Economic dimensions in farmers' decision making remain an important aspect and a key factor for adoption. Integration of information technological tools, such as global navigation satellite systems, chlorophyll meters, remote sensing of soils and crop canopies, soil electrical conductivity sensors and yield monitors with modern agricultural equipment such as fertiliser applicators, planters and sprayers can facilitate intra-field variable management of crops and soils. There is increased ability to predict responsiveness of crops to fertiliser by integrating multiple data sources. It is possible to deliver precise real-time information of the crop and field conditions to farmers allowing them to make their own informed decisions. Implementing interactive and visual DSTs may enable end-users with better understanding and attract potential users. Stott et al. (2018) reported that the 'N-Advisor' tool uses marginal analysis to inform farmers about how a range of N applications applied to a particular paddock for a particular grazing rotation add to profits and enables uncertainty associated with the fertiliser investment to be considered. Production and profit information that can be estimated using the N-Advisor has sufficient rigour and relevance to add value to decisions dairy farmers make about applying N.

Despite such recent advances in highly developed agricultural settings, farmers still lack rapid and economic means of developing nutrient management plans, particularly in less developed countries where DSTs have experienced very little on-going adoption as a practical tool. This is mainly because earlier versions lacked user participation as well as insufficient training and technical support (Thar, 2021). Further work has been done to improve DSTs by incorporating participatory approaches and considering user-centred aspects. User-centric focusses still appear to be minimal and there is a need for active participation by farmers in DST development. Other authors suggested a user-driven approach that defines the end-user prior to the study and develops case studies to understand the requirements of users. Users do not want models but prefer transferable information. Obviously, sophisticated DSTs, particularly those directed at soil management, require sufficient data of several types, including geospatial information on soil distribution, as well as financial data, to operate.

Key findings of the workshop *'Nitrogen fertiliser management for cereal crops in Central Myanmar: Farmer decisions and tools for decision support'* were:

i. Traditional DSTs are unused by many farmers,
ii. Investigation of farmer typologies could be valuable,
iii. DSTs are not designed from the farmers' viewpoint,
iv. Increasingly farmers are interested in the economics of fertiliser decisions,
v. Considering fertiliser as an investment for which a return (over and above repaying principal and interest) could be valuable, and
vi. Changing the focus from making decisions to supporting the discussion of decisions by groups of farmers and/or extension workers could be valuable.

A minimum target ROI of 100% has been suggested in developing recommendations for change in technologies, especially for smallholder farmers in developing countries. The flatness of economic responses at relatively high levels of fertility and crop yields appears to be important, but at low levels of fertiliser use a relatively high hurdle rate of return may offer more assurance to smallholder farmers about borrowing for fertiliser purchases

Another challenge associated with DSTs is the limited on-going funding to maintain and update the tools. Incorporating useful information and decision support functions to social media platforms could have a more useful and sustainable impact (Thar et al., 2020).

7.7.3 Farmers' attitudes to decision support tools

Detailed results for this section are available in Thar et al. (2020); only the key findings are presented here. Mobile phone ownership in the central Myanmar study area was high, with 71% of farmers owning one. Many farmers were also keeping up to date with technology, with 62% owning smartphones. However, the use of internet among the surveyed farmers was relatively low at 38%. A higher proportion of male farmers were using mobile internet

(41%) compared to female farmers (26%). Among the farmers who used internet, 75% rated the internet connectivity as “good”.

Farmers in the study area were optimistic about using agricultural mobile apps or tools, with over 70% willing to use them for farm decision making. However, only 21% of the farmers were found to be currently using such tools or apps, with a majority (56%) only opening them once a month. The positive attitude towards decision support tools or apps, but only a few users, is a challenge to introducing mobile-based agricultural support tools. The main reasons for such low use were lack of awareness and knowledge, and the high cost of internet. The cost of mobile internet in Myanmar is US$1 per GB, when the daily minimum wage is US$3.60.

An interesting finding from the study was that most of the surveyed farmers (54%) were familiar with information received through Facebook groups. Since Facebook has established trust and most of the smallholder farmers were using it, incorporating useful information and functions from a mobile-based DST to a Facebook Page could be useful and have a sustainable impact. This would also alleviate issues such as lack of awareness, lack of use, and long-term servicing and sustainability.

To analyse the socioeconomic factors influencing the use of agricultural mobile apps, a binary Probit model was employed to the survey data. The empirical results demonstrated that socio-economic factors such as age (negatively), education (positively), degree of mechanisation (positively), number of crops (negatively) and market distance (negatively) were found to affect the use of agricultural mobile apps. Hence, when introducing mobile-based support tools, appropriate end users should be targeted and focus should be given to younger, educated farmers with more specialised crops as early adopters.

The typology analysis (section 7.5.3) identified the following six farm types, which exhibited different patterns in the adoption of mobile-based DSTs.

1. Small and subsistence
2. Large and semi-intensive on-farm income
3. Small and intensive
4. Diversified with off-farm income
5. Small and subsistence female farm
6. Commercial farm

Farmer group discussions (FGDs) at each of the farm types were conducted to introduce DSTs to farmers in the study area. Although some farmers had not previously heard of a DST, many farmers were aware of agricultural mobile apps and had some understanding of their ability to provide information. An example prototype of the RiseHarvest mobile-based DST was shown to farmers for demonstration purposes. The application was still at a testing stage and the recommendations provided were not accurate. However, farmers were able to get a general understanding of how the tool operates, what information they need to enter, and how the recommendations would be delivered based on their data input. Farmers liked the picture icons along with the voice features which were helpful for farmers who could not read. Farmers were confused about why the information needed to be repeated for every season and saw no reason for this information over the long term.

Although the participating farmers had no prior knowledge of DSTs, they readily engaged in examining the DST example, and provided considered opinions. Farmers belonging to one type (large and semi-intensive, on-farm income) considered that DSTs could be useful in gaining more information and knowledge. These farmers were more likely to adopt a fertiliser DST than other types of farmers and more focus could be given in the introduction and training of digital tools to these types of farmers. Farmers in other farm types expressed their interest of a DST for other management practices such as pest and disease management instead of fertiliser.

The interactions with farmers from the study showed that the concept of a smartphone DST in providing prescriptive advice was inconsistent with what many farmers want. Farmers in all six groups felt that discussion groups were more likely to be a better learning environment and preferred a learning-based tool rather than a prescription-based tool. Discussion support is a collaborative approach between farmers, whereas a DST is a more instructive approach providing recommendations which can be misinterpreted. Discussion support can be used by individual farmers, groups of farmers, or a group of farmers with extension officers enabling discussion of alternative management decisions, asking specific questions, and seeking new ideas about adjusting farm decisions to meet smallholder management objectives. Farmers, especially females, emphasised their preference for video clips and infographics being integrated into digital platforms including social media and existing agricultural mobile applications.

This information serves as a starting point for developing a framework for discussion support systems enabling targeted deployment of a tool by potential developers which better relates to the needs of farmers.

7.6.4 Discussion support approach using social media

It is apparent that a discussion support approach (DSA) is more promising than a prescriptive-instructive approach in gaining acceptance of IT-based resource materials by farmers for the transfer of knowledge on fertiliser and other cropping management practices. Incorporating practical information in a social media platform could have a more useful and sustainable impact than a new more-specific mobile app, and reduce issues such as lack of awareness, lack of use and sustainability. According to our survey most of the farmers in central Myanmar were familiar with Facebook, and this was selected by the project to provide an example of an interactive discussion platform for introducing improved fertiliser related practices.

It is proposed that farmers, extension officers, and applied researchers be made aware of the project Facebook page under development, and encouraged to comment, post, and ask questions, initially through focus group discussions. The page can be advertised among extension officers (probably during monthly farmer meetings) and they can be encouraged to post videos or some issues that their farmers are currently facing. Farmers would be encouraged to “Like” or “Follow” the page so that they can get notifications whenever new information is uploaded to the page, encourage them to engage in discussions, comment and ask questions to keep the page interactive. The Facebook page could provide information on weather forecasts and crop prices that receive frequent notifications so that targeted content on other subjects such as fertiliser use can be brought to farmers’ attention frequently. Formula and equations with an appropriate graphical interface can also be incorporated into the page so that if a farmer entered proposed fertiliser applications, and additional information such as soil properties (when available), it can generate potential yield and profits forecasts, and discussions can revolve around that. It could also link to other relevant pages such as that of the Myanma Awba Group (facebook.com/myanmaawba).

For the page to be more interactive, it can also be advertised among agricultural research staff of DoA, DAR, and YAU so that those with appropriate information can rapidly provide advice to farmers enquires.

However, the page will require an administrator to manage and keep the page alive - this can include creating context, posting up-to-date information for farmers, including weather and crop market prices, other useful links for farmers to follow - and to ask them questions. It is not clear at this stage who can perform this function in Myanmar.

Implementing this type of social media-based discussion support approach would require more testing and participation with farmers and extension officers would probably require further investigation and trials.

8 Impacts

8.1 Scientific impacts – now and in 5 years

An explanation of the long-term sustainable production of rice in Myanmar, with low yield and little fertiliser N input, was elucidated. The soils that had received little N fertiliser in Myanmar showed greater N fixation and soil microbes efficiently retained mineral N that would otherwise get lost to the environment, resulting in an N-conserving system. This contrasted strongly with rice produced on soils with large N fertiliser additions such as those in Australia. The project showed that dissimilatory nitrate reduction to ammonium dominates nitrate reduction in long-term low-nitrogen fertilised rice paddies in Myanmar, whereas denitrification dominated in rice paddies which received high N input. N fixation more or less compensates the N removed by the rice plant in low or no fertiliser N input rice paddies, and this ensures the N nutrition of rice paddies in these traditional farming systems, which rely heavily on native soil N. The research largely explains the paradox of how Myanmar rice soils that receive no, or very little, nitrogen fertiliser inputs continue to produce modest rice yields in the long term. This finding also reinforces the project's recommendation that high rates of N fertilisation of monsoon season rice are not necessary, and could be detrimental.

The economic subproject discovered important information about actual crop fertilisation practices by smallholders growing cereals in Central Myanmar. Particularly with respect to the types of fertiliser and timing of applications, the research has shown that smallholders generally understand the need to apply nutrients to replace those removed at harvest in cereal grains, that they apply both compound (NPK) and urea fertilisers as basal and in-crop dressings, and many farmers split the applications of urea during the crop growth period. This understanding provides a sound basis for further in-country R&D and extension programmes to improve cereal crop outcomes.

The subproject also discovered the attitudes of smallholders towards decision support and DSTs and determined a novel way of enabling valuable discussion support groups via a Facebook page.

A review of Myanmar Government agricultural policies concerning support for rice cropping, and financial regulations relating to loan size limits by the MADB, has provided a reason why many smallholders growing maize consistently under-fertilise this crop. A lifting of the limit on the size of loan for purchases of farm inputs for crops other than rice could enable higher financial returns from maize and increased farm-family income

8.2 Capacity impacts – now and in 5 years

Research capacity at YAU has been increased by the project by on-the-job field work led by the University of Melbourne. It has fostered research in a university that has had a focus almost entirely on teaching but that had expressed a need to increase emphasis on research. Capacity development encompassed planning, protocol development, implementation, execution, soil and plant sampling and measurements, data management and analysis, interpretation, and reporting. YAU is now capable of implementing detailed field experiments.

The small research project scheme was intended to build capacity for independent research planning and execution by YAU following a competitive funding application process. The scheme evolved so that it that suited YAU's teaching practices rather than being executed as originally planned in the project documentation. Nevertheless the scheme was effective in raising the capacity for research at YAU. It directly impacted 12 senior students and junior staff members.

The project has greatly improved the performance of the YAU laboratory in the analysis of basic soil properties and analysis of plants for nutrients. Analytical capacity in the YAU laboratory largely vested in 3 project-funded staff who departed on 30 June 2020. Two permanent YAU staff were later allocated to the laboratory and received training. The laboratory was also used for training 63 fourth year students in January 2020. The laboratory is still in use after completion of the project and it can be expected to continue for the foreseeable future.

The project also served to validate chemical analyses of fertilisers carried out by LUD's main laboratory in Yangon by exchanging samples with the University of Melbourne.

LUD has continued field trials with N fertilisation of rice (summer 2021) demonstrating sustained research activities beyond the term of the project (section 8.3.1), although planned farmer demonstration activities were curtailed due to civil unrest in response to the February 2021 military coup.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

The project aimed to increase small-scale farmers' incomes by improving fertiliser management of rice and maize crops. A preliminary, very conservative, estimate of economic benefits in terms of reduced costs ('N not wasted' on monsoon season rice), and the potential to increase incomes from increased N applications to maize, is presented in Appendix 11.2. The economic analyses are by necessity hypothetical in that follow-up surveys of actual adoption have not been possible. For the main crop in the region, monsoon rice, there may be economic benefits to local smallholders of up to $A 1.2 million, depending on the extent of change. Over 4 years, a cost reduction over 10% per year of the rice production area could save $A 2 million.

For maize, the survey results show that many farmers apply substantially less than the DoA recommendations and the indicated economic rate based on the potential yield responses to N fertiliser. Up to $A 1 million increased farm income is indicated if maize in the project is produced using more N fertiliser.

It is apparent that the cost of the project to ACIAR ($A 2 M) could be recouped in a period of 4 years, even with the application of very conservative assumptions and estimates.

Extension staff are more or less still providing generalised DoA fertiliser recommendations tempered by cost considerations. However, good progress was being made in communicating the project's results (section 8.4), promising scope for economic impacts in the form of reduced unnecessary urea use on monsoon-season rice, improved incomes from greater use of urea in a more effective split application in summer rice, and in monsoon season maize (section 7.5.5).

Further economic gains are possible if policy reforms concerning loans to farmers (sections 7.5.4 and 7.5.6) are made so that urea fertiliser use is redirected from monsoon- season rice to maize, summer rice, or high-value vegetables. In the future it may be possible for Myanmar to market monsoon season rice grown without fertiliser as "organic" or at least "low input" and attract a price premium.

The LUD is responsible for analysis of imported fertiliser throughout the country. However, there is weak border control for imported fertiliser owing to limited facilities for checking fertiliser quality, especially those entering through the border crossing at Muse (Shan State) which does not have enough staff to examine and take samples. Some products are directly distributed to farmers at Muse without checks on quality. Based on the results of fertiliser quality control activities of the project, the Myanmar Government recognises this limitation and plans to allocate budget from its World Bank Loan to upgrade the Regional Laboratory at Muse, and for training of laboratory technicians and extension staff. Controlling fertiliser quality at township and village levels will be more efficient and will prevent the use of fake fertilisers by farmers.

8.3.2 Social impacts

Social impacts can be expected to flow from economic impacts in the form of improving living conditions in villages, in enabling education of children. Decision making on farms, and the ability to secure subsidised loans, is currently dominated by male farmers, except where in the minority of farms where the household headed by a female. Decision making by females is likely to increase in the future in response to the trend for males to seek off-farm work, which is facilitated by increasing mechanisation. Female preferences on how information is presented in social media were recognised and can be incorporated in the proposed Facebook-based tool.

8.3.3 Environmental impacts

Agencies under MoALI generally advise most farmers to use N fertiliser for growing crops, with rather broad “blanket” recommendations. Adoption of the project’s findings for central Myanmar, particularly ceasing or greatly reducing N fertiliser applications to monsoon season rice, and optimising the rates applied to summer rice and monsoon season maize, will lead to overall reductions in the quantity of N applied, and thereby reduce for losses of N to the wider environment, including surface and ground waters and the atmosphere. It was shown that ~50% of fertiliser N applied was lost or unaccounted for.

Reducing overall N fertiliser use, and optimising its use when it is necessary, will reduce the “N footprint” of agriculture in Myanmar, and raises the opportunity to grow monsoon season rice as an “organic” crop.

The project could contribute to reducing soil degradation in terms of depleting stored N as reducing unnecessarily high N fertilisation of monsoon-season rice does not provide yield benefit but promotes native soil N mining as well as high N losses.

8.4 Communication and dissemination activities

The project had two main strategies for communicating its activities and findings - those directed at farmers in their fields and villages, and those for policy makers in Nay Pyi Taw and Yangon.

The project engaged with farmers at the rice and maize trial locations and farmer discussions throughout its duration. Interactions with farmers during the surveys and at focus group meetings led by the socio-economics team provided insights into farmers’ ideas on where field work should be conducted and how they would like to receive information in the future. Prof. Soe Soe Thein conducted some small-scale farmer discussion days at the two rice field experiment sites for feedback purposes, just prior to harvest. Interactions with farmers were increased as the project developed some messages that could be discussed.

YAU led a successful farmers' field day at Laythar in August 2019, with a focus on the financial aspects of fertiliser use. Over 100 farmers attended the project site and subsequent talks and discussions. A field day for maize was held by YAU at Tatkon in late August 2019 including 100 farmers from five villages and YAU staff (Dr. Kyaw Kyaw Win (Pro-rector), Dr. Kyaw Ngwe (Prof.), U Chit Than (Head), Dr. Shwe Mar Than, Dr. Aung Naing Oo, officers and staff from DoA (Tatkon Township). Another field day for maize was held at Shwe Oh Daung village. On 14 September 2019, Dr. Kyaw Ngwe and Dr. Aung Naing Oo gave a presentation to around 25 Township-level Staff Officers and policy makers at the Land Use Department (LUD), Nay Pyi Taw. They presented the project's results from the field trials.

In August 2019, LUD presented three days of training on fertiliser management for improved profitability and sustainability of rice and maize crop production to trainers. Over 90 trainers of LUD and Extension Division, DoA from 14 States and Regions at Yangon and Nay Pyi Taw attended and subsequent discussions. Farmer consultation workshops were conducted by LUD in 21 Townships of Nay Pyi Taw, Mandalay, and Bago Regions during September 2019 on fertiliser management of rice and maize crop production, fertiliser quality, economics of fertiliser decisions and fertiliser regulation and laws. This benefited 1,050 collaborating farmers regarding fertiliser management depending on soil conditions, and in decision making of fertiliser application. The farmers had better understanding of fertiliser management in rice and maize cropping systems and reduced cost of inputs for their cultivation.

LUD established large-scale demonstration sites in January 2021 to demonstrate improved N fertiliser management. LUD are targeting the poorest farmers in Laeway and Oattaya Thiri Townships, Nay Pyi Taw Region, and Taungoo, Oat Twin and Yay Tar Shay Townships, Bago Region. This is an LUD initiative stemming from the project and is expanding the geographic reach of the project. Unfortunately, farmer field days have been cancelled due to civil disorder following the establishment of military government.

Conversations have been held with influential officials concerning policy implications that arose from the project, particularly with Dr Tin Htut (Secretary MOALI) and Dr Aung Kyi (former D-G of DAR and Vice-Rector of YAU) who were consulted about emerging policy issues.

Scientific communications have also been made with IFDC in Yangon and with IRRI. Prof. Chen made a presentation to senior staff and policy makers at the National Education Policy Commission (NEPC), when he described the project, but more broadly, outlined the changes needed for intensifying research at Myanmar universities.

A project website has been developed and can be seen at: https://blogs.unimelb.edu.au/nutrient-management-myanmar.

LUD has also communicated the project's results on fertiliser quality to policy makers and other DoA directorates with responsibilities for fertiliser use in Myanmar. It has secured funding from other international agencies to promote the results on a website and in fertiliser guidelines. The project's results were presented by LUD at another workshop held by IFC. According to the results of project, DoA now prioritises investments in capacity building of inspectors that will contribute more effective knowledge transfer to dealers and farmers. Therefore, DoA held a training programme on fertiliser quality control including product characteristics, physical and chemical fertiliser quality control, and storage conditions with about 600 inspectors in January 2020 at the Central Agricultural Research Training Centre (Helgu, Bago Region).

According to the project's recommendation on updating commercial fertiliser information, GIZ-Sustainable Agricultural Development and Food Quality Initiative (GIZ SAFI) project funded LUD to establish a web site. LUD established an official website of the product information and promote the project results of fertiliser quality control with the aim of improving the availability of fertiliser information. The establishment of a centralised database with fertiliser data and information will help in decision making, planning and also to assist the private sector achieve better understanding of the demand and supply situation in Myanmar. It will also benefit farmers in terms of planning their activities based on the availability of fertilisers and avoidance of the purchase of unregistered products.

9 Conclusions and recommendations

9.1 Rice

Consultations with farmers in the study area revealed that they generally used fertilisers in their cropping systems and understand the need to apply nutrients to replace those removed at harvest. The smallholders apply both compound (NPK) and urea fertilisers as basal and in-crop dressings to rice, and many split the applications of urea during the crop growth period. In comparison with national fertiliser recommendations the farmers applied excessive amounts of N fertiliser to monsoon-season rice and too little to dry season irrigated rice. The project showed that there is limited potential for N fertiliser to raise yields in the monsoon season, but that yields can be increased from approx. 4 t/ha to 8 t/ha in the irrigated summer season.

N-15 labelled urea used to trace the fate of applied N fertiliser showed that the use by rice plants of N applied as urea rarely exceeded 30%, and the majority of N in the plants was derived from indigenous soil nitrogen. Total recovery of applied N fertiliser in plants and soil was below 60%, so the remaining 40% of the applied N fertiliser was unaccounted for or lost from the system. Measurement of the recovery of N from split applications of urea applied at 10 days after transplanting (DAT) and at panicle initiation (PI stage) showed that the current farmers' practice of applying N fertiliser in two equal split doses is inefficient and that the first dose of N fertiliser at 10 DAT should be reduced to 1/3 of the total and application of the remaining 2/3 of the N dose around active tillering stage (35 DAT) should prove beneficial.

It was shown that dissimilatory nitrate reduction to ammonium (DNRA) exceeded denitrification by a factor of eight in low N fertilised rice paddies, while DNRA was almost half of the denitrification rate of highly N fertilised rice paddies. These findings highlight the self-regulated microbial N cycling in low N input paddy systems, which maintain long-term paddy soil N nutrition. These findings and the observed results from N response trials in rice paddies in central Myanmar indicate that unnecessarily high N fertilisation does not provide yield benefit but rather promotes native soil N mining and high N losses, where ~50% of fertiliser N applied is lost or unaccounted for. Biological N_2 fixation compensates for moderate yields in monsoon seasons, so fertiliser rates exceeding 30 kg N/ha are not advisable. Residue return could be one way to promote DNRA and minimise native N loss in rice paddies with high N input.

Economic analyses of responses of rice to urea fertiliser showed that for monsoon-season paddy rice at Taungoo and Yezin with small yield responses, and with the current prices of urea and rice, that the Economic Optimum N Rate to achieve a 100% Return on Investment (EONR100) that is likely to be of interest to farmers, was only 30 kg N/ha. Furthermore, our results show that unnecessarily high N fertilisation rates not only did not provide yield benefit but rather promoted native soil N mining and large N losses. It can be concluded that N applications above that applied in compound fertiliser before transplanting should not be applied to rice grown in the monsoon season, or at least limited to a maximum of 30 kg N/ha. In the context of farmers' current practices recommendations to farmers should include reducing urea applications to monsoon-season rice.

For dry season irrigated rice at Taungoo the EONR100 was much higher (120 kg N/ha) because of the much greater potential yield response to N fertiliser. The field trials showed that yields can be increased from approx. 4 t/ha to 6-8 t/ha in the irrigated dry season with the existing varieties. For dry season rice it was shown that agronomically statistically significant yield increases were obtained up to 77.6 kg/ha. In one dry season and at one location, raising the N fertiliser application rate to 160 kg N/ha led to significantly higher grain yield compared to grain obtained from an N input of 77.6 kg/ha. The economic results show a (risk adjusted) recommended N rate of 120 kg N/ha. There is clearly scope for increasing rice production in the dry season where irrigation is available, both from agronomic and financial points of view. There are opportunities for farmers to increase incomes from savings made by reducing urea applications to monsoon season rice, and by increasing urea application rates (using the recommended spilt: 1/3 DAT, 2/3 PI) on dry season irrigated rice. Reductions of urea to monsoon season rice, by far the predominant crop in central Myanmar lowlands, presents an opportunity to reduce N losses to the broader environment and the N-footprint of the farming system.

Rice yields and soil nitrogen dynamics from applications of urea by deep placement (UDP) in the form of briquettes placed below the soil surface between transplanted seedlings was compared with surface broadcast urea. The recovery of the labelled urea in the plants in the UDP treatment was greater than surface broadcast urea regardless of the seasons and locations. In general, UDP was promising allowing reductions of the total rate of urea application, with potential financial and environmental benefits. However, the results were inconsistent between sites. Further research would be worthwhile if feasible and adoptable on-farm mechanisation of deep placement becomes available.

Concerns had been expressed about fertiliser quality and there had been claims of adulteration of fertilisers. However, it was found that fertiliser quality was adequate, and that the fertiliser composition generally corresponded with that on the label.

9.2 Maize

There was a marked increase in grain yields with fertiliser N inputs, from ~2 t/ha with zero fertiliser N input to more than 8.5 t/ha with 250 N/ha, in 2017. A yield response to N was apparent in the 2018 monsoon season at Laythar but with smaller yields due to flooding. Crop total N uptake followed very similar trends to crop yields in both 2017 and 2018 seasons. Crop yield and crop N uptake increased from zero to 180 kg N/ha fertiliser inputs but there was no significant increase in crop yield or N uptake above that, indicating that 180 kg N/ha was likely to be the maximum N rate for maize at Laythar. At Tatkon, 180 kg N/ha or 250 kg N/ha resulted in the highest yields of monsoon maize, depending on the year.

Current N fertiliser use on maize is insufficient for increasing grain production or for optimising farmers' incomes, and N application rates can be increased to around 200 kg N/ha.

9.3 Implications for extension and policy

There is clearly scope for improving the timing of urea and compound fertilisers to rice in central Myanmar, and for increasing yields and profits from dry season irrigated rice and monsoon season maize by applying more N. But the question of using more fertiliser to improve crop yields is clouded by lack of clear advice on how much to apply, by concern for fake or adulterated fertiliser, and by the need to borrow money to buy the fertiliser and the terms of repayment. These uncertainties are a friction on using more fertiliser in their cropping systems. How can the findings be transferred to the intended beneficiaries – the smallholder farmers?

Our interactions with farmers in the study showed that the concept of a smartphone DST in providing prescriptive advice was inconsistent with what many farmers actually want.

Farmers felt that discussion groups were more likely to be a better learning environment and preferred a learning-based tool rather than a prescription-based tool. It is proposed that future extension activities take the form of meetings of groups of farmers with extension officers for discussions of their aspirations and that social media be used to present support materials[1]. This is more likely to be attractive to farmers than a new smartphone app. This information serves as a starting point for developing a framework for discussion support systems.

Monsoon-season rice is the predominant crop in lowland areas of central Myanmar. Economic gains from re-directing the application of N fertiliser to crops other than monsoon-season rice of the lowlands, to more responsive, and higher value, crops, may be possible. This is consistent with our findings that farmers in the surveyed areas are interested in expanding their range of crops, including high value vegetables. There is no benefit from an increase in N fertiliser rates applied to monsoon (paddy) rice but there is a potential benefit from increased N fertiliser applied to maize crops in the monsoon season. However, financial restrictions imposed by Myanmar Government policy on the MADB that limits the size of loans for non-rice crops should be reconsidered and may result in closer to optimal N fertiliser rates applied to maize.

Whilst the use of inadequate rates of N fertilisers may decrease overall crop production and result in suboptimal farmer incomes, excessive applications of N fertilisers represents losses to farmers and may contribute to degradation of air and water quality. Implementation of our findings of reducing N to monsoon season rice will reduce N losses to water and the atmosphere and could also lead to development of “organic” rice production that could attract a price premium in export markets, and a reduction in the N footprint of this, the dominant, crop in central Myanmar.

9.4 Recommendations

- The integrated agronomic and economic findings for fertiliser management of rice and maize should be summarised for communication to next users. These will include recommendations on both timing and rates of fertiliser applications, as presented above.
- The findings can only influence the target farmers if they are presented in a form that they a familiar with, and receptive to. Information in the form of graphics and short videos should be packaged in Facebook which would be a key tool for discussion-based meetings between farmers and extension or other field staff.
- That we support Myanmar to present the case for revising loans for fertiliser purchases that favour fertiliser applications to monsoon rice at the expense of other crops (including irrigated summer-season rice).
- Capacity building of Myanmar collaborators in research and supporting facilities, particularly laboratories, should be priority in future, particularly in agencies willing to commit to research over the necessary timeframes
- Further development of the approach of this project, starting from determining farmers’ objectives and culminating with materials to support discussion-based

[1] *Internet services are currently (April – September 2021) disrupted due to actions of the military government, but we assume they will be restored in the future.*

interactions with farmers could be made, perhaps in generally similar countries such as Cambodia and Lao PDR.

- The responses of monsoon-season rice to N, if applicable to paddy rice production elsewhere, have implications for 'sustainable intensification' R&D strategies. A high-input high-output management strategy promoted for monsoon rice is unlikely to be successful if the yield responses to added N fertiliser are relatively low, or flat. A high-input strategy has increased risk of environmental detriments. A low N input model for monsoon rice leading to more resilient and sustainable farming systems in low-income countries is a potential area for further R&D.

10 References

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Farquharson, B. (2019). Nitrogen fertiliser management for cereal crops in Central Myanmar: Farmer decisions and tools for decision support, Report of a workshop for ACIAR project SMCN/2014/044: ‘Management of nutrients for improved profitability and sustainability of crop production in Central Myanmar’. University of Melbourne, 25 November.

11 Appendixes

11.1 Soils of the project areas

11.1.1 Principal soils of the project areas

A.J. Weatherley and S.E. Eldridge

Soil profile descriptions were derived from the reconnaissance survey conducted over the life of the ACIAR project, and are presented here with some contextual information. Soils were investigated during two major periods - May 2017 (auger holes only) and December 2019 (pit and auger holes). The extent of the surveys in the Zeyathiri project area allowed some mapping of the major soil types (Figure A1.1). This was not possible at the Tatkon and Taungoo sites and only the descriptions of the soils of the crop response trial site are presented. The soil 'mapping' in the Zeyathiri region should be regarded as areas where these soils are most likely to be found and generally should be considered compound units. The landscape of the Zeyathiri region is a dynamic flood plain and is shaped to the west by the Sinthey river and relic stream systems. To the east the landscape is shaped by the Yezin river and the close proximity of granitic Yezin foothills. The damming of the Yezin River in 1975 altered water flow and significant land forming works appear to have been carried out on the Yezin Agricultural University and the Department of Agricultural Research field stations (mostly sands and sandy loams, Fig. A1.1)). The actions of these two rivers over a relatively short distance (~5 km) has led to a complex array of soils, with levees associated with prior streams and buried soils with vary degrees of pedogenic development. A number of these type soils have high shrinkage mostly due too high levels of silt in the surface soils. Toward the top of the catchment the Laythar dark cracking clay displays self-mulching when wet. In the lower part of the catchment the Kyobin vertic clay displays strong shrink swell characteristics, including gilgai development.

The CEC to clay ratio (CCR[1]) indicates the clay mineralogy in the cracking silty clay soils is likely to be smectitic.

The inclusion of a range of soil chemical and physical properties should provide an excellent basis for use in mechanistic crop growth models.

In Fig. 11.1.1 the principal soils for each mapping unit are:

- Sands on levees (denoted in blue): Sinthey fine sand
- Dark cracking clays (green): Laythar dark cracking clay
- Silty clay loams (pink): Kyobinzeik silty clay loam
- Cracking silty light clay (red): Ywathit cracking silty light clay
- Sands and sandy loams (yellow): Yezin sandy loam and Yezin coarse sand
- Vertic clay (turquoise): Kyobin vertic clay

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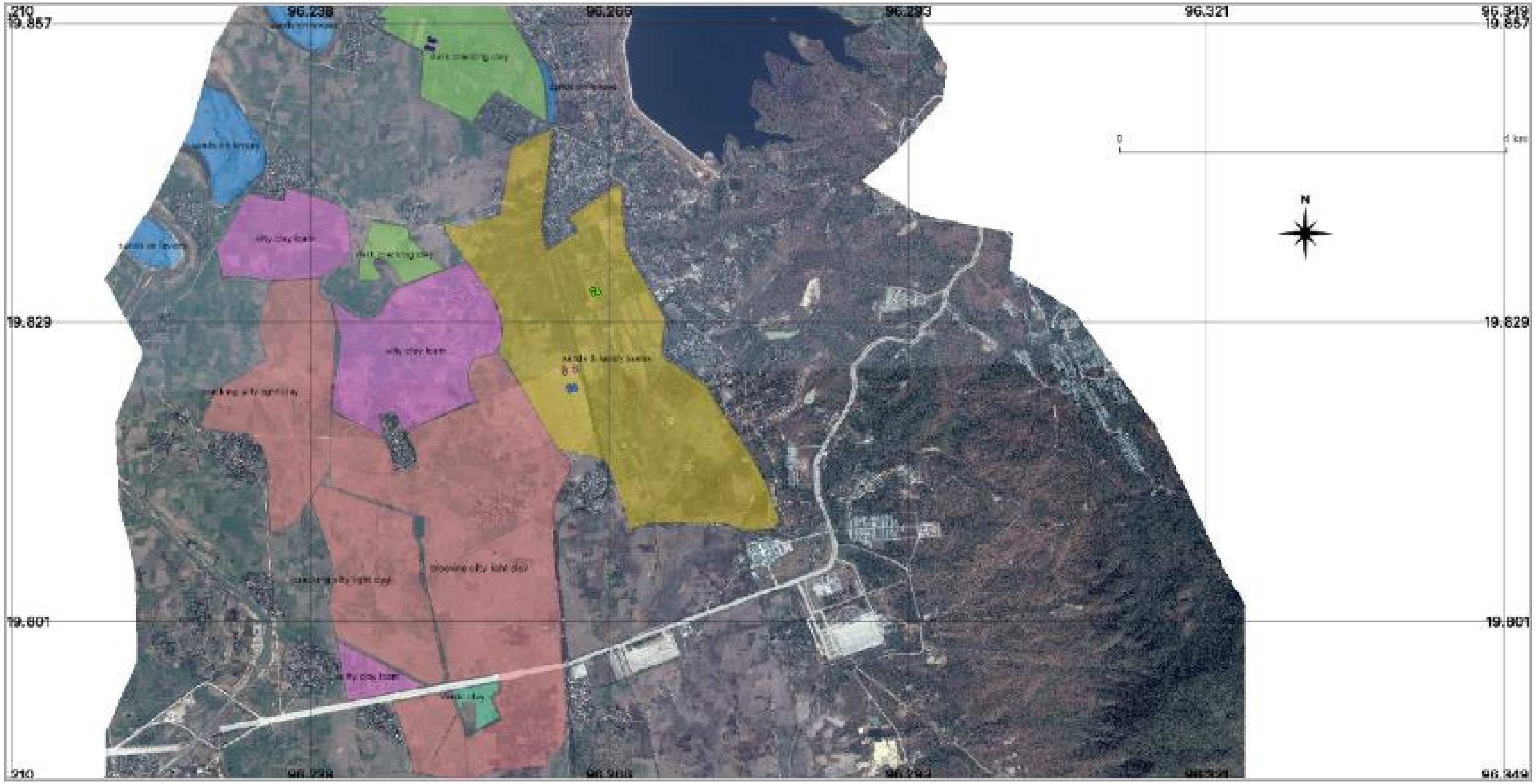


Figure 11.1.1 Reconnaissance soil map of the Zeyathiri project area

Locations of the Zeyathiri field sites are also shown on the soil map.

Laythar Yezin 1 Yezin 3 Yezin 2

11.1.2 Soil profile descriptions for the project areas

Sinthey fine sand **Geo-reference**: 47Q 0207694 2223633

WRB classification: Orthofluvic Arenosol

Location: Adjacent Sinthey river, ~ 700 m west of Ywezu Village, Tatkon area

General landscape description: Active flood plain of Sinthey river

Landscape morphology: Flat

Elevation: 144 m

Landuse: Vegetable crops

Geology: Alluvial sediments, active flood plain

Soil profile morphology

Ap1 0-17 cm	Dark greyish brown (10YR 4/2); *fine sandy clay loam*; structureless; pH 7.0; abrupt change to:
Ap2 17-21 cm	Very dark brown (7.5YR 2.5/2) *fine sandy clay loam*; compacted layer; pH 7.5; abrupt change to:
2Db 21-85 cm	Dark yellowish brown (10YR 4/4); *sand*; single grained massive; pH 7.5; diffuse change to:
3Db 85-95+ cm	Brown (10YR 4/3); *loamy sand*; single grained massive; pH 8.0

Chemical and Physical Analysis:

Depth cm	pHw	EC µS/cm	Exchangeable Cations cmol(+)/kg Ca	Mg	Na	K	CEC	TC %	TN %	Olsen P mg/kg
0-17	7.4	58.0	11.3	4.9	0.1	0.18	16.4	0.5	0.08	19
17-21	7.7	59.5	10.5	4.4	0.1	0.01	14.9	0.2	0.06	11
21-85	5.9	46.4	2.2	0.8	0.0	0.0	3.0	0.0	0.02	3
85-95+	7.3	10.1	1.7	0.8	0.0	0.25	2.8	0.0	0.02	2

Depth cm	Clay % <0.002mm	Silt % 0.002-0.02mm	Fine Sand % 0.02-0.2mm	Coarse Sand % 0.2-2mm	Field Capacity -10 kPa mm^3/mm^3	Wilting Point -1500 kPa mm^3/mm^3	PAWC mm/mm	Bulk ρ g/cm^3	Infiltration Rate mm/hr
0-17	14	20	32	34	0.280	0.163	0.117	1.4	160
17-21	13	16	30	42	0.276	0.166	0.110	1.1	271
21-85	2	0	6	92	0.068	0.014	0.054	1.3	
85-95+	1	1	21	78	0.039	0.013	0.026	1.3	

Other observations: This profile is from Site of the Tatkon maize demonstration trial 2019. Alluvial strata very evident throughout profile. Some slaking in topsoil

Surface condition:

Profile Described by: Tony Weatherley and Simon Eldridge (16 Dec. 2019).

Laythar dark cracking clay **Geo-reference**: 47Q 0211911 2197765

WRB classification: Hydragric Vertisol

Location: ~ 700 m southeast of Thayettaw Village, Zeyathiri area

General landscape description: Alluvial plain

Landscape morphology: Flat

Aspect: 105 ˚ **Elevation**: 106 m

Landuse: Banana, lime and paw paw, previously sweet corn

Geology: Alluvial sediments

Soil profile morphology

Ap 0-11 cm	Wavy boundary, very dark grey (10YR 3/1); *silty light clay*; weak subangular structure; pH 6.5; abrupt change to:
B1 11-19 cm	Dark brown (7.5YR 3/3) *silty light medium clay*; gravels; weak lenticular structure; pH 7.0; gradual change to:
B21 19-42 cm	Very dark greyish brown (10YR 3/2), common diffuse mottles; *silty light clay*; weak angular blocky; pH 7.0; gradual change:
B22 42-58 cm	Dark grey (7.5YR 4/1), common diffuse mottles; *silty light medium clay;* medium lenticular structure; pH 7.0; gradual change to:
B23 58-89 cm	Dark brown (10YR 3/3), common diffuse mottles; *silty medium clay*; gravels; weak polyhedral; pH 7.0; clear change to:
B24 89-94+ cm	Dark yellowish brown (10YR

Depth cm	pHw	EC µS/cm	Exchangeable Cations cmol(+)/kg Ca	Mg	Na	K	CEC	TC %	TN %	Olsen P mg/kg
0-11	6.4	43.7	14.0	10.0	0.2	0.37	24.5	1.33	0.13	45.4
11-19	6.7	34.2	14.9	10.6	0.2	0.27	25.9	1.06	0.12	32.0
19-42	6.9	28.1	14.1	10.7	0.3	0.39	25.5	0.74	0.09	14.1
42-58	6.8	34.1	17.6	16.2	0.5	0.36	34.6	0.91	0.10	7.6
58-89	6.7	32.2	18.0	16.5	0.5	0.30	35.3	0.74	0.10	7.0
89-94+	6.9	30.6	14.5	13.3	0.4	0.22	28.4	0.63	0.07	5.5

Depth cm	Clay % <0.002mm	Silt % 0.002-0.02mm	Fine Sand % 0.02-0.2mm	Coarse Sand % 0.2-2mm	Field Capacity -10 kPa mm^3/mm^3	Wilting Point -1500 kPa mm^3/mm^3	PAWC mm/mm	Bulk ρ g/cm^3	Infiltration Rate mm/hr
0-11	25	45	28	2	0.418	0.334	0.085	1.1	3.4
11-19	23	44	32	1	0.399	0.264	0.136	1.0	
19-42	37	47	16	1	0.377	0.299	0.078	1.2	
42-58	33	49	17	2	0.491	0.435	0.057	1.0	45
58-89	22	56	20	1	0.472	0.405	0.067	0.9	
89-94+	25	45	28	2	0.433	0.344	0.089	1.1	

Other observations: Slaking throughout, imperfectly drained, manganiferous subsoil, polished peds 57 cm, self mulching when wet. Similar to Kyobin cracking clay

Surface condition

Profile Described by: Tony Weatherley and Simon Eldridge (14 Dec. 2019).

Kyobinzeik silty clay loam **Geo-reference**: 47Q 0209952 2195864

WRB classification: Orthofluvic Fluvisol

Location: ~ 500 m southwest of Kyobinzeik Township, Adjacent anabranch of Sinthey river, Zeyathiri area

General landscape description: Alluvial plain

Landscape morphology: Flat

Elevation: 101 m

Landuse: Lablab bean

Geology: Alluvial sediments, recent stream system

Soil profile morphology

Ap 0-16 cm	Dark greyish brown (10YR 4/2); *silty clay loam*; weak angular blocky structure; pH 6.0; abrupt change to:
B1 16-26 cm	Brown (7.5YR 4/2), few mottles; *fine sandy light clay*; weak polyhedral structure; pH 6.5; abrupt change to:
B21 26-43 cm	Brown (10YR 4/3), few mottles; *silty light clay*; weak polyhedral structure; pH 6.5; clear change to:
B3 43-66 cm	Brown (10YR 4/3), few mottles; *silty clay loam*; weak polyhedral structure; pH 6.5; abrupt change to:
2A1 66-88 cm	Very dark greyish brown (10YR 3/2), few mottles; *silty light clay*; weak polyhedral structure; pH 6.5; abrupt change to:
2B1 88-96+ cm	Brown (10YR 4/3); *silty light clay*; weak polyhedral structure; pH 6.5 continuing.

Depth cm	pHw	EC µS/cm	Exchangeable Cations cmol(+)/kg Ca	Mg	Na	K	CEC	TC %	TN %	Olsen P mg/kg
0-16	6.2	29	6.8	3.1	0.2	-	10.1	0.6	0.12	20.8
16-26	6.5	20	9.9	5.1	0.0	-	15.0	0.3	0.08	16.7
26-44	6.5	16	13.0	6.8	0.0	-	19.9	0.2	0.05	5.9
43-66	6.5	14	11.9	6.3	0.1	-	18.2	0.3	0.08	4.5
66-88	6.6	16	13.4	7.7	0.1	-	21.2	0.5	0.05	5.8
88-96+	6.5	16	12.1	7.3	0.0	-	19.4	0.5	0.05	5.7

Depth cm	Clay % <0.002mm	Silt % 0.002-0.02mm	Fine Sand % 0.02-0.2mm	Coarse Sand % 0.2-2mm	Field Capacity -10 kPa mm^3/mm^3	Wilting Point -1500 kPa mm^3/mm^3	PAWC mm/mm	Bulk ρ g/cm^3	Infiltration Rate mm/hr
0-16	14	31	53	3	0.343	0.252	0.091	1.2	149
16-26	15	32	51	2	0.354	0.271	0.082	1.2	34.5
26-44	19	32	42	7	0.369	0.182	0.187	1.2	
43-66	12	23	64	1	0.410	0.179	0.231	1.3	
66-88	16	36	47	1	0.428	0.272	0.156	1.2	
88-96+	14	36	50	1	-	-	-	1.2	

Other observations: Manganiferous throughout, slaked in layers 2,3,4.

Surface condition

Profile Described by: Tony Weatherley and Simon Eldridge (15 Dec. 2019)

Ywathit cracking silty light clay **Geo-reference**: 47Q 0212458 2194527

WRB classification: Orthofluvic Fluvisol

Location: ~ 600 m south-southeast of Tantabin Village, Zeyathiri area

General landscape description: Small terrace on alluvial plain

Landscape morphology: Flat

Elevation: 98 m

Landuse: Rice paddy

Geology: Alluvial sediments

Soil profile morphology

Ap1 0-16 cm	Dark greyish brown (10YR 4/2); few stained yellowish red (5YR 5/6) root channels; *silty light clay*; weak granular structure; pH 5.0; abrupt change:
Ap2 16-27 cm	Brown (7.5YR 4/2), few yellowish red mottles (5YR 5/8); *silty light clay*; structureless; pH 5.5; abrupt change to:
2A1 27-37 cm	Black (7.5YR 2.5/1); *silty medium clay*; moderate columnar; pH 6.0; clear change to:
2B21 37-48 cm	Dark grey (7.5YR 4/1) few yellowish brown mottles (10YR 5/4); *silty medium heavy clay*; weak polyhedral; pH 6.5; gradual change to:
2B21 48-77 cm	Dark grey (10YR 4/1) few dark yellowish brown mottles (10YR 5/8); *fine sandy medium clay*; weak polyhedral; pH 6.5; gradual change to:
3Db 77-97 cm+	Dark grey (10YR 4/1), common brown (10YR 4/3) mottles (manganiferous?) *fine sandy clay loam*, structureless; pH 7.0

Depth cm	pHw	EC µS/cm	Exchangeable Cations cmol(+)/kg				CEC	TC %	TN %	Olsen P mg/kg
			Ca	Mg	Na	K				
0-16	5.2	21.5	9.1	0.4	0.0	0.20	9.7	1.3	0.13	5.4
16-27	5.2	21.7	8.6	0.9	0.1	0.17	9.8	0.9	0.11	6.3
27-37	5.6	22.5	12.3	1.4	0.3	0.31	14.4	0.4	0.08	11.9
37-48	6.8	16.9	13.7	0.2	0.3	0.35	14.5	0.6	0.07	7.0
48-77	6.5	15.2	10.1	1.7	0.3	0.28	12.3	0.3	0.05	7.3
77-97+	6.8	15.3	7.3		0.2	0.22	7.7	0.1	0.03	10.9

Depth cm	Clay % <0.002mm	Silt % 0.002-0.02mm	Fine Sand % 0.02-0.2mm	Coarse Sand % 0.2-2mm	Field Capacity -10 kPa mm^3/mm^3	Wilting Point -1500 kPa mm^3/mm^3	PAWC mm/mm	Bulk ρ g/cm^3	Infiltration Rate mm/hr
0-16	18	37	42	3	0.413	0.33	0.083	0.9	982
16-27	17	35	44	4	0.384	0.28	0.105	1.0	114
27-37	26	33	37	4	0.39	0.307	0.082	0.9	
37-48	31	33	32	3	0.407	0.321	0.086	1.0	
48-77	24	24	37	15	0.312	0.17	0.142	1.2	
77-97+	19	10	54	18	0.307	0.143	0.163	1.4	

Other observations: Higher, raised area (0.75 m) very cracked surface (silt), No other vertic properties observed. Slaking throughout. Dispersion at depth.

Surface condition:

Profile Described by: Tony Weatherley and Simon Eldridge (15 Dec. 2019).

Yezin sandy loam **Geo-reference**: 47Q 0213452 2195209

WRB classification: Gleyic Fluvisol

Location: Yezin Agricultural University, Zeyathiri area

General landscape description: Alluvial plain

Landscape morphology: Flat

Elevation: 98.5 m

Landuse: Rice paddy

Geology: Alluvial sediments, modified stream system (post Yezin dam)

Soil profile morphology

Ap1 0-11 cm	Very dark greyish brown (10YR 3/2); few stained yellowish red (5YR 5/6) root channels; *clay loam, sandy*; weak polyhedral structure; pH 5.0; abrupt change to:
Ap2 11-21 cm	Very dark greyish brown (10YR 3/2) *silty clay loam*; structureless; pH 6.0; abrupt change to:
2Db 21-42 cm	Dark reddish grey (2.5YR 3/1); *silty medium clay*; structureless; pH 6.5; sharp change to:
3Db 42-67 cm	Grey (2.5Y 5/1); *loamy sand*; structureless; pH 6.5; clear change to:
4Db 67-79+ cm	Greyish brown (10YR 5/2) few yellowish brown mottles (10YR 5/8); *sandy loam*; structureless; pH 6.5; continuing.

Horizon Depth cm	pH (water)	EC µS/cm	Exchangeable Cations cmol(+)/kg Ca	Mg	Na	K	CEC	TC %	TN %	Olsen P
0-11	5.1	55	3.7	0.6	0.2	0.05	4.5	1.3	0.14	13
11-21	5.1	73	3.8	0.6	0.3	0.04	4.7	1.3	0.14	12
21-42	7.1	53	6.8	1.5	0.3	0.13	8.8	0.7	0.06	15
42-67	5.7	27	1.3	0.3	0.1	0.04	1.7	0.2	0.02	10
67-79+	6.2	24	1.7	0.4	0.1	0.04	2.3	0.2	0.01	11

Depth cm	Clay % <0.002mm	Silt % 0.002-0.02mm	Fine Sand % 0.02-0.2mm	Coarse Sand % 0.2-2mm	Field Capacity -10 kPa mm^3/mm^3	Wilting Point -1500 kPa mm^3/mm^3	PAWC mm/mm	Bulk ρ g/cm^3	Infiltration Rate mm/hr
0-11	14	19	41	26	0.355	0.074	0.281	1.1	296
11-21	13	16	45	26	0.271	0.107	0.164	1.2	
21-42	22	25	37	16	0.314	0.180	0.14	1.4	65
42-67	3	4	65	29	0.157	0.026	0.131	1.3	
67-79+	3	4	74	18	0.242	0.028	0.213	1.3	

Other observations: Site of 2017 monsoon and dry season rice crops. Boundaries irregular, imperfectly drained, coarse sand lenses. Locals suggest the possibility of land forming practices in this area post Yezin Dam to achieve better outcomes for paddy rice (slow infiltration).

Surface condition

Profile Described by:
Tony Weatherley and Simon Eldridge (11 Dec. 2019).

<u>Kyobin vertic clay</u> **Geo-reference**: 47Q 0212232 2191101

WRB classification: Hydragric Vertisol

Location: ~ 900 m east of Kyobin Village, Zeyathiri area

General landscape description: Drainage line on alluvial plain

Landscape morphology: Open depression

Aspect: 180 ˚ **Elevation**: 93 m

Landuse: Rice paddy

Geology: Alluvial sediments, relic stream system

Soil profile morphology

Ap 0-7 cm	Dark grey (7.5YR 4/1); common yellowish red (5YR 4/6) mottles; *silty light medium clay*; weak polyhedral structure; pH 5.0; wavy boundary:
B21 7-13 cm	Dark greyish brown (10YR 4/2), common reddish brown (5YR 4/4) stained root channels; *silty medium clay*; weak polyhedral structure; pH 5.5; abrupt change to:
B22 13-25 cm	Very dark greenish grey (Gley1, 3/5GY), common (5YR 4/6) mottles; *silty heavy clay*; moderate angular blocky structure; pH 6.0; clear change:
B23 25-38 cm	Dark reddish grey (2.5YR 4/1), few diffuse mottles; *heavy clay*; moderate lenticular structure; pH 6.5; gradual change to:
B24 38-87+ cm	Dark grey (10YR 4/1) few mottles; *heavy clay*; strong lenticular structure; pH 7.5

Soil chemical and physical properties

Depth cm	pHw	EC µS/cm	Exchangeable Cations cmol(+)/kg				CEC	TC %	TN %	Olsen P mg/kg
			Ca	Mg	Na	K				
0-7	5.13	42.6	11.8	6.2	0.0	0.07	18.1	1.5	0.21	7
7-13	5.24	38.7	15.3	11.1	0.4	0.21	27.0	1.6	0.18	7
13-25	6.16	44.8	16.6	13.7	0.9	0.28	31.5	1.4	0.16	10
25-38		48.5	18.9	17.9	1.2	0.26	38.3	0.5	0.09	10
38-87+		45	18.5	17.7	1.4	0.17	37.7	0.6	0.08	11

Depth cm	Clay % <0.002mm	Silt % 0.002-0.02mm	Fine Sand % 0.02-0.2mm	Coarse Sand % 0.2-2mm	Field Capacity -10 kPa mm^3/mm^3	Wilting Point -1500 kPa mm^3/mm^3	PAWC mm/mm	Bulk ρ g/cm^3	Infiltration Rate mm/hr
0-7	38	47	12	3	0.55	0.407	0.143	0.8	884
7-13	38	48	13	2	0.569	0.325	0.244	1.0	
13-25	38	48	13	2	0.531	0.44	0.091	1.2	
25-38	38	53	9	0	0.504	0.395	0.11	1.1	33
38-87+	38	49	13	1	0.542	0.398	0.144		

Other observations: Deep hexagonal shaped cracks, soil removed in hexagonal blocks, biopores in surface, slickensides and cutans in subsoil, manganese nodules, charcoal, watertable around 87 cm. Farmer observation: 'not too extensive'. Floods in depression but drains to the south. He was not aware of other occurrence in the area (was DoE employee). Bounded by drain to west and highway to north. High hydraulic conductivity in surface owing to cracks/biopores in dry condition. These cracks will close on wetting of the profile.

Surface condition

Profile Described by: Tony Weatherley and Simon Eldridge (17 Dec. 2019

<u>**Yezin coarse sand**</u>	**Geo-reference**: 47Q 0212538 2195786
WRB classification: Fluvic Arenosol	
Location: YAU and DAR and surrounds, Zeyathiri area	

General landscape description: Levees on alluvial plain

Landscape morphology: Flat

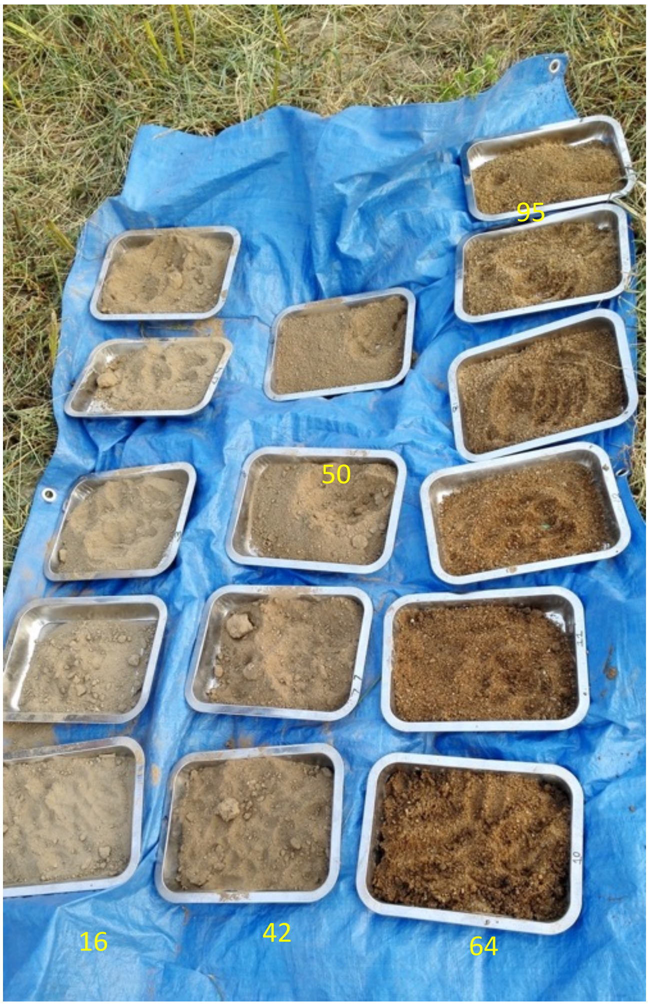
Elevation: 101 m

Landuse: Sesame, vegetable crops

Geology: Alluvial sediments, modified stream system (post Yezin dam)

Soil profile morphology

Ap1 0-16 cm	Brown (10YR 4/3)*; coarse clayey sand,* structureless; pH 5.5:
2Db 16-42 cm	Brown (10YR 4/3) *coarse sandy loam*; structureless; pH 5.75:
3Db 42-50 cm	Brown (10YR 4/3); *clayey sand*; structureless; pH 6.5:
4Db 50-64 cm	Dark yellowish brown (10YR 4/4); *clayey coarse sand;* pH 6.5:
5Db 64-95+ cm	Dark yellowish brown (10YR 4/4); *coarse sand*; structureless; pH 7.0.



Chemical and Physical Analysis:

Horizon Depth cm	pH (water)	EC µS/cm	Exchangeable Cations Ca cmol(+)/kg	Mg	K	Na	CEC	TC %	TN %	Olsen P
0-16*	5.14	61	-	-	-	0.25	-	0.5	0.1	10
16-42										
42-50										
50-64										
64-96+										

Depth cm	Clay % <0.002mm	Silt % 0.002-0.02mm	Fine Sand % 0.02-0.2mm	Coarse Sand % 0.2-2mm	Field Capacity -10 kPa mm³/mm³	Wilting Point -1500 kPa mm³/mm³	PAWC mm/mm	Bulk ρ g/cm³	Infiltration Rate mm/hr
0-16	9	11	33	48	-	-	-	-	-
16-42									
42-50									
50-64									
64-96+									

Other observations: Oxidised colours throughout. * Limited analysis of auger sample

Surface condition

Profile Described by:
Tony Weatherley and
Simon Eldridge
(7 May 2017).

<u>Tatkon cracking clay</u>

Geo-reference: 47Q 0208902 2229137

WRB classification: Hydragric Vertisol

Location: DAR field station, Tatkon

General landscape description: Alluvial plain

Landscape morphology: Flat

Elevation: 146 m

Landuse: Planted to sunflower

Geology: Alluvial sediments

Soil profile morphology

Ap1 0-8 cm	Dark brown (10YR 3/3); *silty light medium clay*; structureless; pH 6.5; abrupt change to:
Ap2 8-21 cm	Very dark brown (10YR 2/2) *silty medium clay*; structureless; pH 7.5
B21 21-47 cm	Very dark gray (10YR 3/1); *silty medium heavy clay*; moderate lenticular structure; pH 7.0
B22 47-78 cm	Brown (10YR 4/3); *silty medium clay*; weak lenticular structure; pH 7.0
B23 78-94+ cm	Dark yellowish brown (10YR 3/4); *heavy clay*, medium lenticular and polyhedral structure; pH 7.5

Soil chemical and physical properties

Depth cm	pHw	EC µS/cm	Exchangeable Cations cmol(+)/kg Ca	Mg	Na	K	CEC	TC %	TN %	Olsen P mg/kg
0-8	7.5	98	15.6	11.1	0.5	0.42	27.7	1.0	0.14	39
8-21	7.2	77	16.5	11.7	0.8	0.30	29.3	1.0	0.14	37
21-47	7.2	66	17.9	13.6	1.2	0.25	33.0	0.9	0.10	10
47-78	7.2	62	14.5	13.2	1.5	0.22	29.4	0.4	0.08	12
78-94+	7.5	69	13.9	15.4	2.6	0.26	32.1	0.5	0.08	9

Depth cm	Clay % <0.002mm	Silt % 0.002-0.02mm	Fine Sand % 0.02-0.2mm	Coarse Sand % 0.2-2mm	Field Capacity -10 kPa mm^3/mm^3	Wilting Point -1500 kPa mm^3/mm^3	PAWC mm/mm	Bulk ρ g/cm^3	Infiltration Rate mm/hr
0-8	18	51	30	1	0.406	0.190	0.216	1.0	45.9
8-21	23	41	34	1	0.393	0.198	0.195	1.1	
21-47	31	47	21	1	0.405	0.188	0.217	1.0	3
47-78	21	48	30	1				1.2	
78-94+	26	53	20	1	0.374	0.156	0.216	1.1	

Other observations: Cracking surface, manganiferous throughout, dispersion and cutans in subsoil

Surface condition.

Profile Described by: Tony Weatherley and Simon Eldridge (16 Dec. 2019)

Taungoo cracking clay **Geo-reference**: 47Q 0218925 2096322

WRB classification: Hydragric vertisol

Location: Adjacent to highway, 1 km north of Kha Paung River, Taungoo area

General landscape description: Alluvial plain

Landscape morphology: Flat

Aspect: 150 ˚ **Elevation**: 58 m

Landuse: Rice residues

Geology: Alluvial sediments

Soil profile morphology

Ap 0-13 cm	Brown (10YR 4/3); few mottles; *clay loam, silty*; weak granular structure; pH 5.5; clear change to:
B21 13-45 cm	Brown (10YR 4/3) *silty light clay*; weak subangular blocky; pH 6.5; gradual change to:
B22 45-71 cm	Brown (10YR 4/3) few mottles; *silty medium clay*; weak subangular blocky; manganese gravels; pH 7.0; gradual change to:
B23 71-90+ cm	Dark yellowish brown (10YR 4/6); common mottles; *silty medium clay*; structureless; pH 7.0

Depth cm	pHw	EC µS/cm	Exchangeable Cations Ca	Mg	Na	K cmol(+)/kg	CEC	TC %	TN %	Olsen P mg/kg
0-13	5.0	58.8	5.6	4.5	0.2	0.14	10.4	0.6	0.10	9
13-45	6.6	28.2	7.4	7.0	0.5	0.16	15.1	0.5	0.07	15
45-71	6.1	22.4	7.5	9.5	0.4	0.21	17.5	0.4	0.07	9
71-90+	6.2	25.8	7.5	10.7	0.2	0.19	18.7	0.4	0.07	7

Depth cm	Clay % <0.002mm	Silt % 0.002-0.02mm	Fine Sand % 0.02-0.2mm	Coarse Sand % 0.2-2mm	Field Capacity -10 kPa mm^3/mm^3	Wilting Point -1500 kPa mm^3/mm^3	PAWC mm/mm	Bulk ρ g/cm^3	Infiltration Rate mm/hr
0-13	16	36	46	2	0.43	0.21	0.223	1.0	249
13-45	19	36	42	3	0.39	0.31	0.078	1.0	
45-71	23	30	46	1	0.38	0.28	0.106	1.1	58
71-90+	21	35	42	2	0.41	0.34	0.070	1.2	

Other observations: Slakes throughout, deep cracking surface

Surface condition

Profile Described by: Tony Weatherley and Simon Eldridge (9 Dec. 2019).

11.2 Scaling out potential economic benefits of improved N fertiliser management.

Bob Farquharson, Thiagarajah Ramilan, So Pyay Thar

The objective of this Appendix is to review the main results from the project's field work in Myanmar to estimate potential economic benefits to Burmese smallholder farmers if the project's recommendations are adopted. This estimate is necessarily hypothetical as follow-up surveys of farmer adoption have not been possible.

The field trial data were used to estimate smoothed (regression) response functions of likely cereal crop yields as more N fertiliser is added over the range from zero N to very high N fertiliser levels.

This analysis was conducted for three crops – monsoon (paddy) rice, dry season irrigated rice and monsoon maize. Four trial sites were situated in the Townships of Tatkon, Zeyathiri and Taungoo as described in Section 5.

11.2.1 Economic analysis

The regressed yield response functions were combined with farm-level prices of crops and fertiliser sourced through the farm survey (Section 7.5.2) to estimate an 'economic optimum' N fertiliser application rate for smallholder farmers in central Myanmar. This 'best' economic N rate was adjusted to account for likely risk aversion, or caution, on the part of smallholders due to the possibility that the crop yields and crop prices expected to be achieved at the date of sowing (and application of fertiliser) might not eventuate at the time of harvest when the crop is sold.

Smallholder farmers must generally borrow money to buy fertiliser, and the need to pay interest on the loan and repay the loan capital imposes additional financial risk which can lead to caution in fertiliser decision making and a reluctance to apply higher levels of fertiliser.

The analysis of yield response patterns in field plot trials was compared with actual smallholder fertiliser decisions; these data were collected in a 600-farmer survey of the Townships surrounding the project trial sites (Section 7.5.2).

11.2.2 Economic analyses for each crop

Results of field trial crop yields and associated smoothed (regression) response functions, economic N rates (EONR100) and Myanmar Department of Agriculture (DoA) N fertiliser recommendations are given for monsoon rice and dry season irrigated rice at Taungoo in Figure 7.5.5, and monsoon maize at Laythar in Figure 7.5.7.

The yield response function for paddy rice at Taungoo indicates an economic N rate of only 30 kg N/ha and compares with the DoA recommended N rate of 86 - 90 kg/ha. The yield response function for irrigated dry season rice at Taungoo indicates an economic N rate of 105 kg N/ha whereas the DoA recommended N rate is again 86 - 90 kg/ha.
In the case of maize at Laythar, the indicated economic N rate is 200 kg N/ha in comparison with the DoA recommended N rate of 176 kg/ha.

11.2.3 Survey results of smallholder fertiliser decisions

The 600-farm survey in the project township areas provided information about actual smallholder N fertiliser application rates. The results for monsoon rice, dry season irrigated (summer) rice and maize are shown in Figure 7.5.3.

Figures 7.5.5 and 7.5.7 show what the best economic N rate should be (i.e., a 'normative' approach) if smallholders are assumed to be motivated, at least in part, to achieve high economic returns from crop production while accounting for likely attitudes to risk. Figure 7.5.3 shows the actual N fertiliser rates (i.e., a 'positive' approach). With respect to the actual farm-level decisions shown in Figure 7.5.3 there is, as expected, a range of N fertiliser decisions within the population of smallholder farmers. This can be rationalised if we remember that farmers are likely to have different goals (within the range from subsistence to semi-subsistence (semi-commercial) to fully commercial motivations), different attitudes to the risk of adverse crop outcomes (from very risk averse, mildly risk averse or risk neutral, to risk preferring) and different access to capital (via loans).

11.2.4 Implications

The results have important implications for N fertiliser decisions by smallholders growing cereal crops in central Myanmar. In general, the results showing the patterns of crop yield responses, together with the analysis of best economic N rates when compared with patterns of actual farmers' decisions, imply that smallholders may be over-fertilising monsoon rice and under fertilising dry season irrigated rice and monsoon maize.

There has not been the time or opportunity to discuss these results with Myanmar DoA scientists or extension officers, with private sector fertiliser providers, or to speak with smallholder farmer groups about these findings. This can be the basis for further research and development. An important next step is to consider the likely benefits from such discussions and farmer extension activities if changes to farmers' fertiliser practices could be achieved in the future. An estimation of the potential benefits can be used by R&D funding bodies as a basis for future projects.

11.2.5 Scaling out and potential economic benefits to smallholders

An estimate of potential economic benefits from fertiliser practice change is necessarily a 'what if' exercise. What would be the benefits to smallholder farmers in the project townships if some changes in farm fertiliser practices occur? This analysis focusses only on potential economic benefits from changes to N fertiliser applications. There are likely to be environmental and health benefits if N fertiliser applications are reduced substantially. This type of calculation is based on a series of assumptions about farm management changes in the scale and timing of fertiliser use from the current baseline situation. Recent data on the areas of crops grown within the township areas are shown in Table 11.2.1.

Table 11.2.1. Areas of crops grown by township.

	Tatkon	Zeyathiri	Taungoo	Total
	ha	ha	ha	ha
Monsoon rice (2015-2016)	18,859	4,915	24,156	47,930
Dry season Irrigated rice (2015-2016)	97	1,457	6,217	7,771
Monsoon Maize (2014-2015)	1,130	1,163		2,293
Winter Maize (2014-2015)	478	193		671

11.2.6 Methods and results

Monsoon rice: For monsoon rice the EONR100 is 30 kg N/ha (Figure 7.5.5). From the farm survey results the distribution of N applications by smallholders is shown in Figure 7.5.3. The total area of monsoon rice grown in these four townships in 2015-16 was 47,930 ha. One way of estimating potential economic benefits is to consider whether some farmers change to applying the EONR100 of 30 kg N/ha. Many would therefore apply less N fertiliser resulting in cost saving as less N would be applied. Given the generally flat shape of the yield response above 30-40 kg N/ha, we assume that reducing excess N fertiliser will not change the crop yield but will only have a cost reduction effect.

For each urea fertiliser category in Figure 7.5.3, the average N rate is estimated and the excess over 30 kg N/ha calculated (Table 11.2.2). The number of surveyed farmers in the sample is then used to calculate the area for each urea application rate category. Finally, a cost saving is estimated based on a farm-level price for N of $AU 1.10/kg. In Table 11.2.2 the estimated cost saving from reducing N applications to the economic rate, if applied to only 1% of the total crop area (47,930 ha), is about $AU 25,000.

A sensitivity analysis of the cost saving estimate for a range of crop areas is shown in Table 11.2.3. Cost savings range from $AU 25,000 at 1% of a total area of crop for which fertiliser rates are reduced to the economic rate, to AU$1.2 million if adoption is achieved for 50% of the total crop area. To illustrate the scale of possible benefits, if 10% of the total area achieved reduced annual costs of $AU 254,000 over 4 years, there would be an estimated AU$1 million of savings.

Table 11.2.2. Estimated cost savings from reduced N applications to monsoon rice

Category of urea application [a]	Av N rate in category [b]	Excess over 30 kg N/ha [c]	% farmers in sample [d]	Estimated area [e]	Cost savings [f]
kg N/ha	kg N/ha	kg N/ha	%	ha	$AU
46-69	58	28	29	13,900	4,281
69-92	81	51	23	11,024	6,184
92-115	104	74	18	8,627	7,023
115-138	127	97	3	1,438	1,534
138-161	150	120	3	1,438	1,898
161-184	173	143	6	2,876	4,524
Total					25,444

[a] From Figure 7.5.3
[b] Mid-point of urea category
[c] Economic N rate is 30 kg N/ha
[d] From survey farmer population of 34,814
[e] Based on 47,930 ha of monsoon rice in 2015-16 and percent of farmers in sample
[f] Based on $AU 1.10/kg N and 1% of total area monsoon rice

Table 11.2.3. Estimated cost savings for monsoon rice according to percentage of crop area in 4 Townships

Percent of crop area	Cost savings for monsoon rice
%	$AU
1	25,000
2	51,000
5	127,000
10	254,000
50	1,270,000

Maize: The total area of monsoon maize grown in 2014-15 was nearly 2,300 ha (Table 11.2.1) but this area is likely to have increased substantially since then: Clive Murray (Myanma Awba Group, personal communication) estimated the current area to be 14,700 ha in Pyinmana and Tatkon. An estimate of potential income gains over 4 years from applying urea fertiliser and achieving higher yields shows a substantial increase in farm-level income (Table 11.2.4).

Table 11.2.4. Estimated extra income from applying more N fertiliser to maize

Year	Area (ha)	Extra urea applied (bags/ha)	Yield gain (t/ha)	Maize price ($AU/t)	Extra income ($AU/ha)	Extra income [a] ($AU/area)
1	100	1	1.84	238	439	43,877
2	300	1.5	2.76	238	658	197,446
3	800	2	3.68	238	878	702,031
4	1,200	2	3.68	238	878	1,053,046

[a] Does not include extra material and labour costs of applying fertiliser N

When the extra costs of applying fertiliser (product and labour) is costed, the net income increase ranges from AU$40,000 to AU$966,000 up to year 4.

In total for paddy rice and maize, an estimate of aggregated savings over 4 years from improved fertiliser use is in the order of $AU 2 million.

11.2.7 Summary and conclusions

This ACIAR project in Myanmar found valuable information by combining bio-physical and socio-economic activities in a multi-disciplinary approach. The patterns of cereal crop responses from replicated trials on farmer fields showed likely crop yield increases that farmers could expect from applying more, or less, N fertiliser.

The farmer survey results showed that, contrary to initial expectations, some smallholder farmers in central Myanmar often practise ‘good’ fertiliser management in terms of the quantity and timing of N fertiliser applications.

The results summarised here show that there are likely to be substantial economic benefits for smallholder farmers by increasing fertiliser productivity. For the main crop in the region, monsoon rice, the shape of crop yield responses to added N indicates a relatively low economic rate compared to recommendations from the DoA and the rates used by many farmers. A relatively simple calculation shows that there may be economic benefits to local smallholder populations of up to $AU 1.2 million, depending on the extent of change. Over 4 years, a cost reduction over 10% per year of the rice production area could save $AU 2 million.

For maize, the survey results show that many farmers apply substantially less than the DoA recommendations and the indicated economic rate based on the potential yield responses to N fertiliser. Up to $AU 1 million increased farm income is indicated if a large area of maize is produced using more N fertiliser.

It apparent that the cost of the project to ACIAR ($AU 2M) could be recouped in a period of 4 years, even with the application of very conservative assumptions and estimates.

11.2.8 Further research

The response function for monsoon rice (Figure 7.5.5), if applicable to paddy rice production elsewhere, has implications for ‘sustainable intensification’ R&D strategies. A high-input high-output management strategy promoted for monsoon rice is unlikely to be successful if the yield responses to added N fertiliser are relatively low, or flat. A high-input strategy has increased risk of environmental detriments. A low N input model for monsoon rice leading to more resilient and sustainable farming systems in low-income countries is a potential area for further R&D.