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On-Farm Nutrient Balance Studies in the Dry Zone of Myanmar

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On-farm experiments to study soil fertility depletion – one of the biophysical factors limiting crop production – were conducted in six villages of central Myanmar during 1997 to 1999. Systematic socioeconomic surveys and analysis of socioeconomic and crop production factors aided the selection of farmers.

Topsoil mineral nitrogen content at the start of the cropping season was high (10–25 mg N kg^{-1}). Available phosphorous was around the threshold level for most crops, but exchangeable potassium was low. The predominant continuous cropping system of sole groundnut was on average positive for P (0.24 kg ha^{-1} y^{-1}) and K (7.05 kg ha^{-1} y^{-1}) and negative for N (−32.4 kg ha^{-1} y^{-1}). A negative balance for N in the groundnut/pigeonpea (−58 kg ha^{-1} y^{-1}) and mung bean/pigeonpea (−56 kg ha^{-1} y^{-1}) intercropping systems was noted. The nutrient balances were positive in early sesame–late sesame (29 kg N ha^{-1} y^{-1}, 8 kg P ha^{-1} y^{-1}, 33 kg K ha^{-1} y^{-1}) and early sesame/pigeonpea (8 kg N ha^{-1} y^{-1}, 15 kg P ha^{-1} y^{-1}, 44 kg K ha^{-1} y^{-1}) production systems while sole sorghum system resulted in positive balance for N (23.8 kg ha^{-1} y^{-1}) and negative balance for K (−3.8 kg ha^{-1} y^{-1}).

Keywords cropping systems, dry zone, farmers' fields, nutrient balances, nutrient mining

Introduction

The dry zone region of central Myanmar (677,000 km^2; population 11 million) is characterised by diversified agricultural production systems that are typically low in inputs (Ministry of Agriculture and Irrigation, 1997). Rainfall amount and distribution are erratic and unpredictable during the rainy season from May to November; the rest of the year is dry. Land degradation affects a considerable part of the dry zone as a result of continuous cultivation with low inputs and uncontrolled grazing (Thu Kha, 1993). The use of improved varieties and crop husbandry practices increases the demand on soil nutrient reserves. Additionally, exploitive practices, without application of nutrients from external sources, cause a further drain on soil nutrients. Pressure for immediate financial returns from investments in crop production also contributes to low fertility of soils (Hla Aye, 1990). After the removal of grain, stalks and other residues are exported from the field and often from the farm. Dung is valued as fuel, and its increased use as such decreases the nutrient return to the soil. Nevertheless, the farmers recognise the value of manure. Small amounts of farmyard manure (FYM) are applied to the land and itinerant herders are sometimes paid to herd sheep or goats on cultivated fields with high value crops.

In rural appraisals, Myanmar farmers increasingly mention soil fertility decline as a major constraint to farming. However, nutrient depletion is expected with dryland agriculture, where input of purchased fertilisers and FYM is usually low. Nutrient balance studies conducted in sub-Saharan Africa, where the weather conditions are similar to that of dry zone of Myanmar, have shown that increasing soil nutrient depletion and decreasing crop yield indicate unsustainable agriculture (Smaling *et al.*, 1993; Stoorvogel *et al.*, 1993; Van der Pol, 1992).

The yield increasing effect of mineral fertilisers has been the main nutrient management technology researched in Myanmar, and most studies are focused on nitrogen (N) dynamics and balance in lowland rice-based cropping systems. No systematic research efforts were made on how dryland crops and cropping systems affect N, P and K dynamics under rainfed conditions. In the dry zone, crops are grown using different rates of FYM and NPK fertilisers, and sown as relay (seeds sown either by dibble or drill method with proper spacing between rows or hills of the main crop during its early reproductive stage) and intercrops to avert the risk of crop failure and/or for additional farm income (Myanmar Agriculture Service, 1996; Rajan, 1978). A nutrient balance study was, therefore, designed on farmers' fields with an objective to obtain reliable information on nutrient flows (N, P and K) in dryland cropping systems of the Myanmar semi-arid tropics which will be used both by the farmers and policy makers to increase and sustain crop production in the dry zone.

Materials and Methods

Selection of experiment sites

Alfisols are the predominant soil type in the dry zone region of Myanmar, and their principal cropping systems were identified using crop statistics from provincial and district extension departments (Table 1). The groundnut-, sesame-, sorghum- and mung bean-based systems were selected because they are the most important dryland cropping systems. Subsequently, surveys were carried out to identify suitable locations that are representative of the target cropping systems. The initial survey covered demographic and agricultural information and was carried out with the support of the District Agricultural Office and the Regional Agricultural Research Station at Nyaung Oo and the Central Agricultural Research Institute at Yezin. Based on the survey data, six villages in Nyaung Oo district, Magwe province (lat 21° 22′ N, long 94° 54′ E, 63 m altitude) were selected. These were Than Sin Kye and Phyauk Seik Pin from Kone Tan Gyi village tract; Taung Ba from Taung Ba village tract; and Bone Taw, Htanaung Su and Kone Ywa from Taung Zin village tract.

The semi-arid climate of Nyaung Oo is characterised by distinct hot and dry weather from December to May and a monsoon season from May to October. The rainy season consists of first and second monsoons concentrated during 5–6 months in a bi-modal pattern (May–October), with an interruption during the month of July. The average total annual rainfall during the experimental period (1997–1999) was 563 mm. The mean of annual daily temperatures was 34.7°C maximum and 22.6°C minimum.

Farmer selection

We surveyed 109 farmers and stratified them according to farm size as small (<2 ha), medium (2–10 ha), and large (>10 ha) farmers. Within this sample, 20 farmers were chosen for this study from these villages. These sub-groups of farmers were further classified based on the crop they preferred to grow in the rainy season of 1997–1998. Farmers thus selected for each cropping system were directly proportional to the percentage of farmers who have showed preference to the cropping system in the main sample. The average proportion of each subgroup was based on an initial survey. Once a field was selected, the nutrient balances of the same field were determined in the subsequent seasons regardless of the crop.

Table 1 Area (ha) of crops in the study villages, 1996–1997

Crop	Village tract			Total (ha)
	Kone Tan Gyi	Taung Ba	Taung Zin	
Groundnut erect	46	8	130	184
Groundnut runner	264	415	5603	6282
Early sesame	248	253	833	1334
Late sesame	261	21	766	1048
Sorghum	293	89	563	945
Mung bean	184	135	192	511
Pigeonpea	31	35	264	330
Horse gram	3	2	106	111
Total (ha)	1330	958	8457	10,745

Source: Ministry of Agriculture and Irrigation, 1997

Soil sampling and analyses

Composite soil samples to a depth of 0–30 cm were collected from each field at the start of the study to determine initial nutrient status. The full profile depth was sampled in selected fields. Subsequent soil samples were collected at sowing and harvest of rainy season crops and harvest of postrainy season crops for each cropping system in all fields, to the depth of the semi-weathered stratum. The soil samples were analysed for mineral nitrogen (N) (Black *et al.*, 1965), available phosphorus (P) (Hesse, 1971) and exchangeable potassium (K) (Page *et al.*, 1982).

Crop management

The on-farm trials were managed by farmers from sowing to harvest of the crops (including nutrient management). Land preparation, sowing, harrowing and intercultivation operations were done with bullock-drawn implements, while insecticide spraying and crop harvesting was done manually. Sesame (*Sesamum indicum*), groundnut (*Arachis hypogaea* L.) and mung bean (*Vigna radiata*) were sown in rows spaced at 45–50 cm with two plants per hill and 10–15 cm between the hills. Pigeonpea (*Cajanus cajan*) was intercropped either with sesame (one pigeonpea: four sesame rows) or groundnut (one pigeonpea: 10 groundnut rows) and sorghum (*Sorghum bicolor*) was grown as a fodder crop.

Nutrient balance

The nutrient balance for N, P and K was estimated for the cropping systems grown during 1997 to 1999. Although five inputs (mineral fertilisers, organic manure, atmospheric deposition, biological N fixation, sedimentation) and five outputs (harvested products, residue removal, leaching, gaseous losses, water erosion) for plant nutrients were conceptualised as ideal for a nutrient balance study, not all, particularly in an on-farm study, can be easily measured. An index, consisting only of nutrient flows that can be easily determined would have more practical meaning. Observations therefore, were confined to nutrient flows (mineral and organic fertilisers, and harvested crops and residues leaving the farm) that are managed directly by the farmer. The flows are strongly human influenced and directly reflect the farm household's allocation of capital and labour as well as income generation and food security strategies.

Plot-specific input data from individual farmers were collected during the three cropping seasons at the beginning and at harvest of the rainy and post-rainy season crops. This was done with a specific reference to the identification number of the plot, extent of land, quantities of FYM, goat penning, organic cake, tank silt, ash and mineral fertilisers applied. Outputs were obtained through the harvest of crop samples in terms of grain and stover, and were related to yields obtained by the individual farmer. Samples of organic manures and plants were analysed for N, P and K contents. In the case of inorganic fertilisers, the fertiliser type used by the farmer was identified and the contents of N, P and K in the fertilisers used were calculated based on manufacturers' grading.

Nutrient removal by crop was determined through crop sampling. Four subsamples per field were taken, each consisting of at least four rows of one-meter length. All the crops were sampled and the whole plant biomass was weighed in the field, subsampled and oven-dried. Total biomass dry weight and grain yields were determined. In some cases, it was not possible to obtain yield data, because farmers had already harvested the crop. In these cases, farmers supplied the yield information and a sample of the plant material for analysis. Grain and vegetative parts were analysed separately for total N, P and K (Chapman & Pratt, 1982). Since farmers changed their plans according to the prevailing weather, and abiotic and biotic conditions during the experimentation period, the number of harvested fields is not always identical with the number of fields and crops selected.

Results

Soil nutrient status

Mineral nitrogen

The mineral N content before the onset of the rainy season during all the three years (1997–1999) was unexpectedly high. The topsoil (15 cm) $NH_4^+ + NO_3^-$ N content in the majority of fields during 1997 and 1998 was 10–25 mg N kg^{-1} while in 1999 it was in the range of 25–40 mg N kg^{-1} (Figure 1). This is in accordance with the hypothesis that a greater proportion of legumes in the cropping system

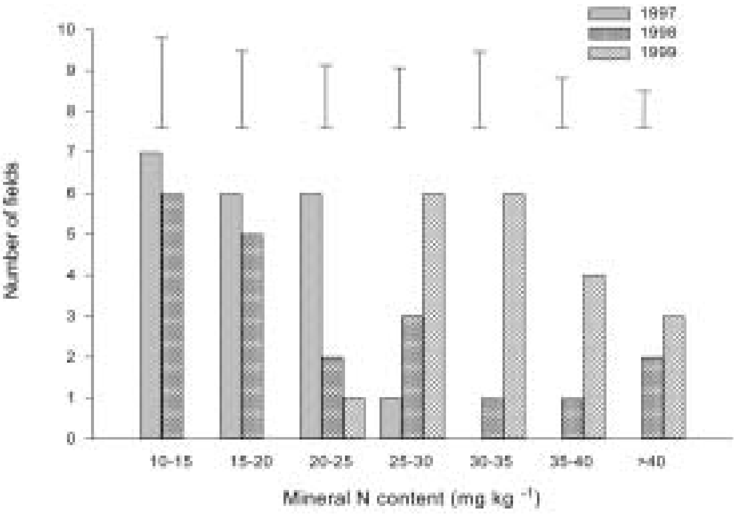

Figure 1 Mineral N content at the start of the crop season in the topsoil (0–15 cm) during three years (1997–1999)

might lead to higher mineral N contents in the topsoil. However, mineral N content in the topsoil says little about soil N supply to the plant.

Available phosphorus

The greater part of the fields (about 90%) had available phosphorous (Olsen-P) <10 mg P kg^{-1} in the topsoil, which is the threshold value for most crops (Figure 2). In 1997, most fields had a P content of 5–10 mg P kg^{-1} while the majority of fields in the remaining two years had a lower P content (0–2.5 mg P kg^{-1}). A high P content (>10 mg P kg^{-1}) was found in one field each in 1997 and, 998 and in five fields during 1999.

Exchangeable potassium

Except for one field in 1997, all the fields in the study location had a low exchangeable K content (<50 mg K kg^{-1}) during the entire period of the study. The majority of fields in 1997 (56%) and 1999 (88%) had an exchangeable K content in the range of 10–20 mg K kg^{-1}, while in 1998 the range was 20–30 mg K kg^{-1} (Figure 3).

Nutrient input

The nutrient input ($N+P+K$) was in the range of 0–310 kg ha^{-1} y^{-1} and came mostly from organic manures, owing to either

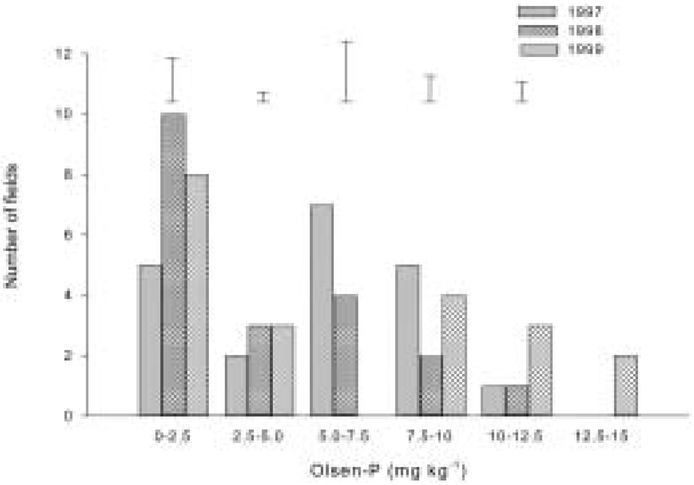

Figure 2 Available P (Olsen-P) content at the start of the crop season in the topsoil (0–15 cm) during three years (1997–1999)

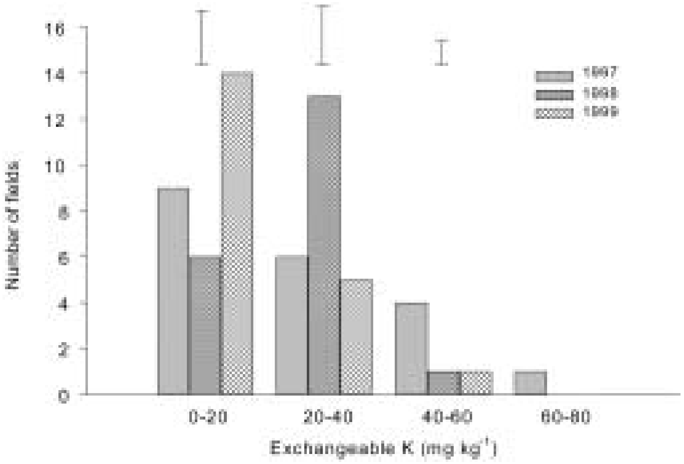

Figure 3 Exchangeable potassium content at the start of the crop season in the topsoil (0–15 cm) during three years (1997–1999)

unavailability or the high cost of inorganic fertilisers. The most widely used organic nutrient sources were FYM, tank silt, ash and goat dung. The size of landholdings appears to have a significant influence on nutrient inputs. The nutrient input was in the range of 144–342 kg ha^{-1} in small, 77–498 kg ha^{-1} in medium, and 96–141 kg ha^{-1} in large landholdings, respectively (Figure 4). This is contrary to the belief that small and medium landholdings receive lower quantities compared with large landholdings. Another striking feature was farm level variation in the N, P and K content and quantity of FYM applied to various crops (data not shown). Cash crops such as sesame and groundnut receive higher levels of nutrient input regardless of farm size. Higher variation in nutrient input used among the medium size landholding was due to large size of the group.

Crop performance

Among 20 selected farmers, 13 farmers in 1997, 14 farmers in 1998 and 16 farmers in 1999 cultivated groundnut, and the mean pod yields were 650 kg ha^{-1}, 1055 kg ha^{-1} and 635 kg ha^{-1}, respectively (Table 2). The range in the pod yields was 520–865 kg ha^{-1} in the first year, 580–1345 kg ha^{-1} in the second year and 520–1010 kg ha^{-1} in third year. Five farmers grew early sesame and only three of them grew late sesame after the harvest of early sesame in the first year and the mean yields were 455 kg ha^{-1} and 480 kg ha^{-1}. However, during the second year, both early and late sesame failed because of drought. In the third year only two farmers grew early sesame. Pigeonpea was grown as an intercrop with groundnut, sesame and mung bean, and the mean yields were

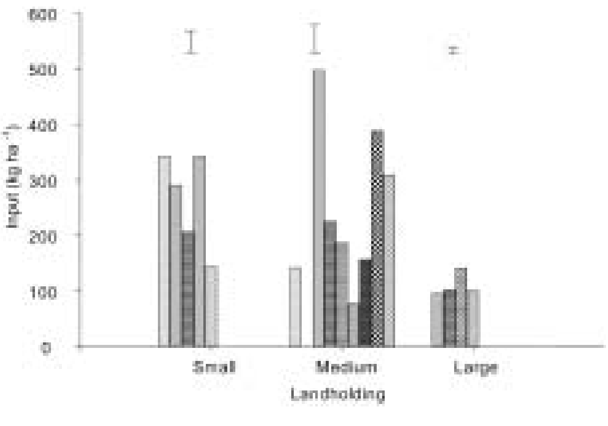

Figure 4 Influence of landholding size on input in the selected fields for nutrient balance study

Table 2 Average yields (kg ha^{-1}) of various crops. SE is the standard error of the mean and n is the number of experiments

Crop	1997–1998			1998–1999			1999–2000		
	n	Yield	SE	n	Yield	SE	n	Yield	SE
Groundnut	13	651	112	14	1055	232	16	634	113
Pigeonpea	3	272	38	5	236	136	1	630	
Mung bean	2	303	62	3	380	50	—	—	—
Sesame (early)	5	455	54	—	—		2	539	103
Sesame (late)	3	480	46	—	—	—	—	—	—
Sorghum	1	250	—	—	—	—	—	—	—

270 kg ha^{-1} during the first year and 240 kg ha^{-1} in the second year. Only one farmer grew sesame in the third year and the yield was 630 kg ha^{-1}. Two farmers grew mung bean in the first year and three farmers in the second year with the average yields of 305 kg ha^{-1} and 380 kg ha^{-1}. Only one farmer grew sorghum in each year.

Plant nutrient uptake

The nutrient uptake by various crops is shown in Table 3a and b. The groundnut/pigeonpea cropping system had the highest N uptake followed by the mung bean/pigeonpea system. This was mainly because of higher biomass production and high N content of legumes. Of the crops that rely only on applied or soil nitrogen, sesame turned out to be the major nutrient remover. Phosphorus uptake was highest in the groundnut/pigeonpea system followed by mung bean/pigeonpea intercropping and sesame sole cropping systems. Groundnut/pigeonpea and mung bean/pigeonpea systems also had the highest K uptake. However, among the crops, sesame had the highest K uptake followed by pigeonpea and mung bean.

Nutrient input/output in different cropping systems

We have estimated nutrient balances in the main cropping systems based on the flows that are managed directly by the farmer, i.e. mineral and organic fertilisers, and harvested crops and residues leaving the farm (Figure 5). The sole groundnut cropping system is dominant and

Table 3a Average nutrient concentration (g 100^{-1}) in crops at harvest. Mean of three years. SE is the standard error of the mean

Crop	Generative parts						Vegetative parts					
	N	SE	P	SE	K	SE	N	SE	P	SE	K	SE
Pigeonpea	4.25	0.11	0.48	0.05	0.81	0.07	1.68	0.09	0.21	0.02	0.6	0.06
Mung bean	4.27	0.09	0.45	0.04	0.74	0.13	0.87	0.08	0.14	0.01	0.4	0.09
Sesame	3.68	0.04	0.68	0.01	0.89	0.01	0.85	0.08	0.41	0.03	0.6	0.05
Sorghum	1.15	—	0.35	—	0.38	—	0.52	—	0.09	—	0.4	—

Table 3b Average nutrient concentration (g 100^{-1}) in groundnut stalk, shell and kernel. SE is the standard error of the mean

Plant part	N	SE	P	SE	K	SE
Stalk	1.87	0.22	0.25	0.05	0.36	0.098
Shell	1.1	0.18	0.23	0.07	0.34	0.07
Kernel	4.38	0.84	0.38	0.09	0.30	0.11

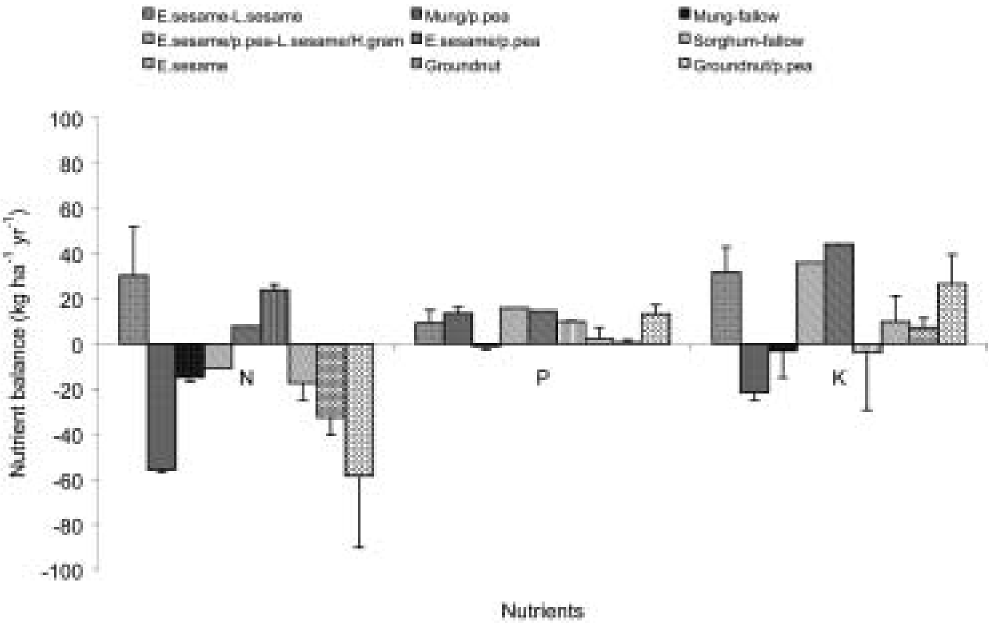

Figure 5 Nutrient balance (kg ha^{-1} y^{-1}) in major cropping systems

was, on average positive for P (0.24 kg ha^{-1} y^{-1}) and K (7.05 kg ha^{-1} y^{-1}) and negative for N (−32.4 kg ha^{-1} y^{-1}). The atmospheric N fixed by the legumes (BNF) was not estimated in this study. Even if we assume 50% of groundnut N uptake is from the atmosphere, yet the balance will be negative (−3.95 kg ha^{-1}). Positive P (37 kg ha^{-1}) and negative N (−111 kg ha^{-1}) and negative K (−20 kg ha^{-1}) nutrient balances were also reported by Rego *et al.* (2002), when biological nitrogen fixation was not included and −26 kg N ha^{-1} when BNF was included, in a recent study on a continuous groundnut cropping system on extremely shallow soils with low water holding capacity in Anantapur district of Andhra Pradesh, India, representing more or less similar features to semi-arid region of Myanmar, therefore can be very well related. However, the largest offtake of nutrients was found in the groundnut/pigeonpea (−58 kg N ha^{-1} y^{-1}) and mung bean/pigeonpea (−56 kg N ha^{-1} y^{-1}) intercropping systems followed by mung bean–fallow system (−14.4 kg N ha^{-1} y^{-1}). On the contrary, favorable nutrient balances were estimated in the early sesame–late sesame (29 kg N ha^{-1} y^{-1}, 8 kg P ha^{-1} y^{-1}, 33 kg K ha^{-1} y^{-1}) and early sesame/pigeonpea (8 kg N ha^{-1} y^{-1}, 15 kg P ha^{-1} y^{-1}, 44 kg K ha^{-1} y^{-1}) cropping systems.

The fallow–sorghum system resulted in positive balance for N (23.8 kg ha^{-1} y^{-1}) and negative balance for K (−3.8 kg ha^{-1} y^{-1}) while early sesame/pigeonpea–late sesame system showed negative balance for N (−10 kg ha^{-1} y^{-1}) and positive balance for P (15.9 kg ha^{-1} y^{-1}) and K (36 kg ha^{-1} y^{-1}). The early sesame–fallow system resulted in negative balance (−17.43 kg N ha^{-1} y^{-1}, −2.54 kg P ha^{-1} y^{-1}, −4.18 kg K ha^{-1} y^{-1}).

We also observed that nutrient balances are not related to net farm income. Another striking feature is that small and medium landholdings received substantial amounts of nutrients from animal manure and tank silt compared to large farms, as resource poor farmers' interest lies more on food security at subsistence levels rather than in bumper harvests and high income earnings.

Discussion

Crop performance

The six villages selected for this study represent the drier region of semi-arid central Myanmar – a region endowed with less and erratic rainfall, and sandy, often-shallow soils. The large differences in rainfall, particularly the distribution (Figure 6) between and within the seasons influenced crop performance and yields. The rainfall received during the first and the second year was 372 mm and 489 mm, which was below the long-term average of the

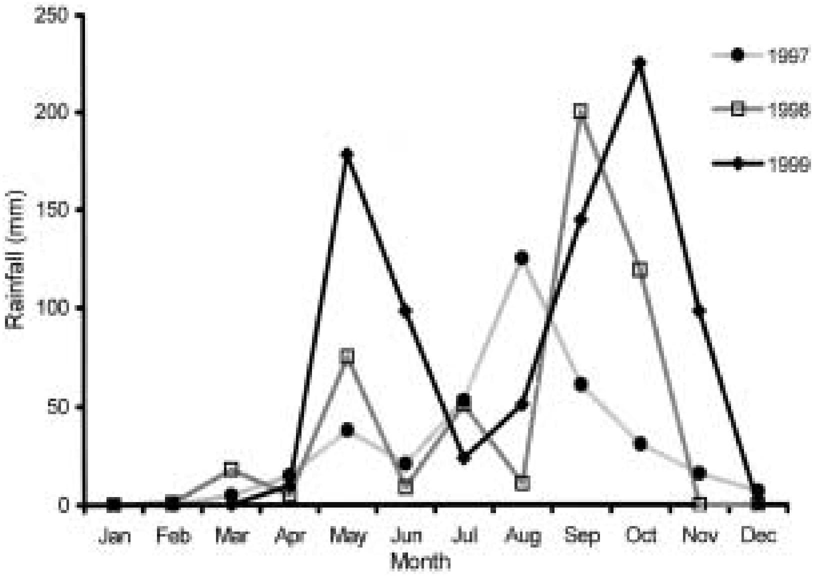

Figure 6 Rainfall distribution in the study area. (Source: Dryland Research Station, Nyaung Oo)

region (600 mm). In addition to the low amount of rainfall, the distribution was also not conducive for good crop growth. During the third year, although the total rain received (828 mm) was above the mean annual rainfall, one quarter of the rainfall occurred before the normal cropping season, whereas half of the remainder was received at the end of the growing season, thus rendering little help to good crop growth and economic yields. The vegetative and early reproductive stages of the crops experienced drought in all the three years which resulted in low biomass as well as economic yields.

Yield differences in groundnut between the sample villages and years were relatively small indicating greater yield stability over other crops. This could be the reason for the steady increase in the number of fields planted to groundnut during the study period. For example, the sesame crop completely failed during the second year and farmers could not plant late sesame during the third year. Nevertheless, yield differences between individual fields were still high. This variation in production among the farmers is mainly because of input variation and management practices.

Pigeonpea had excellent vegetative growth in all the three years because of its deep rooting ability and drought tolerance traits. However, poor grain yields were realised because of the low yield potential of the landrace, severe pod borer infestation, and inadequate pest control measures adopted by the farmers because of lack of cash and unavailability of effective insecticides. Mung bean performed reasonably well because of its short maturity and appears to be economically viable. Even though mung bean appeared to be a better choice over sesame, farmers were reluctant to increase the area under mung bean cultivation owing to non-synchronous maturity and pod shattering characteristics of the current varieties that demand high labour.

Low levels of productivity and high instability of production owing to low and erratic rainfall and poor soil fertility are the two important constraints in the dry zone. As a result of not being exposed to modern methods of agricultural technology, productivities (seed yield per unit area) have tended to remain low at sustenance levels. Cultural practices were more intensive to tolerate stresses such as drought and pests with reference to inputs such as seeds of improved varieties, fertilisation and plant protection, rather than the practices being more input intensive.

Nutrient balance

The study comprised a cross section of farmers and focused on determination of nutrient balances that result because of crops and farmer-oriented nutrient management practices based on their perceptions and resources available. Our study encompasses cropping systems as a superset, intersecting several farms as subsets within an agro-ecological zone unlike Brouwer and Powell (1998) who studied nutrient flows within the plot and Van den Bosch *et al.* (1998) in a farming system. Harris (1998) adapted the farming systems approach to estimate nutrient balances, but restricted the measurements to inputs and outputs to those that farmers see and manipulate. Not all inputs and outputs, particularly in on-farm research, can be easily and reliably measured, and it is all the more difficult in low-data environments like Myanmar. We, therefore, followed Harris methodology and restricted measurements of inputs and outputs that are strongly human influenced and directly reflect the farm households' allocation of capital and labour as well as income generation and food security strategies. Nutrient balances were restricted to main cropping systems and to major nutrients. The entire study was conducted on dryland cropping systems. We feel that upscaling of this information will be useful and relevant to farmers in the dry zone of Myanmar. Our methodology could also be used for integration of data at the agro-ecological region (AER), and upscaling of all AERs to the national scale and should provide more authentic information on nutrient balance than the methodologies adapted by Brouwer and Powell (1998).

The major nutrients (N, P and K) were estimated individually for their balance in each cropping system to generate information to be of more use to farmers and aid in managing soil nutrition effectively. N losses owing to leaching were not studied, although these are considered to be high in Alfisols. Van den Bosch *et al.* (1998) speculated that leaching losses of 0–22% was a reasonable range for inorganic fertilisers, although losses depend on factors such as time and mode of application in relation to rainfall in Africa.

The high mineral N content in the topsoil (25–40 mg N kg^{-1}) in the later years of the study could be attributed to the increased proportion of legumes in the rotation. This was not considered as an important input into the system for two reasons. Firstly, mineral N is exposed to leaching losses beyond the root zone within 30 days of the onset of rainy season (Vlek & Vielhauer, 1994). Secondly, crops such as runner groundnut and medium duration pigeonpea used in this study are initially slow growing and are unlikely to utilise the mineral N available at the time of sowing. Erosion losses are also higher in this environment because of poor soil structure and high intensity of rains, but the number of runoff events is generally small. However, we assume that the effect of erosion on P and K balances may be higher based on the movement of surface soil. As there is no information on these losses, it is difficult to estimate the extent of nutrient loss through soil erosion. Farmers applied FYM on bare soil before the onset of monsoon when the temperatures are generally higher, there by inducing higher losses of N by volatilisation.

The negative balance for N observed in sole groundnut, groundnut/pigeonpea and mung bean/pigeonpea cropping systems could be attributed to less N-fixation compared to greater removal by harvested biomass in legumes. Rego *et al.* (2002) estimated N_2 fixation by pigeonpea at 19.4 kg N ha^{-1} and the removal by harvested biomass as 41 kg N ha^{-1}, resulting in a net negative N balance (-21 kg N ha^{-1}). Wani *et al.* (1994) recalculated the net N balance from the data of Peoples and Crasswell (1992) assuming that legume crop residues are generally removed from the system and concluded that different maturity groups of pigeonpea mine soil N in a range of 20–49 kg N ha^{-1}, besides fixed N. On the contrary, positive nutrient balances in early sesame–late sesame sequential cropping, sesame–pigeonpea intercropping and sole sorghum systems can be attributed to differences in nutrient stocks and flows. For instance, sole groundnut cropping system received least organic input (4 t ha^{-1}) while all the remaining cropping systems received about 10–12 t ha^{-1}. The early sesame–late sesame cropping system received highest nutrient inputs (16 t ha^{-1}). The amount of manure reaching various crops and cropping systems largely determined differences in nutrient stocks and flows (Mohammad Saleem, 1998; Van den Bosch *et al.*, 1998). Phosphorus and potassium inputs met the crop requirements in most of the cropping systems studied.

The large farm holders applied smaller amount of nutrient inputs per unit area to the test crops, because the amount available at their farm was spread thinly across all the fields. On the other hand, the small and medium landholders applied more nutrients per unit area through organics available at their farm itself, because of their sole dependence on the farm produce. This is contrary to the belief that small and medium landholdings receive lower quantities compared with large landholdings. Another striking feature was farm level variation in the quality and quantity of applied FYM to various crops. Input through manure derived from common lands, where animals graze during the daytime, is the major source of nutrient particularly in small and medium landholdings. All the farmers applied very small quantities of inorganic fertilisers because they were expensive and wanted to avoid risk.

Nutrient stocks of individual plots within farms and village territories also differed considerably. Reasons range from differences in soil texture, land use, fallow history to microclimatic differences. Small farmers exploited the micro variability very well, because for each weather condition there are pieces of land where crops perform well (Brouwer *et al.*, 1993).

It became quite clear from this study that resource-poor farmers with small and marginal landholdings place more emphasis on soil fertility, compared with their resource-rich counterparts, since their goal is to maintain reasonable soil productivity (within their means) for increased food security. Off-farm income is an important source for nutrient inputs by small farmers. In large holdings, cash and food crop plots were treated quite differently as regards to nutrient flows. Cash crops such as sesame and groundnut received more nutrient inputs by the large farmers. A negative balance does not necessarily mean that crop production will further decline because soils may have a large buffering stock of nutrients, sufficient to keep production going for many years (Smaling *et al.*, 1996).

Conclusions

Our study provides guidance to the dryland farmers in managing soil and plant nutrition efficiently as we have calculated all the three major nutrients individually for their balance in soil–plant system of a crop rotation. In addition, this study provides factual information on nutrient balances specifically for different dryland cropping systems on farmers' fields, hither to unavailable in Myanmar and can be scaled-up for the entire dryzone region. Since nutrient balance is mainly drawn from mineral and organic fertilisers, and harvested crops and residues leave the farm, a negative balance should provide a warning for the unsustainability of the farming practice. Therefore, it is advisable to apply sufficient amounts of nutrients (both organic and inorganic) and recycling of crop residues. Farmyard manure (FYM) is the major source of applied N, therefore appropriate mechanisms to reduce N losses at the stages of manure production and application in fields need to be investigated to achieve nutrient balances with lesser costs. As most fields have low exchangeable K, efforts to apply sufficient quantities of K along with N and P are recommended either through FYM or fertiliser inputs to reduce nutrient mining and sustaining crop productivity on already degraded lands of Myanmar's dryzone. Positive nutrient balances in non-legume based cropping systems shall be attributed to farmers' preference for nutrient application to non-legume crops. Land-use planning approaches aimed at integrated nutrient management, perceived here, as the best combination of available nutrient management technologies, i.e. those that suit local biophysical conditions and are economically attractive and socially relevant should be encouraged to maintain soil fertility and sustain good crop productivity.

As the results of this study have amply indicated that most farmers in the dryzone of Myanmar prefer nutrient application to non-leguminous crops, does this encourage negative nutrient balance in legume systems? Does negative balance of P and K lead to poor BNF, and therefore, negative N balance? Does negative P and K balance have consequences because of need to import the nutrients? These are some of the key issues that emerged out of this study and appear to have implications not only in Myanmar, but also elsewhere in the region warranting further research. Inoculation of appropriate rhizobium strains for efficient BNF, measuring biological N fixation by natural abundance method and measuring N losses precisely, with different cropping systems in farmers' fields by applying isotope ^{15}N would help in understanding N dynamics in this environment more precisely. Development of databases on nutrient balances on various crops within the cropping systems on a regional scale would act as a guide to policy makers in taking appropriate measures in terms of crop intensification, diversification and nutrient management strategies including import of large-scale inputs *vis-à-vis* foreign exchange constraints for developing countries like Myanmar.

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