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EVALUATION OF ON-FARM SOIL FERTILITY RESEARCH IN THE RAINFED LOWLAND RICE FIELDS OF SUKUMALAND, TANZANIA

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SUMMARY

The first ever on-farm soil fertility research in the rainfed lowland rice (*Oryza sativa*) fields of Sukumaland, in northwest Tanzania, was carried out between 1990 and 1996 in response to farmers' complaints about declining rice yields. From diagnosis to extension, the research approach followed that of the International Maize and Wheat Improvement Center (CIMMYT). In 1990/91, rice yields in the Maswa district increased sharply when nitrogen at a rate of 30 kg ha^{-1} in the form of urea was broadcast in flooded rice fields at tillering. Similar research was subsequently conducted in other parts of Sukumaland to evaluate this type of low-dose nitrogen application under varying circumstances. In 1995/96, higher doses of nitrogen (60 and 120 kg ha^{-1}) and a high dose of phosphorus (17.5 kg ha^{-1}) were applied for comparison in Sengerema district. Between 1990 and 1996, the average increase in rice yield from the application of 30 kg N ha^{-1} varied between 463 and 986 kg ha^{-1}. In 1995/96, the same application of N was more economical than both 60 and 120 kg N ha^{-1}, and no phosphorus deficiency was found. The deteriorating ratio between the price of rice at the farm gate and that of urea, however, threatens the adoption of this technology by farmers. Adaptability analysis showed that the relatively small differences in response per field (environment) in all years did not justify a need for multiple different extension messages. Until more detailed recommendations can be made, therefore, a single dose of 30 kg N ha^{-1}, in the form of urea, applied to rice at tillering is recommended for the whole of Sukumaland to reverse the decline in yields. Further on-farm research should concentrate on improving the efficiency of nitrogen fertilization and on determining the optimum rates of other major nutrients to refine this initial recommendation.

INTRODUCTION

In the Mwanza and Shinyanga regions of northwest Tanzania (Figure 1), also known as Sukumaland, rice (*Oryza sativa*) has become a major food and cash crop in the past 25 years. This has been due to both population growth and the profitability of rice cultivation in comparison with other crops. That population growth has reduced the average farm size in many parts of the Mwanza region, and rice is able to produce high amounts of calories on small areas of land, has increased its popularity. In addition,

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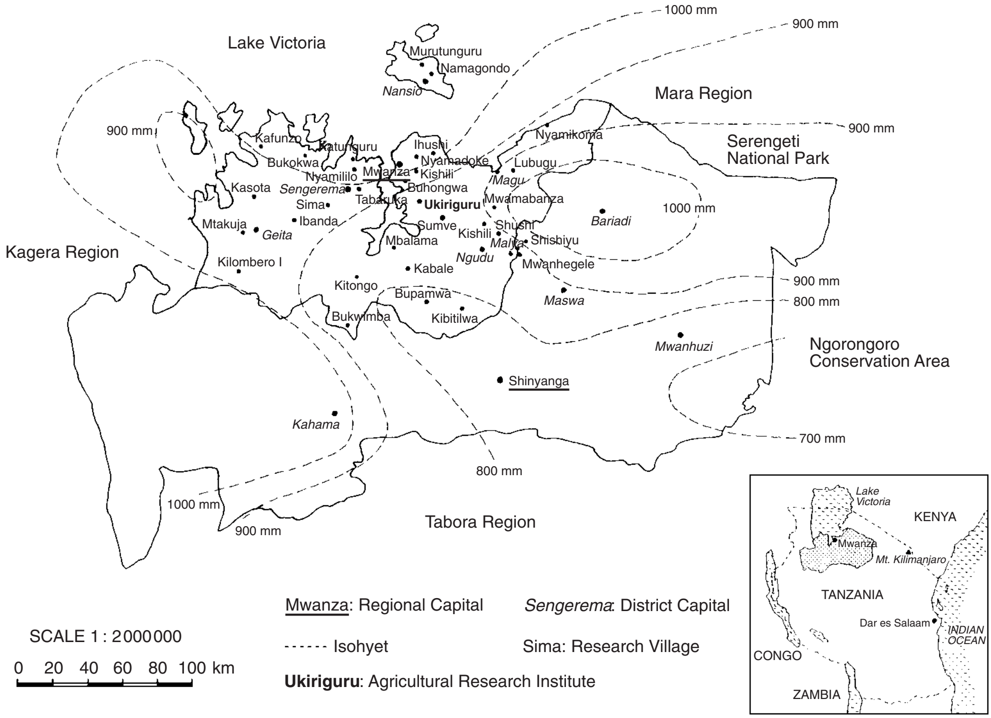

Figure 1. Location of villages from 1990–1996 on-farm rice-fertilizer research in Sukumaland, Tanzania.

government control during the 1970s and 1980s caused a general decline in the producer price of cotton, the major cash crop in Sukumaland. The producer price of rice, however, remained favourable during this period due to good, open markets for rice in the fast-growing town of Mwanza and in neighbouring Kenya, Uganda, Rwanda and Burundi. As a result, by the end of the 1980s many farmers in the areas of Sukumaland with more than 800 mm average annual rainfall and soils (hardpan and/or heavy clay soils) favourable for rainfed lowland rice had switched from cotton to rice (Meertens *et al.*, 1995).

In 1989, the Farming Systems Research (FSR) Project Lake Zone conducted a rapid rural appraisal covering 12 villages in the Maswa and Meatu districts of the Shinyanga region. This survey showed that rainfed lowland rice dominated the farming systems in the western part of Maswa district. Group discussions with farmers from villages in this part of Maswa district revealed that weeding was generally regarded as the main constraint in rice cultivation. Farmers also mentioned that they experienced decreasing yields in their rice fields. They had been growing rice almost continuously on the same fields for the past 20–30 years with very little use of farmyard manure or mineral fertilizers (Enserink *et al.*, 1994). This led to the hypothesis that the decrease in yields was perhaps caused by a decrease in soil fertility. Observations of yellow rice plants during the rapid rural appraisal were also interpreted as indications of mineral deficiencies. To optimise the chance of success, possible solutions to the weeding and soil fertility problems in rice were evaluated according to several criteria mentioned by Tripp and Woolley (1989). Simple cost-benefit calculations showed that the use of locally available herbicides could hardly be profitable. The ratio between fertilizer prices and rice farmgate prices was, however, more promising. It was decided to conduct a diagnostic on-farm trial in western Maswa district to test if the use of farmyard manure and mineral fertilizers could significantly, and profitably, increase rice yields. Farmyard manure was included because about half of the households own cattle in this area (Meertens *et al.*, 1995).

The cultivation of rainfed lowland rice in Sukumaland is based on trapping runoff and seepage water in the lower parts of gently undulating slopes through the construction of small bunds around the rice fields (Meertens *et al.*, 1999). In western Maswa district, rice field sizes range from 0.02 to 0.6 ha with an average of 0.12 ha. The soils in the valleys are mainly: (i) imperfectly drained, shallow sandy clays with hardpan within 0.5 m of the surface, which are often calcareous and often sodic in the subsoil (Solodic Planosols); or (ii) moderately deep and often imperfectly drained, usually calcareous, dark grey, cracking clays (Pellic Vertisols). The former have moderate natural fertility and the latter have good natural fertility (De Pauw, 1984). Such types of soils usually contain adequate quantities of potassium (K) (Grist, 1975). The diagnostic trial (1989/90), therefore, was aimed at identifying possible deficiencies in nitrogen (N) and/or phosphorus (P). Treatments were: (i) 30 kg N ha^{-1} at tillering in the form of urea; (ii) 8.7 kg P ha^{-1} at planting in the form of triple superphosphate (TSP); (iii) the combination of 30 kg N ha^{-1} at tillering and 8.7 kg P ha^{-1} at planting; (iv) 5 t ha^{-1} farmyard manure prior to land preparation; and, (v) as a control, the farmers' practice of no added organic or inorganic fertilizers. The results showed that N alone increased rice paddy yields far more (+740 kg ha^{-1}) than did P alone (+124 kg ha^{-1}), and the application of farmyard manure (+192 kg ha^{-1}). The open-kraal farmyard manure increased the number of weeds in the fields and this diminished the positive effect it had on soil fertility. The N-only treatment was also much more economical than all other treatments (Enserink *et al.*, 1994).

On the basis of the results from this diagnostic on-farm trial, it was decided to continue only with the application of a low dose of N in the form of urea. An on-farm verification test conducted during 1990/91 showed that the application of urea proved to be profitable under a range of circumstances. This prompted the FSR Project Lake Zone to convey this technology to a wider audience (Enserink *et al.*, 1994). Pre-extension campaigns followed in the next two seasons, and the Kilimo/FAO Plant Nutrition Programme conducted an extension campaign during 1994/95 in the Mwanza region. A N-level on-farm trial was finally executed in the Mwanza region during 1995/96 to investigate if levels other than 30 kg N ha^{-1} were more economical. One treatment also contained a high dose of P to detect any P deficiencies in this part of Sukumaland.

This paper presents, in an integrated way, the results from all tests, trials and demonstrations that followed the diagnostic on-farm trial. It provides an example of evaluating, from diagnosis to extension, on-farm soil fertility research in rainfed lowland rice.

MATERIALS AND METHODS

Experiment area

The Mwanza and Shinyanga regions of Sukumaland border on Lake Victoria to the north, the Kagera region to the west, the Tabora region to the south, and the Ngorongoro Conservation Area and Serengeti National Park to the east (Figure 1).

Average annual rainfall ranges between 700 and 1000 mm. The rainy season starts around mid-October and ends around mid-May. The pattern is bimodal, with peaks in November/December and March/April. Rain showers are often very localized and unpredictable. Dry spells are common throughout the rainy season, but are most pronounced during January. Potential evapotranspiration rates of 4.5 mm d^{-1} occur during the rainy season (ICRA, 1991).

The landscape in the Mwanza region is dominated both by broad and narrow valleys separated by rocky hills that consist mainly of granitic and, sometimes, gneissic rocks. In the Shinyanga region, the landscape is characterized by vast fluvial and lacustrine plains with sediments derived from the same type of rocks (Meertens *et al.*, 1995). Rice cultivation is more important in areas with gently undulating slopes, where there is a high proportion of sandy clays with shallow hardpan soils (Solodic Planosols) within the catena (Meertens *et al.*, 1999). On the basis of criteria documented by Garrity *et al.* (1986), the rainfed lowland rice system in Sukumaland can be classified as drought-prone with a short rice-growing season and relatively fertile soils.

Figure 1 shows the location of the village areas where the on-farm evaluations were done. The 1990/91 on-farm verification test and the 1991/92 pre-extension campaign were conducted in the same two villages as was the diagnostic on-farm trial, namely Mwanhegele and Shishiyu, which lie between the towns of Ngudu and Maswa. The 1992/93 pre-extension campaign was conducted in Malya and Kishili villages, to the east and north of Ngudu respectively. During 1994/95, the extension campaign in the Mwanza region was carried out in 26 villages spread over the entire region. The 1995/96 N-level on-farm trial was replicated over Katunguru, Sima and Tabaruka, three villages near the town of Sengerema in the Mwanza region.

Treatments

The on-farm activities from 1990/91 to 1994/95 had two treatments; N application at the rate of 30 kg ha^{-1} in the form of urea (46 % N) and the farmers' practice, equivalent to 0 kg N ha^{-1}. The 1995/96 N-level on-farm trial had five treatments: the farmers' practice as control (zero application); 30 kg N ha^{-1}; 60 kg N ha^{-1}; 60 kg N ha^{-1} +17.5 kg P ha^{-1}; and 120 kg N ha^{-1}. All applied N was in the form of urea, and P in the form of TSP (20 % P).

In most situations, ammonium-containing (e.g. ammonium sulphate) or ammonium-producing (e.g. urea) fertilizers applied to flooded rice are similar in effectiveness. Urea, however, has the highest content of N and this reduces the cost of transport and, eventually, the price of N kg^{-1}. That is why urea became the principal N fertilizer for rice in tropical Asia (De Datta, 1981). In Sukumaland also, urea turned out to be the cheapest source of fertilizer N (Enserink *et al.*, 1994). To take account of the cash constraints in most households, a dose of 30 kg N ha^{-1} was chosen, though 40 kg N ha^{-1} is recommended for the Mwanza and Shinyanga regions (Samki and Harrop, 1984). In the Maswa district, levels of 30–40 kg N ha^{-1} are appropriate for tall, leafy Indica cultivars such as Tondogoso, Lugata and Faya. Higher levels usually result in more lodging and excessive straw growth (Grist, 1975). The most important cultivars in the Mwanza region, however, are short Indica cultivars such as Super, Rangi mbili and Sindano. Therefore, the 1995/96 N-level, on-farm trial included rates of 60 and 120 kg N ha^{-1} to see if amounts higher than 30 kg ha^{-1} were more appropriate for these cultivars that have a lower susceptibility to lodging.

Every 30 kg N ha^{-1} treatment was applied as a single dose of urea broadcast on the flooded rice fields at tillering. The common method in Asia is to broadcast urea directly into the floodwater at two to four weeks after transplanting (De Datta, 1987). Most cultivars in Sukumaland have a medium growth duration (145 days) and such cultivars use low doses of N fertilizer most efficiently during maximum tillering and the flowering stage (De Datta, 1981). The higher levels of N (60 and 120 kg ha^{-1}) during 1995/96 were applied to flooded rice fields in split applications of equal amounts, one at tillering and one at booting. The P was applied at transplanting by broadcasting the TSP prior to puddling.

Sites description and experiment design

Verification test (1990/91). The authors selected two rice-growing valleys in both Mwanhegele and Shishiyu districts. Six fields were selected in each valley at, as near as possible, regular intervals down the slopes. In one valley, farmers failed to plant rice on two fields due to drought. One extra field was added in another valley. Thus, urea was applied in central strips of about 8 × 15 m along the slopes, to a total of 23 fields. Small, temporary ridges were constructed across the fields to prevent urea from moving with water from the strips. At harvest, three crop cuts of 3 × 3 m were obtained from the fertilized and non-fertilized areas of each field. These were taken from upper, middle and lower parts of the fields to cover non-experimental variations along the slope. Crop cuts were paired to reduce the variation, between treatments, in variables other than fertilizer application. From each field, a composite soil sample was taken shortly after the harvest. Table 1 shows that there was little difference between the soil analysis results and data on similar soils from other parts of the Maswa district. The relatively wide ranges of the analytical data reflect the considerable differences in soil characteristics along the slopes. Generally, the rice soils in the Maswa district have, according to criteria mentioned in Ngailo *et al.* (1994), a low amount of moderate-quality organic matter, a very low amount of total N, a low amount of available P and a medium amount of exchangeable K.

The 1991/92 pre-extension campaign. Sixty fields were selected in Mwanhegele and Shishiyu at various positions along the slopes. Ultimately, though, urea was applied to only 30 fields because drought prevented farmers from planting rice in the other fields. Urea was applied to one half of each field along the slope and a small ridge

Table 1. Analytical data from composite soil samples in rice valleys of the Maswa District.

	Samples from 1990/91 verification test†		Samples from 1991 Soil Survey‡	
	Average	Range	Average	Range
Sand (%)	59.9	39–84	–	–
Silt (%)	10.9	5–15	–	–
Clay (%)	29.2	11–49	–	–
pH-H_2O	6.8	5.6–8.1	7.1	5.6–8.4
Organic C ($g\,kg^{-1}$)	12.4	3.2–19.5	10.0	3.0–19.0
Total N ($g\,kg^{-1}$)	0.9	0.4–2.1	0.7	0.3–1.4
C/N	14	5–25	14	10–18
P-Bray ($mg\,kg^{-1}$)	2.9 (17 sites)	0.7–12.0	6.3 (4 sites)	2.0–10.0
P-Olsen ($mg\,kg^{-1}$)	3.0 (6 sites)	1.0–5.0	3.1 (7 sites)	1.0–5.0
CEC ($cmol_c\,kg^{-1}$)	18.5	5.4–32.0	16.9	1.3–51.4
Na ($cmol_c\,kg^{-1}$)	0.76	0.23–1.65	0.64	0.12–1.51
K ($cmol_c\,kg^{-1}$)	0.25	0.04–0.87	0.37	0.11–0.83
Ca ($cmol_c\,kg^{-1}$)	15.85	1.6–32.48	6.62	0.5–16.5
Mg ($cmol_c\,kg^{-1}$)	2.22	0.48–4.12	1.82	0.20–4.60

† Taken at the end of the season from 23 sites to a depth of 0−200 mm (Meertens *et al.*, 1992).
‡ Taken at the end of the season from topsoils at 11 sites within mapping unit L2 in different parts of the Maswa district (Ngailo *et al.*, 1994).

was constructed to prevent movement of fertilizer from the fertilized area. At harvest, three crop cuts of 2 × 2 m were taken from the fertilized and non-fertilized areas of each field. These were taken from upper, middle and lower parts of the fields to cover non-experimental variations along the slope. Averages of the three cuts were calculated for each treatment.

The 1992/93 pre-extension campaign. In the villages of Malya and Kishili, a total of 138 fields were selected with various positions along the slopes. Urea was applied to only 46 of these due to dry circumstances at the other fields. The experiment's design and harvesting method were similar to those used in 1991/92.

The 1994/95 extension campaign. An extension leaflet on the efficient use of urea in rice farming was prepared in Kiswahili by the FSR Project Lake Zone. It was to be used for demonstrating the application of urea in rice to farmers from the entire region. The campaign involved 160 rice-farming households from 26 villages, which were selected to represent all possible combinations of rainfall patterns and dominant soil types in Mwanza. Equal numbers of rich, average and poor households were purposely selected. Due to the high number of households, a fair number of rice fields on different parts of the slopes were included. Three households failed to plant rice due to drought so urea was applied to 157 fields. It was applied in a central strip of about 10 × 15 m across each field along the slope. As in the previous assessments, small, temporary ridges were constructed to limit fertilizer loss from the fertilized area. The fertilized strip of about 150 m^2 was harvested and compared with two unfertilized areas of about 75 m^2 to the left and right of the fertilized strip. This was done to reduce the influence of variables other than fertilizer application. After urea application, one field was not harvested due to the death of the farmer, and another due to drought. The results therefore are from 155 fields.

The 1995/96 nitrogen-level on-farm trial. A total of 45 fields were selected, 15 fields each in the Katunguru, Sima and Tabaruka villages. In most cases, these fields located in the upper, middle and lower parts of several slopes were divisible into five subplots of about 50 m^2 (5×10 m). The five treatments were allotted randomly to each field. Small, temporary ridges were constructed between treatments to avoid movement of fertilizers from one plot to another. Yields were obtained from harvesting whole subplots. In Sima and Tabaruka, the late onset of the wet season delayed planting and the rains stopped when many rice crops were still in the early reproductive stages. As a result, seven fields were not planted and, in a further seven fields, not all the required urea was applied. Another field was destroyed by goats. In the remaining 15 fields of these villages, the results were too affected by the delays in urea application to be valid. Only the results from the 15 fields in Katunguru, therefore, were considered.

Non-experimental variables

The researchers made sure that urea was only applied to weeded, moist rice fields. All other management practices were left to the rice-farming households. This enabled evaluation of the performance of urea under different, but realistic, farmers' circumstances. Variations in factors such as land preparation, planting dates and methods, weeding practices, cultivars and water availability were recorded. Data were also collected on the circumstances prevailing at the time urea was applied (water depth, number of tillers), plant population at harvest, position of the field on the slope, type of soil, rainfall, and grain yield after sufficient drying. These field data were combined with data on prices for rice (farmgate), labour and fertilizers, and with opinions and observations of the farmers. All this information was used to evaluate the performance of the low dose of N in rainfed lowland rice under different agro-ecological and socio-economic conditions in Sukumaland.

Statistical analysis

In the 1990/91 urea-verification test, the three paired crop cuts in the upper, middle and lower parts of the fields served as replicates. A combined analysis of variance over all fields was possible due to homogeneous error variances in the fields (Neeley *et al.*, 1991).

The crop cuts in the 1991/92 and 1992/93 pre-extension campaigns were not paired and could thus not serve as replicates. Both the 1994/95 extension campaign in the Mwanza region and the 1995/96 N-level trial in the Sengerema district of Mwanza region involved only one replicate per field. Because of this, a combined analysis of variance over fields could not be carried out to provide information about the interaction between treatment and field. In such situations, adaptability analysis

(Hildebrand and Russell, 1996) is an alternative way to see if treatment effects vary significantly across fields. In this method, all treatment yields in a given field are compared with the environmental index, which is the average yield of all treatments in that field. The environmental index is the product of the entire set of biophysical and socio-economic factors, and is assumed to reflect the overall growing conditions and the quality of management in a particular field (Mutsaers *et al.*, 1997). In fact, adaptability analysis examines whether treatment effects differ significantly between fields with overall good conditions (high environmental index) and fields with overall poor conditions (low environmental index).

In this case, the environmental index varied according to differences in management (such as land preparation, type of planting, and weeding), soils, cultivars, water depth and tillering stage at the time of urea application, rainfall, and position of the field in relation to the slope.

RESULTS

Verification test in the Maswa district

In 1990/91, the application of urea (30 kg N ha^{-1}) increased the average grain yield of rice over all 23 fields from 4067 to 4708 kg ha^{-1} (Table 2). The combined analysis of variance shows that effects of fields, replicates and urea application on rice grain yields were significant at the 1 % level of probability. The field × treatment interaction ($F_{22,46} = 0.878$) was, however, not significant at the 10 %-level of probability. The latter means that the selected fields belonged to the same recommendation domain with regard to the application of a low dose of N. The effect of urea on rice yield was better when fields had higher sand contents, when water depths were less than 150 mm at application, and when rice plants were at the maximum tillering stage. Correlation coefficients between increase in rice yield due to urea application and soil type ($r = 0.139$), water depth at application ($r = -0.065$) and tiller stage at application ($r = -0.349$) were, however, not significant at the 5 % level of probability (18 *d.f.*).

Pre-extension campaigns in the Maswa and Kwimba districts

In 1991/92, the application of 30 kg N ha^{-1} increased the average grain yield of rice grown in 30 fields from 3057 to 3881 kg ha^{-1} (Table 2). Similarly, in 1992/93, 30 kg N ha^{-1} increased yields in 46 fields from 3088 to 3551 kg ha^{-1} (Table 2). Calculations from linear regression analysis showed that each additional millimetre water depth at urea application reduced the beneficial effect on rice yield by an estimated 6.7 kg ha^{-1} during 1991/92 (Kajiru *et al.*, 1998). Figure 2 shows the regression lines of the farmers' practice (0N) and urea application (30N) on the environmental index for the 1991/92 pre-extension campaign. In the combined analysis of variance on rice grain yields, the difference in regression of the farmers' practice and urea application on the environmental index (Mutsaers *et al.*, 1997) is not significant at the 5 % level of probability ($F_{1,28} = 3.199$), while urea application and fields are significant at the 1 % level of probability. This points to no clear interaction between treatment and fields, despite the finding of Kajiru *et al.* (1998) of significant interactions between

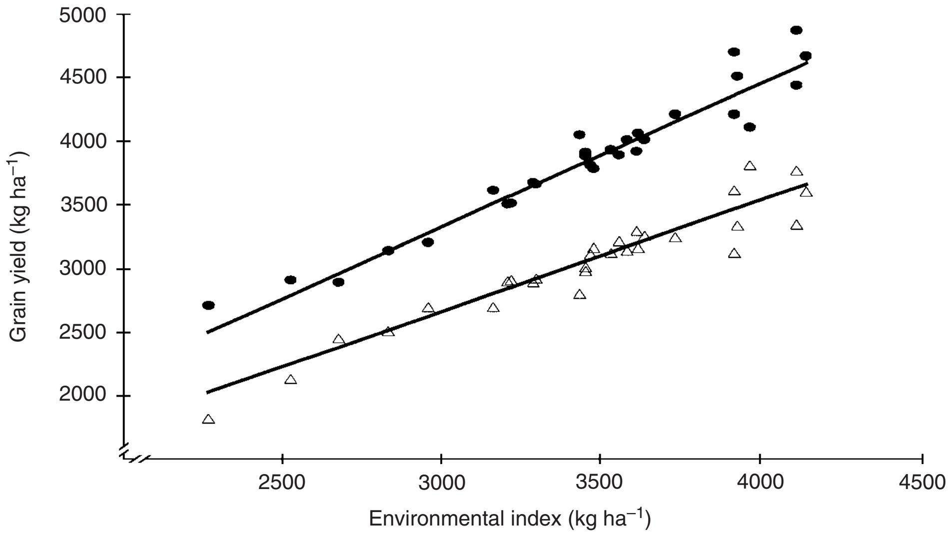

Figure 2. Regressions of farmers' practice, zero N (△), and urea application, 30 kg N ha^{-1} (●), on the environmental index (e) for the 1991/92 rice pre-extension campaign in the Maswa district (30 fields). Fitted lines: △ Y = −51 (184) + 0.896 (0.053) e (kg ha^{-1}), $r^2 = 0.91$; ● Y = 51 (184) + 1.104 (0.053) e (kg ha^{-1}), $r^2 = 0.94$.

urea application and cultivar ($p < 0.05$), position of field on the slope ($p < 0.01$) and water depth at time of urea application ($p < 0.01$) in the 1991/92 pre-extension campaign.

Extension campaign in the Mwanza region

In 1994/95, the application of 30 kg N ha^{-1} increased the average grain yield of rice grown in 155 fields from 3127 to 4113 kg ha^{-1} (Table 2). Figure 3 shows the results of the adaptability analysis. The difference in regression of the farmers' practice (0N) and urea application (30 kg N ha^{-1}) on the environmental index is not significant at the 5 % level of probability ($F_{1,153} = 3.16$) but urea application and fields are significant at the 1 % level.

Table 2. Rice mean yields (kg ha^{-1}) with and without application of 30 kg N ha^{-1} in Sukumaland.

Season	n†	Area/Soils	Rainfall (mm)‡	Yield (kg ha^{-1}) 0N	Yield (kg ha^{-1}) 30 kg N ha^{-1}	Yield increase	*s.e.d*
1990/91	23	Maswa/Hardpan	1033	4067	4708	641	74.9
1991/92	30	Maswa/Hardpan	814	3057	3881	824	52.3
1992/93	46	Kwimba/Hardpan	800	3088	3551	463	–
1994/95	155	Mwanza/Mixed§	1137	3127	4113	986	48.7
1995/96	15	Sengerema/Vertisol	817	3613	4149	536	196.8

† n = total number of observations.
‡ Rainfall data from Maswa town (1990/92), Ukiriguru (1992/93), average from Mwanza region stations (1994/95) and Sengerema town (1995/96).
§Mixed stands for a combination of hardpan soils and Vertisols.

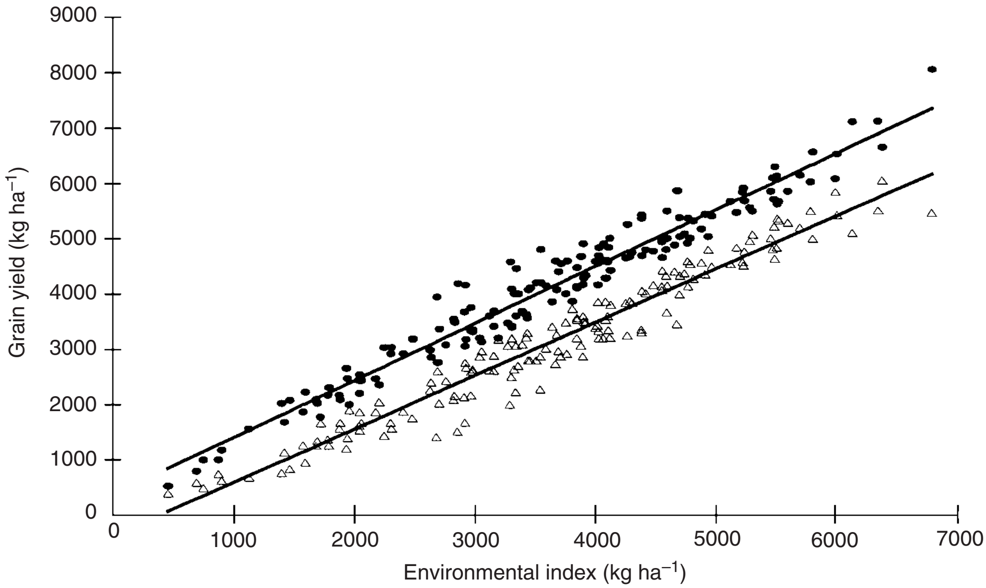

Figure 3. Regressions of farmers' practice, control = zero N (△), and urea application, 30 kg N ha^{-1} (●), on environmental index (e) for the 1994/95 rice extension campaign in the Mwanza region (155 fields). Fitted lines: △ Y = −376 (70) + 0.968 (0.018) e (kg ha^{-1}), $r^2 = 0.95$; ● Y = 376 (70) + 1.032 (0.018) e (kg ha^{-1}), $r^2 = 0.95$.

Nitrogen level trial in the Sengerema district

The results of the adaptability analysis for the 15 fields from Katunguru village in 1995/96 are presented in Figure 4. The differences in regression of the treatments on the environmental index are not significant at the 10 % level of probability ($F_{4,52} = 1.01$) while treatments and fields are significant at the 1 % level.

The mean grain yield of rice for the control was 3613 ± 677 kg ha^{-1}; for treatment N_{30}, 4149 ± 689 kg ha^{-1}; for N_{60}, 4424 ± 757 kg ha^{-1}; for $N_{60}P_{17.5}$, 4593 ± 969 kg ha^{-1}; and for N_{120}, 4918 ± 898 kg ha^{-1}. All fertilizer applications were significantly ($p < 0.05$) different from the control. Treatment $N_{60}P_{17.5}$ was better than N_{30}, and N_{120} yielded more than N_{30} and N_{60} ($p < 0.05$). Almost all the fields in Katunguru were planted with the Super cultivar and there were no lodging problems even after an application of 120 kg N ha^{-1}.

DISCUSSION

Discussion of agronomic data

From 1990 to 1996, annual average rice yields on the on-farm control plots varied between 3 and 4 t ha^{-1} (Table 2). However, the average rice yield from farmers' fields over all kinds of seasons in Sukumaland is near 2.5 t ha^{-1} (Meertens *et al.*, 1999). The higher control plot yields in Table 2 for 1990/91 in Maswa and 1994/95 in Mwanza can be explained by better water availability due to good rainfall, and for 1995/96 in Mwanza by better water availability due to the selection of a valley with a large

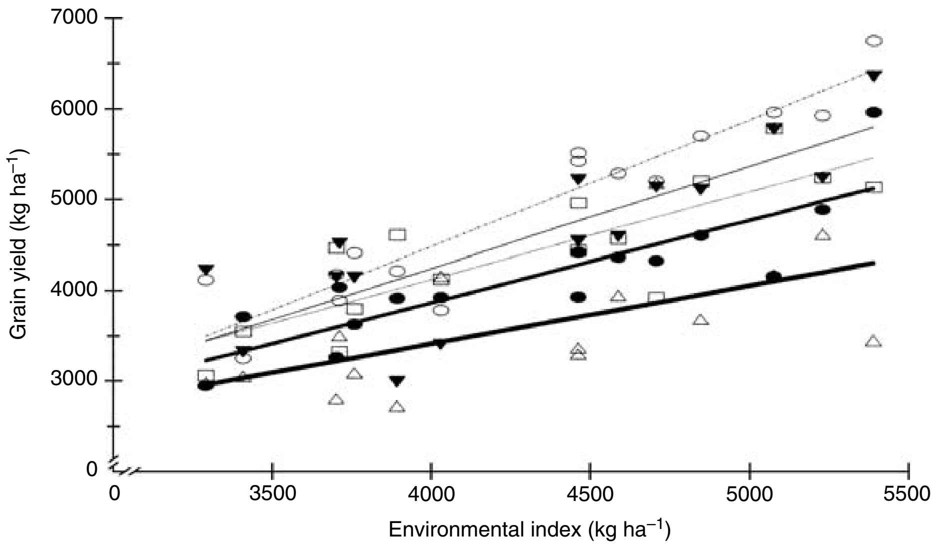

Figure 4. Regression of 1995/96 N-level trial treatments, 0N (△), 30 kg N ha^{-1} (●), 60 kg N ha^{-1} (□), 60N + 17.5P kg ha^{-1} (▼), 120N (○) on environmental index (e) in Katunguru village (15 fields). Fitted lines: △ Y = 791 (1000) + 0.660 (0.231) e (kg ha^{-1}), $r^2 = 0.39$; ● Y = 186 (672) + 0.927 (0.155) e (kg ha^{-1}), $r^2 = 0.73$; □ Y = 205 (799) + 0.987 (0.185) e (kg ha^{-1}), $r^2 = 0.69$; ▼ Y = −323 (983) + 1.150 (0.227) e (kg ha^{-1}), $r^2 = 0.66$; ○ Y= −1186 (638) + 1.427 (0.148) e (kg ha^{-1}), $r^2 = 0.88$.

water-catchment area. Generally, the rice yields from farmers' fields in Sukumaland are in the upper range of reported yields from farmers' rainfed lowland rice fields in Asia (De Datta *et al.*, 1988; Fujisaka, 1990). Unlike Asia, rice cultivation in Sukumaland is a fairly recent phenomenon and, furthermore, in one out of three years many rice fields are left to fallow because of insufficient rainfall (Meertens *et al.*, 1999).

The increase in yield from application of a low dose of N (30 kg ha^{-1}) varied between years from +463 to +986 kg ha^{-1}. The variation in response to urea application among the seasons is due to variation in rainfall, soil type and circumstances at urea application (water depth, rice tillering stage). Performance was less optimal in 1990/91 because urea was, for research reasons, also applied to rice fields in the late tillering stages and/or with high water depths. The low dose of N is used most efficiently by the Sukumaland rice cultivars when plants have 1–3 tillers. High water depths at application increase the loss of N through ammonium volatilization (De Datta, 1987). Urea performed better in 1991/92 and 1994/95 because, in these extension efforts, farmers were advised to apply urea in rice fields with low water depths and where there were few tillers. There were, furthermore, no serious water constraints. In 1992/93, the effect of urea application was less due to drought and in 1995/96, it was less and highly variable due to the fertility of the selected Vertisol valley in Katunguru.

The average agronomic efficiency of applied nitrogen (kg increase grain yield kg^{-1} N applied) over all seasons was 23. Similar agronomic efficiencies of 22–27 kg kg^{-1}

were obtained with low doses of urea (29–30 kg N ha^{-1}) in rainfed lowland rice in the Philippines (De Datta *et al.*, 1988). Dobermann and Fairhurst (2000) state that with proper nutrient and crop management the agronomic efficiency of applied N should be in the range of 20–25 kg kg^{-1}. Research in Asia has shown that incorporation of urea before transplanting, and the use of modified urea products (sulphur-coated urea, urea supergranules), increase the efficiency of N application in lowland rice (De Datta, 1987). However, deep placement of urea supergranules has very limited adoption in Asia because of the large labour requirements for hand placement and availability problems (Mohanty *et al.*, 1999).

Apart from conditions at urea application, soils and rainfall, there were a number of other variables (for example, valley, cultivar and weeding practice) and several interactions between variables that also had an effect on the performance of the low dose of N (30 kg ha^{-1}) in the selected rice fields. The differences in response per field (environment) were, however, not significant in all seasons. Cultivars, soils, position of field on the slope, planting method, water depth at urea application and rainfall are all embedded in environment and each analysis for a single variable is less meaningful due to correlations with, and importance of, other variables. Choice of cultivar is, for example, correlated with position of field on the slope (Meertens *et al.*, 1999). Figures 2, 3 and 4 show that increase in yield is higher in fields with a high environmental index. A high value can reflect not only good water availability and favourable soils but also good management practices (timely and proper land preparation, planting, weeding and harvesting). However, the response to the low dose of N is, by and large, constant throughout Sukumaland for all kinds of years. The effect of urea application is strong enough to overcome the combined influence from all variables on its performance.

The variation in response to applications of N higher than 30 kg ha^{-1} and to application of P (17.5 kg ha^{-1}) between fields (environment) was also not significant. Figure 4 shows, however, that especially applications of high nutrient doses ($N_{60}P_{17.5}$ and N_{120}) perform relatively better in fields with otherwise optimum conditions. That there were no significant differences in yields between the N_{60} and $N_{60}P_{17.5}$ treatments tends to confirm that there were no important P deficiencies in the Katunguru village valley.

Economic analysis and farmers' assessment

During the 1970s and 1980s, mineral fertilizers were subsidized by the Tanzanian government to encourage their use by farmers. By 1988/89, mineral fertilizers had an implicit subsidy of up to 80 % (World Bank, 1994). Reform programmes from the International Monetary Fund/World Bank forced the government to phase out the subsidy in steps from 70 % in 1990/91 to zero in 1994/95. Devaluation of the Tanzanian shilling increased prices of inputs even further.

The average value : cost ratio (VCR) for the low dose of N (30 kg ha^{-1}) in rice was 13.8 in 1990/91, 11.7 in 1991/92, 5.8 in 1992/93, 4.8 in 1994/95 and 2.3 in 1995/96. The removal of the subsidy on urea has clearly reduced enormously the profitability of applying 30 kg N ha^{-1} to rice. In 1995/96, an increase in rice yield of 457 kg ha^{-1} was needed to reach a VCR of two, which is considered to be the minimum level acceptable to farmers (FAO, 1989). Table 2 shows that attaining such a yield increase through applying 30 kg N ha^{-1} is very difficult in seasons with adverse rainfall. In such seasons, however, most farmers do not apply urea.

The results from the 1995/96 nitrogen level on-farm trial in Katunguru were subjected to a partial budget and marginal analysis (Table 3). Only the N_{30} treatment had a marginal rate of return higher than 100 % and this is necessary to make a technology adoptable under small farmers' circumstances (CIMMYT, 1988). The marginal rate of return for the N_{60} treatment in comparison to the N_{30} treatment was 15 %, and for the N_{120} treatment in comparison to the N_{60} treatment only 8 %. The $N_{60}P_{17.5}$ treatment had a lower net benefit than all other fertilizer application treatments. Thus, N_{30} is the most attractive treatment to farmers in that particular area of Sukumaland.

In all seasons, farmers were impressed by the increase in rice yield from the application of 30 kg N ha^{-1} in the form of urea. Broadcasting of the fertilizer in flooded rice fields is easy and can be done in less than a day for an entire hectare. The interactions of this technology with farmers' cultural practices determine that weeding has to be done prior to urea application. Secondly, high water depths at application are to be avoided. Unfortunately, the unreliable rainfall pattern in Sukumaland prevents farmers from drastic drainage actions prior to urea application. At the recommended time of application, however, farmers are in a position to predict fairly accurately the success or failure of a particular rice field (Enserink *et al.*, 1994). No farmer will then apply urea to rice fields already affected by drought. To farmers, the advantage of applying urea to flooded rice fields is that the risk of losing the invested cash due to drought becomes relatively small. Unfortunately, high farmgate prices of urea and its lack of availability in many villages prevents it from being purchased by farmers (Meertens and Röling, 2000).

Table 3. Marginal analysis (in TShs ha^{-1})[†] of the 1995/96 nitrogen-level rice on-farm trial in Katunguru village (15 fields) of Sengerema district in the Mwanza region.

Treatment	Costs that vary[‡] (Tshs ha^{-1})	Marginal costs (Tshs ha^{-1})	Net benefits[§] (Tshs ha^{-1})	Marginal net benefits (Tshs ha^{-1})	Marginal rate of return (%)
N_0	0		309 490		
N_{30}	20 410	20 410	334 993	25 503	125
N_{60}	40 820	20 410	338 140	3147	15
$N_{60}P_{17.5}$	67 752	26 932	325 684	dominated	n/a
N_{120}	79 950	39 130	341 326	3186	8

[†] 580 Tanzanian shillings (TShs) = 1 US $, January 1996.
‡ Price N in 1995/96 = 652 TShs kg^{-1}. Price P in 1995/96 = 1491 TShs kg^{-1}. Opportunity cost labour in 1995/96 = 845 TShs day^{-1}. Treatment N_{30} involves 1 d ha^{-1} for fertilizer application, treatments N_{60} and N_{120} two days ha^{-1} and treatment $N_{60}P_{17.5}$ three days ha^{-1}.
[§]Average grain (paddy) price during 1996 harvest = 86 TShs kg^{-1}.

CONCLUSIONS

The paper shows how a sequence of related on-farm activities, and recognition of farmer financial limitations, led to a recommendation on the application of a lower than often advised dose of N in rainfed lowland rice for Sukumaland in northwest Tanzania.

The rice-fertilizer on-farm activities in Sukumaland between 1990 and 1996 demonstrated that a low dose of N (30 kg ha^{-1}), in the form of urea, at maximum tillering, to flooded rice fields increased grain yield significantly. The average agronomic efficiency of N (30 kg ha^{-1}) applied at tillering of 23 kg kg^{-1} over all seasons shows that N was used in a fairly efficient way. The responses to N ha^{-1} were stable throughout Sukumaland, indicating that N deficiency is common in these rainfed lowland rice fields. No significant differences in response to urea application existed between fields and seasons, due to the low level of applied N. Adaptability analysis underlines that there is no need for multiple extension messages and this simplifies the work of the extension service. The deteriorating ratio between rice farmgate price and urea threatens, however, the adoption of this sound agronomic technology by farmers. The risk of losing the invested cash is high, especially in years with adverse rainfall.

On-farm research in one village during 1995/96 showed that a dose of 30 kg N ha^{-1} was more efficient and economical than doses of 60 kg N ha^{-1} and 120 kg N ha^{-1} and that P was not deficient in the rice fields of that village. Further research in more villages from different parts of Sukumaland over more seasons is needed to confirm these results and should concentrate on improving the efficiency of N fertilization and determining the optimum rates of other major nutrients to refine the initial recommendation.

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REFERENCES

CIMMYT (1988). *From Agronomic Data to Farmer Recommendations: An Economics Training Manual*, completely revised edn. Mexico, D.F.: International Maize and Wheat Improvement Center.

De Datta, S. K. (1981). *Principles and Practices of Rice Production*. New York: John Wiley and Sons.

De Datta, S. K. (1987). Advances in soil fertility research and nitrogen fertilizer management for lowland rice. In *Efficiency of Nitrogen Fertilizers for Rice*, 27–41. Manila: International Rice Research Institute.

De Datta, S. K., Garcia, F. V., Abilay, Jr., W. P. and Alcantara, J. M. (1988). Yield constraints and fertilizer management in shallow rainfed transplanted and broadcast seeded lowland rice in the Philippines. *International Rice Research Institute Research Paper Series, No. 132*.

De Pauw, E. (1984). *Soils, Physiography and Agroecological Zones of Tanzania.* Dar es Salaam: FAO Crop Monitoring and Early Warning Systems Project, Food and Agriculture Organization of the UN.

Dobermann, A. and Fairhurst, T. H. (2000). *Rice: Nutrient Disorders and Nutrient Management.* Potash & Phosphate Institute (of Canada) and International Rice Research Institute.

Enserink, H. J., Bunyecha, K. F., Meertens, H. C. C., Kajiru, G. J. and Bagarama, F. (1994). From farming systems research and extension to zonal strategies: rice research in Sukumaland, Tanzania. *Proceedings of the 13th International Symposium on Systems-Oriented Research in Agriculture and Rural Development, Center for International Cooperation in Agronomy and Warm Climate Research Montpellier, 21–25 November 1994*, 86–91.

FAO (1989). *Fertilizers and Food Production. Summary Review of Trial and Demonstration Results 1961–1986.* Rome: FAO Fertilizer Programme, Food and Agriculture Organization of the UN.

Fujisaka, S. (1990). Rainfed lowland rice: building research on farmer practice and technical knowledge. *Agriculture, Ecosystems and Environment* 33: 57–74.

Garrity, D. P., Oldeman, L. R., Morris, R. A. and Lenka, D. (1986). Rainfed lowland rice ecosystems: characterization and distribution. In *Progress in Rainfed Lowland Rice*, 3–23. Manila: International Rice Research Institute.

Grist, D. H. (1975). *Rice*, 6th edn. London: Longman.

Hildebrand, P. E. and Russell, J. T. (1996). *Adaptability Analysis. A Method for the Design, Analysis and Interpretation of On-Farm Research-Extension.* Ames: Iowa State University Press.

ICRA (1991). An analysis of agricultural and livestock production systems in Misungwi Division, Lake Zone, Tanzania. *Working Document Series, International Center for Development Oriented Research in Agriculture, No. 16.*

Kajiru, G. J., Kileo, R. O., Stroud, A. and Budelman, A. (1998). Validating a fertilizer recommendation across a diverse cropping environment. *Nutrient Cycling in Agroecosystems* 51:163–173.

Meertens, H. C. C. and Röling, N. G. (2000). Non-adoption of a rice fertilizer technology based on a farming systems research-extension methodology in Sukumaland, Tanzania: A search for reasons. *Journal of Extension Systems* 16(2):1–22.

Meertens, H. C. C., Ndege, L. J. and Enserink, H. J. (1992). Results of the urea test in farmers' rice fields; Maswa District, 1990/91. *Field Note, Farming Systems Research Project Lake Zone, Ukiriguru>*

Meertens, H. C. C., Ndege, L. J. and Enserink, H. J. (1995). *Dynamics in Farming Systems: Changes in Time and Space in Sukumaland, Tanzania.* Amsterdam: Royal Tropical Institute.

Meertens, H. C. C., Ndege, L. J. and Lupeja, P. M. (1999). The cultivation of rainfed, lowland rice in Sukumaland, Tanzania. *Agriculture, Ecosystems and Environment* 76:31–45.

Mohanty, S. K., Singh, U., Balasubramanian, V. and Jha, K. P. (1999). Nitrogen deep-placement technologies for productivity, profitability, and environmental quality of rainfed lowland rice systems. *Nutrient Cycling in Agroecosystems* 53:43–57.

Mutsaers, H. J. W., Weber, G. K., Walker, P. and Fisher, N. M. (1997). *A Field Guide for On-Farm Experimentation.* Ibadan: The International Institute of Tropical Agriculture / Technical Centre for Agricultural and Rural Cooperation ACP-EU (CTA)/International Service for National Agricultural Research.

Neeley, D., Matata, J. and Kisyombe, F. (1991). *Statistical Techniques for the Analysis of On-Farm Crop Trials. A Manual.* Harare/Nairobi: International Maize and Wheat Improvement Center.

Ngailo, J. A., Shaka, J. M., Kiwelu, A. and Msangi, A. (1994). Soils of Maswa District and their suitability for cultivation of maize, rice, cotton, cassava, and extensive grazing. *Reconnaissance Soil Survey Report (with map), National Soil Service, Tanga, No. R6.*

Samki, J. K. and Harrop, J. F. (1984). *Fertilizer Recommendations in Tanzania on district-to-district basis.* Tanga: National Soil Service.

Tripp, R. and Woolley, J. (1989). *The Planning Stage of On-Farm Research: Identifying Factors for Experimentation.* Mexico, D. F. and Cali: International Maize and Wheat Improvement Center/International Center for Tropical Agriculture.

World Bank (1994). Tanzania agriculture: A joint study by the Government of Tanzania and the World Bank. *World Bank Country Study. Washington D.C., USA.*