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Effect of moisture conservation and nutrient management on rice production in rainfed lowland ecology of East and Southern Africa

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ABSTRACT

International Rice Research Institute, East and Southern Africa Regional Office, Tanzania conducted a baseline survey during 2008 to identify the causes of low productivity of rice in rainfed lowland ecology of east and southern African countries. The survey data revealed that poor moisture conservation and nutrient management practices are the major factors responsible for low productivity of rice in rainfed lowland ecosystem. To assess the effect of moisture conservation and nutrient management on productivity of rice under rainfed lowland ecosystem and to make a strategic moisture conservation and nutrient management plan to enhance rice productivity at Bagamayo-2, Bagamayo-3, Lupembe, Milema and Dakawa in different agro climatic regions of Tanzania during 2010. Moisture conservation through bunding increased water availability in upper soil layers at the time of critical dry spell. Substantial yield gains ranging from 0.34 t ha^{-1} to 0.93 t ha^{-1} were recorded following the use of improved technologies. The integration of moisture conservation and nutrient management technologies revealed that the average yield enhancement due to bunding only was 56.14% over no bunding. However, rice yield with good agricultural practices such as bunding + recommended dose of fertilizers ((N80:$P_2O_5$40:K_2O40) was 110.52%, 54.50%, 34.83% and 12.51% higher over no bunding and no nutrients (control), no bunding + 1 bag urea /acre 20 days after germination (Farmers practices), bunding+ no nutrient and no bunding + recommended dose of fertilizers. Relative yield gains decreased in the following order: bunding + recommended dose of fertilizers (110.5%)>no bunding + recommended dose of fertilizers (87.13%), bunding + no nutrient (56.14%), and no bunding + 1 bag (50kg) urea /acre 20 days after germination (Farmers practices). The gains obtained through combined effect of moisture conservation and nutrient management can be further enhanced through use of improved rice cultivars. It is concluded that moisture conservation through bunding enhanced 14.6 % grain yield over the farmer's practices. Bunding + recommended dose of fertilizer gave 117% more income than the prevailing farmer's practices. Therefore, it is recommended that bunding + recommended dose of fertilizers in two splits is advocated/encouraged/recommended for higher productivity of rice in rainfed lowland ecologies of east and southern African countries.

Key words: Moisture conservation, nutrient management, rainfed lowland ecology, rice, East and Southern Africa

INTRODUCTION

The East and Southern African (ESA) region in sub-Saharan Africa has perhaps the greatest concentration of poverty in the world, and for the foreseeable future, it will continue struggling to overcome widespread food insecurity and deprivation. Presently, rates of economic growth vary considerably across the region. But in many East and Southern African countries, poverty and malnourishment are on the rise. About 70 per cent of the region's population, 230 million people live in rural areas, and more than half of those people live on less than US$1(Rs. 60/-) a day. Agriculture is the most important economic activity in the region supporting over 67 percent of the population, but 60 percent of these depends on rain-based rural economies. Rural areas continue to be marked by stagnation, poor productivity, low incomes and rising vulnerability. The vast majority of poor rural people in East and Southern Africa

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are smallholder farmers working in conditions of either static or declining productivity. ESA may suffer more severely from loss of soil fertility. Annual rainfall in ESA ranges from 150 mm in the arid and semi-arid areas to over 2,000 mm in the wet, mostly highland regions. This amount of rainfall itself is capable of ensuring sustainable agricultural productionbut the agricultural production is below potential land capabilities in nearly all the ESA countries, and crop failures are a common occurrence due to prolonged and recurrent drought and dry spells. The importance of rice production in this region has significantly increased over the past decades. Currently, rice plays a pivotal role in improving household food security and national economies in ESA. However, current rice productivity of smallholder farms is low due to a myriad of production constraints and suboptimal production methods, while future productivity is threatened by climate change, water shortage and soil degradation. Rice crop production in ESA is generally below potential, averaging about 2.1 t ha^{-1} (Fig.1). Low yield associated with poor inherent soil fertility (Table 1), continuous cultivation with low inputs and poor soil moisture availability. The region is characterized by semi-humid to semi-arid climate, where 73 percent of the land is classified as dry land. Yet only about 5 percent of the irrigation potential has been exploited. There is, therefore, an urgent need to make rain-fed agriculture more productive. Sometimes the region is described as the "Greater Horn of Africa" (IGAD 2001). East Africa is occupied by some of the poorest communities in the world and over 50 percent of the population lives below the poverty line. Recent studies (Reij and Waters-Bayer 2001; Bittar 2001; Abbay *et al.*, 2000, Critchley *et al.*, 1999; Hatibu and Mahoo 2000) have shown the emergence of success cases of rain-fed agriculture in East Africa, which are transforming the lives of many poor farmers. However, these success cases are few and far between, and there is a need to have continuous collation of information, building on knowledge gained from the successful practices, so as to reach as many farmers as possible, and thereby enhance agricultural development in the region. Feedback from the surveyed farmers revealed that the farmers were not aware of the amount of fertilizer required, timing and method of fertilizer application. During survey it was also elaborated by the 90% farmers that they don't know how to conserve the moisture in rainfed eco- system. They were growing rice in large plots without following any moisture conservation measure even without making any bund. Rain water was lost through runoff immediately after precipitation and crop dried after three to four days if there was no continuous rain. Adequate plant nutrient supply holds the key to improving the food grain production and sustaining livelihood. Nutrient management practices have been developed, but in most of the cases farmers are not applying fertilizers at recommended rates. They feel fertilizers are costly and not affordable and is a

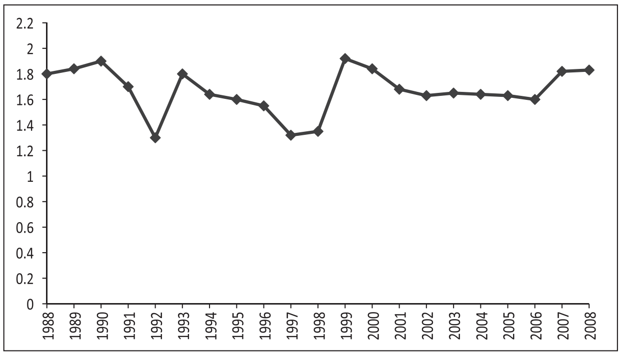

Fig. 1. Rice production pattern in East and Southern African Countries

Table 1. Soil characteristics of experimental sites

Location	Soil Depth (cm)	pH	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	S (ppm)	Na (ppm)	OC (%)	N (%)
Bagamoyo- 3	0-15	5.09	10	258	2669	3133	1798.00	3708.0	2.04	0.11
	15-30	5.43	11	318	1124	3005	9874.00	3226.0	1.02	0.05
Dakawa	0-15	5.60	17	192	525	157	15.68	122.2	1.97	0.11
	15-30	6.60	8	255	429	151	8.52	184.30	0.93	0.05
Lupembe	0-15	4.62	6	220	202	68	12.02	59.81	1.78	0.11
	15-30	4.82	10	232	264	61	11.07	92.23	0.77	0.08
Milama	0-15	6.17	33	431	2251	548	8.56	50.66	1.99	0.11
	15-30	6.92	24	385	2170	533	11.43	54.83	1.73	0.10
Bagamayo- 2	0-15	6.97	10	160	4163	1588	17.83	296.90	1.81	0.12
	15-30	6.82	7	117	3642	1689	16.88	472.90	1.24	0.09

risky undertaking particularly under rainfed agro eco-systems, as they are unsure of the rains. The nutrient use efficiency in rainfed agro-eco systems should be improved through optimizing the nutrient levels with the limited water availability. Crops under rainfed farming systems suffer more from nutrients deficiency rather than moisture inadequacy. Low yields of rainfed crops are due to low level of fertilizer application. Fertilizer use in most of the rainfed areas in the country is suboptimal. Soil organic carbon is the source of energy to fuel for biological activities in the soil, which in turn control the availability of nutrients for plant growth as well as soil water availability. The supply of nutrients in the form of organic manures helps in retaining more moisture, which otherwise will go to waste as runoff water, increasing the water storage capacity and thereby increases water and nutrient use efficiency in rainfed soils. Therefore, International Rice Research Institute, East and Southern Africa Regional Office in Tanzania initiated the study to monitor the effect of moisture conservation and nutrient management to enable farmers to increase rice productivity in Tanzania. They conducted experiments on moisture conservation and nutrient management in rainfed low land conditions with improved rice variety SARO-5 (TXD 306) at 5 locations in different agro-climatic conditions of Tanzania.This study was focused on some of the more commonly adopted moisture conservation and nutrient management technologies and approaches in ESA with special emphasis on Tanzania.

Status of Soil conservation and Nutrient management in ESA

Soil conservation management

Water and soil nutrient management form a critical component of agricultural production. ESA have a rich heritage of indigenous and innovative water and nutrient conservation technologies, including irrigation and water harvesting systems that date back centuries (McCall, 1994; Reij *et al.*, 1996, Wolde-Aregay, 1996; Thomas, 1997, Critchley *et al.*, 1994; Mutunga *et al.*, 2001, SIWI, 2001). Water and nutrient conservation technologies are dictated by the need for soil conservation on usually very steep slopes while draining excess runoff safely, the need for water harvesting and conservation in the drier areas.

Various interventions in soil water conservation (SWC) are implemented by farmers throughout East Africa, and they also form the foundation of many development projects with agriculture and land management on their agendas (Reij *et al.*, 1996; Lundgren, 1993; Hurni and Tato 1992; WOCAT 1997). Indigenousand innovative technologies in SWC (Soil and Water Conservation) and soil nutrient management abound in East Africa (Mulengera, 1998; Reij and Waters-Bayer 2001; Hamilton, 1997), some of which have proved easier to replicate, especially those that are applicable over diverse biophysical conditions and have lowlabor requirements. The more common methods of soil water conservation and nutrient management include: leveling, contour bunds, grass strips, cutoff drains, hill terracing and graded bench terraces (Wolde-Aregay, 1996; Hurni and Tato, 1992). In Tanzania, the main interventions have included the tapping of runoff fromroads, diversion of surface runoff from rocky areas, footpaths, conservation tillage, pitting systems, bunded basins, ridging, terracing and various types of runoff farming systems (McCall, 1994; Reij *et al.*, 1996; Hatibu and Mahoo, 2000).

Soil nutrient management

The declining per capita food production in East Africa is associated with declining soil fertility in small holder farms. This is because nutrient capital is gradually depleted by crop harvest removal, leaching and soil erosion (IFPRI, 1996). The use of crop residues by farmers as fodder, and none or shorter fallow periods due to a shrinking land resource base, should be balanced by addition of chemical fertilizers and organic manure, which most smallholder farmers in the region cannot afford. There is, therefore, a need to develop appropriate soil nutrient and cropping systems that minimize the need for chemical fertilizers and also find ways to integrate livestock into the farming system. The focus of any soil fertility replenishment should be integrated nutrient management involving the application of leguminous mulches, agroforestry, composting as well as technologies that reduce the risks of acidification and salinization. Sanchez *et al.* (1997) suggest that soil fertility replenishment should be considered as an investment in natural resource capital. Studies by Murage *et al.* (2000) showed that soil fertility depletion results from an imbalance between nutrient inputs, harvest removals and other losses, and that it is reaching critical levels among smallholders in East Africa (with depletion of soil organic matter being a contributory factor). For example, Smaling *et al.* (1993) estimated that 112, 2.5 and 70 kg ha^{-1} per year of nitrogen, phosphorus and potassium respectively, are lost from agricultural soil in Kenya. In many small-scale farms, crop residues are harvested and fed to livestock, and very little is returned to the soil to replenish lost nutrients. The depletion of organic matter thus exacerbates this condition. In soil and water management, technologies that improve soil fertility and productivity are as important as those that reduce erosion and loss of water. These include practices such as residue mulching, contour tillage and tied ridging, minimum tillage, sub soiling, crop rotation, cover cropping, rotational grazing, contour cropping and direct application of organic matter, farmyard manure and inorganic fertilizers.

MATERIALS AND METHODS

Farmer survey

To find out the prevailing rice cultivation practices as well as moisture conservation and nutrient management status of both irrigated and rainfed environments in east and southern African countries, a combination of key informant interviews and a questionnaire survey were conducted during 2008. A total of 687 farm families were surveyed in three regions of Tanzania representing east and southern African countries. Purposive sampling methods were used in drawing up a list of interviewees from the sampling frames of each region and the resultant sample constituted of farmers from both irrigated and rainfed lowland ecologies. To find out the moisture conservation and nutrient management status farmers were divided into small (<1.0ha), medium (1.0-2.0ha) and large (>2.0ha) categories based on land holding.

Design and layout of experimental fields

Researcher managed four times replicated experiments were conducted at five (Bagamayo-2, Bagamayo-3, Lupembe, Milema and Dakawa) locations in Tanzania representing rainfed ecology of ESA countries (Fig. 2). Before initiating the experiments composite soil samples were collected from each experimental site and analyzed for soil pH, organic carbon (OC), N, P, K, Ca, Mg, S and Na. The soil of the experimental sites was acidic in nature having soil pH 4.62-6.97. The details of soil status are given in Table 1. The treatments were comprised of no bunding and no nutrient (Control), no bunding + 1 bag urea /acre 20 days after germination (farmers practices), bunding + no nutrient, bunding + recommended dose of fertilizers (N80:$P_2O_5$40:K_2O40) and no bunding + recommended dose of fertilizers. Before dibbling the seed, bunds of 45 cm width and 30 cm height were made to store the rain water within the plots. The plots were leveled properly and dry seeding of traditional high yielding rice variety SARO-5 was done with dibbling method at a spacing of 15 cm x 20 cm before monsoon with a seed rate of 80kgha^{-1}. Recommended fertilizer dose of 80kg N: 40kg P_2O_5:40kg K_2O was applied at all the locations irrespective of amount of rainfall. No fertilizer was applied at the time of dibbling the seed. Half dose of N and full dose of P and K were applied 20 days after germination and the remaining half dose of N was applied at flowering stage. The treatments of the experiment were evaluated by recording yield attributes and grain and straw yields and soil analysis. Five plants were selected and tagged randomly at harvest from each plot. Plant height and panicle length were recorded from these plants and were averaged to express the plant height (cm). Similar practices were followed to record number of tillers/hill, number of effective tillers/hill. For panicle length and grain weight/panicle, five panicles were selected from each five hills and averaged. To measure the weight, random samples were drawn from the produce of each plot, 1000 seeds were counted, weighed and expressed as test weight in both the crops. After harvesting, weighing of sun dried grains and straw collected from each plot was recorded and the same was converted to express in grain and straw yield in t ha^{-1}. Treatments were evaluated based on total variable cost, gross return, net return, and benefit cost ratio (BCR). In order to calculate the total cost of cultivation, variable cost and return was calculated by taking into account the prevailing market prices of inputs (seed, fertilizer, and pesticides) during the study period; costs of human

Fig. 2. Location of experiments

Table 2. Basic statistics of rice cultivation in rainfed ecology of sample regions in Tanzania.

Parameters	Morogoro	Mbeya	Shinyanga	Average
Sample size	175	108	254	537
Paddy yield (t/ha)	2.0	1.5	1.6	1.7
Cultivated area in the sample parcel (ha)	1.0	0.8	1.8	1.2
Share of bunded plot (%)	8.6	15.7	26.1	16.8
Share of hh who levels the plot (%)	22.3	39.8	88.2	61.2
Share of modern variety (%)	17.7	0.0	1.6	11.2
Share of farmers applied fertilizer (%)	5.4	3.8	4.3	4.5
Chemical fertilizer use (kg/ha^{-1})	16.9	15.4	0.9	14.7

Source: Nakano *et al*. (2012)

labor for land preparation, irrigation, fertilizer, and pesticide application, harvesting and threshing; and costs of hiring power tillers for land preparation and an irrigation pump. Gross return was calculated by multiplying the amount of produce (grain and straw) by its prevailing market price at harvest. The net return was computed as gross return – total cost of production and BCR as gross return/total cost of production. The cost economics was analyzed by taking into account the prevailing market prices of inputs, labor, and produce during the year of study in Tanzanian ceilings, and then converted into U.S.$ using the conversion rate of $.

Statistical analysis

The data from the survey was captured and analyzed using SPSS version 15, summary statistics, frequency tables and cross-tabulations and were used to analyze the individual questions. The significance of treatment effect was tested with the help of 'F' test and the differences between treatments by critical differences (CD) at 5% level of probability as per procedure given by Panse and Sukhatme 1985. The data from the experiments were analyzed using Windo STAT. The mean yield for treatments from different sites were separated using least significant differences (LSD) at $P < 0.05$ significance level.

RESULTS AND DISCUSSION

Farmers survey

From the survey, it was observed that small and marginal farmers in East Africa predominantly produce rice under lowland rainfed ecology and in Tanzania the irrigated ecology constitutes 12% of total land under rice (Kanyeka *et al.,* 1996; Singh *et al.*, 2013). Small and marginal famers contributed largest share of rice without using any good agricultural practices including technologies on management of nutrients, cultivars and water. On the basis of survey, it was observed that, the farmers were not aware about the amount of fertilizer required and time and method of fertilizer application. During survey it was also elaborated by the farmers that they don't know how to conserve the moisture in rainfed eco- system. They were growing rice in large plots without following any moisture conservation measure even without making any bund. The whole rain water lost through runoff immediate after precipitation and crop dried after three four days if there is no continuous rain. The data given in Table 3 summarizes the basic statistics of rice cultivation in sample region in Tanzania. The data revealed that the average land holding of farmers in rainfed ecology is 1.2 ha. However, average paddy yield is 1.7 tha^{-1}. The average share of bunding is only 16.8% which showed that the farmers are not aware of the benefits of moisture conservation measures (Nakano, 2012). Similar to this, usually the paddy fields are leveled to distribute the water equally in the plot but only 61.2 % of household leveled the plot. The share of modern variety is only 11.2% on average which is quite low compared to Asian countries. The use of chemical fertilizer in rainfed ecology is quite low,compared to the Asian countries (Table 2).

Plant growth and yield

Input use of chemical fertilizers on cereals is very low in Sub-Saharan Africa. High cost, low access and limited knowledge of use have been cited as the major reasons for low adoption of this technology by farmers (Mwangi, 1996). However, even readily available low cost organic nutrient sources are not consistently used by farmers. Under rainfed conditions where moisture is a function of rainfall pattern, few farmers (4.5 %) applied fertilizers in rice fields. The average results of five locations revealed that maximum plant height

(88.87cm) was recorded with bunding + recommended dose of fertilizers whereas, minimum with control where farmers are neither making any bund nor using any fertilizer (Fig. 3). Plant growth and yield attributory values of rice were significantly increased with combined effect of bunding and recommended dose of fertilizers. Maximum number of tillers/hill, number of effective tillers/hill, length of panicle, grain weight /panicle, test weight, straw yield and grain yield

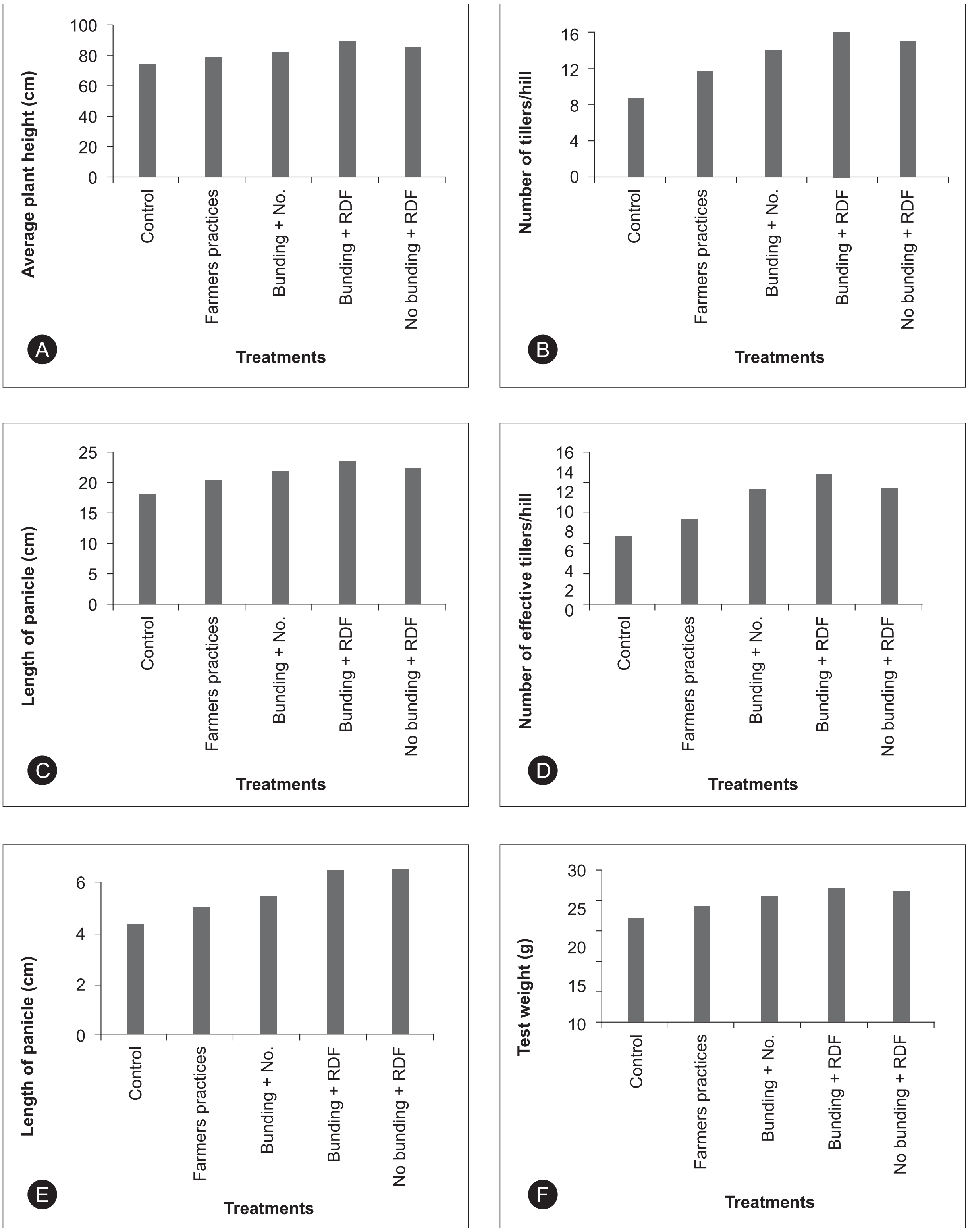

Fig. 3. (A) Plant height (cm), (B) Number of tillers/hill (C) Number of effective tillers/hill (D) Length of panicle (cm) (E) Grain weight/panicle (g) (F) Test weight

Table 3. Effect of moisture conservation and nutrient management on grain straw and biological yields under rainfed environment.

Treatments	Lupembe			Bagamayo-2			Bagamayo-3			Milema			Dakawa		
	Biological yields ($t ha^{-1}$)	Straw yield ($t ha^{-1}$)	Grain yield ($t ha^{-1}$)	Biological yields ($t ha^{-1}$)	Straw yield ($t ha^{-1}$)	Grain yield ($t ha^{-1}$)	Biological yields ($t ha^{-1}$)	Straw yield ($t ha^{-1}$)	Grain yield ($t ha^{-1}$)	Biological yields ($t ha^{-1}$)	Straw yield ($t ha^{-1}$)	Grain yield ($t ha^{-1}$)	Biological yields ($t ha^{-1}$)	Straw yield ($t ha^{-1}$)	Grain yield ($t ha^{-1}$)
Control	7.02	5.17	1.85	4.10	3.10	1.00	4.30	3.14	1.16	9.30	7.11	2.19	8.80	6.43	2.37
Farmers practices	11.50	8.61	2.89	7.60	5.65	1.95	7.60	5.76	1.84	9.70	7.43	2.27	11.20	8.49	2.71
Bunding + no nutrient	12.46	9.35	3.11	8.20	6.05	2.15	9.00	6.84	2.16	10.10	7.25	2.85	12.65	9.54	3.11
Bunding + RDF	16.60	12.50	4.10	13.10	9.97	3.13	10.10	6.94	3.16	11.60	8.17	3.43	17.10	12.89	4.21
No bunding + RDF	13.30	9.78	3.52	9.20	6.35	2.85	9.43	6.70	2.73	10.10	6.95	3.15	13.80	10.04	3.76
LSD(P=0.05)	1.32	1.51	0.43	1.63	1.14	0.36	1.12	0.86	0.16	ns	ns	0.21	1.46	1.43	0.42

were observed under bunding +recommended dose of fertilizers followed by no bunding + recommended dose of fertilizers. The improvement in plant growth, yield attributing characters and yields under bunding + recommended dose of fertilizers may be due to higher availability of soil moisture for longer duration even during dry spells which helped in better nutrient uptake by the crop which in turn resulted in assimilation of photosynthates towards sink as well as higher dry matter accumulation.

Grain, straw and biological yields of rice markedly increased due to combined effect of bunding the field and application of recommended dose of fertilizer (Table 3). Bunding + recommended dose of fertilizer resulted in highest grain, straw and biological yields at all the locations. The average grain yield with bunding + recommended dose of fertilizer was 110.5%, 54.5%, 34.83% and 12.51% higher than control, farmers practices, bunding + no nutrient and no bunding + recommended dose of fertilizer respectively. The data shows that bunding plays an important role in conserving the moisture. Growing of rice with bunding only even without application of fertilizer enhanced grain yield to 56.14% over without bunding. This is because bunding control rainwater within the plot and maintain moisture in the field for a longer period even in period of dry spell. Mean straw and biological yield exhibited the trend similar to that of seed yield. The use of recommended dose of fertilizer even without bunding results in significant gains in rice grain yield albeit of different magnitude across ecologies but it was remarkably less than the bunding + recommended dose of fertilizer.

Cost economics

The mean value of yield of all the five locations revealed that the maximum grain yield (3.6 $t ha^{-1}$) was recorded with bunding + recommended dose of fertilizer followed by no bunding + recommended dose of fertilizer (3.20 $t ha^{-1}$) and bunding + no nutrient (2.67 $t ha^{-1}$) (Table 4). There was a huge yield gain (1.89 $t ha^{-1}$and 0.87 $t ha^{-1}$) between the yield recorded from control plot and farmers practices. Net benefit calculated from the data shows that bunding + recommended dose of fertilizer gave 767.82, 475.45, 364.10 and 108.0 US $ additional income over control, farmers practices, bunding + no nutrient and no bunding + recommended dose of fertilizer treatments which shows a positive return to investment in bunding and fertilizer use in rainfed lowland ecologies. Similar responses have been reported by other researchers working on rice in rainfed lowland ecology (Meertens *et al,*. 2003; Kajiru *et al.*, 1998). However, survey interview results showed that farmers are reluctant to apply significantly large amounts of fertilizer especially on rainfed fields probably due to high initial cash outlay required to hire the laborer for making bunds and purchasing inputs, uncertainty of rainfall *vis-à-vis* production, access and lack of confidence in the performance of some technologies which are some of the causes of low adoption (Mowo *et al.*, 2006).

The results of this study suggested that bunding of fields before sowing of seed and application of recommended dose of fertilizer in rainfed lowland rice where there is no control of water, adoption of water conservation techniques e.g., bunds can improve productivity and can be a highly profitable option for East and Southern African countries. The high yield gains following use of good agricultural practices and the positive economic returns warrant the investment required in rice production.

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