Soil Fertility Improvement Using Crop Residues and Azolla for Sustainable Production of Rice and Fish in Irrigated Rice-Fish Farming System in the Lake Victoria Basin of Kenya

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Abstract

Rice paddy-fields are potential fish ponds that can be used to promote agricultural development by increasing fish production to improve farmer"s income and the nutrition of rural populations in developing countries. An experiment, whose target was to increase both water and land productivity through poly-culture of rice and fish was set up in the Lake Victoria Basin, West Kano Irrigation Scheme (WKIS), Kenya. The experiment, with six treatment combinations and control, was laid in a completely Randomized Design (CRD) replicated four times. The treatments consisted of two levels of commercial Urea, at 48 & 72Kg N/ha in combination with two organic inputs; Nitrogen bio-fixer azolla at 2 ton/ha and rice straw at 3 ton/ha and fish culture. Results showed that application of azolla at 2 ton/ha + urea, 72Kg N/ha + Fish and that of Urea 72 Kg N/ha + Fish gave significant increase in plant height of 25.9% and 15.8% respectively compared to control. The former treatment gave the highest rice yield 4.16 ton/ha. It was also evident that yields from two azolla containing treatment did not differ significantly ($P \leq 0.05$) from each other despite having different levels of commercial urea. Fish potential in rice nutrient inputting was also explained, i.e. there is significant ($P = 0.05$) increase in rice yield in treatment with fish as the only nutrient input. Isolation of fish from other rice nutrient sources gave the highest fresh body weight yield 134.7 Kg/ha. The fish yields of the latter treatment had no significant ($P \leq 0.05$) difference to that of 2 ton azolla + 48Kg N/ha Urea which yielded 131.0Kg/ha. This study will help reduce the cost of production of paddy rice through use of organic inputs to supplement inorganic fertilizers and also reduced paddy rice field water requirement.

Key Words: Soil Fertility, Crop Residues, Azolla, Rice, Fish

INTRODUCTION

Agriculture is the backbone of Kenya's economy. Its dominance is indicated by several factors including contributing 24.0% of GDP (FAO, 2006b); generating over 60% of foreign exchange earnings; providing employment to over 70% of the population; providing raw materials to about 70% of all industries and providing over 45% of the annual government budget. Fresh water fisheries account for almost all of annual national production and almost all fisheries production derives from Lake Victoria. The lake accounts for about 92% of the total fish production in the country. Recent disputes in the fish-rich areas of Lake Victoria have deprived Kenya of its potential fisheries production and lessons should be borrowed from Japan's experience during the Second World War.

In Japan, problems of food supplies during the Second World War stimulated extensive fish culture in paddy-fields. The latter case, coupled with natural and artificial decay of fish population, influenced by animals and human activities calls for stimulation off-lake culture of fish. Currently, the dominant aquaculture production systems in Africa, particularly in sub-Saharan Africa (SSA) are earthen ponds. It is only of late that the government of Kenya (GoK) through economical stimulus package (ESP) rolled out KES.1.12 billion programme funded by treasury targeting construction of 28,000 earthen ponds in 140 constituencies (GoK, 2007). This should be complemented by exploring other potential production systems such as paddy-fields.

Paddy-fields are potential fishponds since in its aquatic phase the rice field can produce a crop of fish. The use of rice fields to grow rice and raise fish concurrently or rotationally is one way of increasing productivity of paddy-fields. It is generally accepted that integrated rice-fish farming often increase rice yield and produce fish while using the same resource bases of land, water, fertilizer, and labour. Rice-fish farming is therefore relevant to the agricultural development plan of increasing productivity, farmer‘s income, and improving the nutrition of rural populations. Globally Inorganic fertilizer required to increase rice productivity of small scale resource-poor farmers remains an expensive commodity. In addition, the potential of using azolla in rice cultures as a source of nitrogen has been well documented from studies done mainly in China and other Asian countries (Lejeune *et al.*, 1982). In Kenya there is limited information on the use of low cost nutrient sources, among the fish to increase rice productivity. Therefore, a study was conducted in West Kano Irrigation Scheme (WKIS) in which low cost rice nutrient sources which included rice straw, azolla, and fish were used in contrast to high cost commercial urea - 46% N fertilizer. The experiment capitalized on two symbiotic relationships: on the one hand, rice-fish symbiosis where rice benefited from; urea-rich fish droppings, pest control and soil physical properties improvement and, on the other hand, fish benefited on physical protection and attraction of food-insects.

MATERIALS AND METHODS

The on-farm experiment was carried out at West Kano Irrigation Scheme (WKIS) Nyando District, Nyanza Province, Kenya. The site lies between 00 6^{o}S and 00 12 ^{o}S latitude and 34 48^{o}E and 34 57^{o}E longitude and at altitude of 1137m asl. It receives average annual rainfall of about 1100mm which is distributed as long rains from March to early June and short rains from September to December. The six treatment experiment was laid out in a Completely Randomized Block Design (RCBD) replicated four times.

The treatments comprised: Urea at 72Kg N/ha + Fish (T1), Urea at 72Kg N/ha + 2ton/ha azolla incorporation + Fish (T2), Urea at 48kg N/ha + 2ton azolla incorporation + Fish (T3), Urea at 72 Kg N/ha + 3ton/ha straw incorporation + Fish (T4), Urea at 48Kg/ha + 3ton/ha rice straw incorporation + Urea 48Kg N/ha + Fish (T5), Fish as the only input (T6), and a control with no fertilizer addition(T7). Six treatment plots and a control, each measuring 5m by 5m, were constructed. Each plot had elevated dikes with base of 0.6m, top width 0.4m and height of 0.4m having separate screened water inlets and outlets. The plots were physically modified to provide refuge for the fish by constructing peripheral trenches each with an area of 5m^2 and a depth of 0.5m.The plots were ploughed, flooded and puddling followed prior transplanting of rice. Rice straws and azolla green manure were incorporated to the soil 2 weeks to rice transplanting. Seeds of rice variety IR 2793 - 80-1 were germinated and seedlings managed for 30 days. Rice seedlings were transplanted from the nursery to experimental plots at 35 days after seeding (DAS) and at spacing of 25cm between the rows and 10cm within the rows, with 2 seedlings per hill.

The seedlings were allowed to establish at a shallow water level of less than 5cm to allow anchoring and then raised to 25cm on the day of fish stocking (DFS) 14 days after transplanting (DAT) at a rate of 6000 fingerlings per hectare. The average weight of the fingerlings at stocking was 15.4 ±0.6g. During the experiment the fish in the rice-fish culture received supplementary feeding of rice bran at 3% of body weight. Nitrogen fertilizer Urea was applied manually, placed at 5cm below soil surface in three parts to give the total prescription (according to Rao et al., 1971) in each urea-containing treatments.

During fertilization, flooded fields were drained and fish made refuge in trenches. Water physical and chemical properties were monitored during the culture period to ensure fish growth was not inhibited. Rice performance was monitored in terms of plant height, productive tillers/m^2, straw yield, grain yield, N in grain sink and N in straw all at harvest. Characterization of soils and rice tissues was performed using the following laboratory analyses; soil carbon was determined by Walkley and Black sulphuric acid-dichromate digestion followed by back titration with ferrous ammonium sulphate (Anderson and Ingram, 1993). Total N determined using Se, $LiSO_4$, H_2O_2 and conc. H_2SO_4 digestion (Anderson and Ingram, 1993) followed by colorimetric calibration. Soil pH was determined using a glass electrode pH meter at 1:2.5 soil: water ratio (Okalebo et al., 2002). The available P was extracted by the Olsen method as described by Okalebo et al. (2002). Rice grain, rice straw and Fish fresh weights was determined using digital balance and extrapolated to yield/ha is conversion; Yield/ha = Plot yield* Hectare size/plot size.

RESULTS

The results in Table 1 are parameters of rice plant growth and Nitrogen assimilation as influenced by treatments. Application of azolla at 2 ton/ha + urea 72Kg N/ha + Fish (T2) and that of Urea 72 Kg N/ha + Fish (T1) gave significant increase in plant height of 25.9% and 15.8% respectively compared to control. On the contrary, application of 3 ton/ha straw + urea 48Kg N/ha + Fish (T5) significantly gave 21% decrease on plant height compared to control. The remaining three treatments had no significant difference on plant height as compared to control. T1, T2, and T3 gave significantly higher productive tillers/m^2 compared to control while other three were of the contrary. Significantly highest yield was recorded in treatment with 2 ton/ha azolla + Urea 72Kg N/ha + Fish (T2) yielding 4.160 ton/ha but this yield do not differ significantly to that of 2ton/ha azolla + Urea 48Kg N/ha+ Fish (T3). Urea 72 Kg N/ha + Fish (T1), Urea 72Kg N/ha + 3ton/ha straw + Fish and that Fish alone were significantly lower in yield compared to the latter two treatments, also significant difference in yield existed within the three treatments and also when each treatment is compared to control.

Nitrogen assimilated rice grain sink differed significantly within all treatments and also when each treatment was compared to control. Nitrogen content in straws had the same trend as that in rice grain as influenced by the six treatments, only that the value in straw was approximately half that of the grain. Plant height indicated positive correlation with both grain-N and straw-N.

Table 1. Mean effects of treatment combination on rice growth components and yield

Treatment	Height (cm)	Productive Tillers/m2	Grain yield Ton/ha	Grain-N Kg/ha	Straw-N Kg/ha
T1	104b	302c	3.670b	51.00b	20.900a
T2	133.2a	308.5b	4.160a	53.30a	21.175a
T3	84.5c	235.7a	4.140a	44.18c	17.750c
T4	85c	219.5f	3.505d	32.80d	18.900b
T5	71d	194.5g	2.120f	23.25g	12.750d
T6	89.2c	230e	3.980c	26.75f	12.925d
T7	89.75c	233.6d	3.070e	27.83e	13.050d
LSD (0.05)	5.533	2.13	0.0859	0.946	0.5575
SED	2.634	1.001	0.0409	0.450	0.2654

Values in the column followed by a different letter are significantly different at ($p \leq 0.05$).

TI=Urea at 72Kg N/ha + Fish; T2=Urea at 72Kg N/ha + 2ton/ha azolla incorporation + Fish; T3= Urea at 48kg N/ha + 2ton azolla incorporation + Fish; T4= Urea at 72 Kg N/ha + 3ton/ha straw incorporation + Fish; T5= Urea at 48Kg/ha + 3ton/ha rice straw incorporation + Urea 48Kg N/ha + Fish; T6= Fish as the only input; T7= control.

Post-harvest soil status data are presented in Table 2. The data showed that only two treatments - urea 72Kg N/ha + Fish and urea 48Kg N/ha + 3ton/ha straw + Fish – had significant increase in pH compared to control but the former had the highest value 6.68. The four other treatment neither differed significantly within the treatments nor when compared to control. Organic input of either azolla or straw yielded significant increase in soil organic carbon as compared to control or those without carbon rich organic input. Control (T7) had the least decline in available phosphorus when compared to all treatments.

All the two treatments with azolla in the combination had the highest residual nitrogen and there existed no significant difference between the two treatments. Low post-harvest soil Nitrogen status was registered in T1 despite having high input of commercial urea fertilizer. Fish alone (T6) had significantly higher post-harvest soil Nitrogen compared to control. All the soil treatments except that of Urea at 48Kg N/ha + 2ton/ha Azolla had significant (P=0.05) lower fish yield when compared to fish alone treatment. Treatment Urea at 72Kg N/ha with fish (T1) had the lowest fish yield. Comparing the two Urea levels at 72Kg N/ha and 48Kg N/ha, the higher dose of Urea had negative effect on yields of fish but to less extend on combination with Azolla.

Table 2. Post-harvest soil nutrient status after treatment application

Treatment	Soil pH	Soil Carbon (%)	OlsenP (mg/Kg)	Soil Nitrogen (%)
T1	6.683a	2.397d	55.82a	0.158d
T2	6.115c	3.000b	45.54e	0.345a
T3	6.145c	3.745c	47.86d	0.323a
T4	5.963d	3.990b	51.36c	0.251b
T5	6.328b	4.075a	51.00c	0.167c
T6	6.003d	2.412d	57.84b	0.179c
T7	5988d	2.397d	59.63a	0.104e
LSD (0.05)	0.1351	0.0504	0.851	0.0302
SED	0.0881	0.02399	0.405	0,0143

Values in the column followed by a different letter are significantly different at ($p \leq 0.05$).

TI=Urea at 72Kg N/ha + Fish; T2=Urea at 72Kg N/ha + 2ton/ha azolla incorporation + Fish; T3= Urea at 48kg N/ha + 2ton azolla incorporation + Fish; T4= Urea at 72 Kg N/ha + 3ton/ha straw incorporation + Fish; T5= Urea at 48Kg/ha + 3ton/ha rice straw incorporation + Urea 48Kg N/ha + Fish; T6= Fish as the only input; T7= control.

Table 3. Yield of fish as affected by other paddy-field nutrient input

Treatments	Fish yield (Kg/ha)
1	104.0c
2	114.7d
3	131.0a
4	108.3cd
5	121.0b
6	134.7a
LSD (0.05)	7.80

Values in the column followed by a different letter are significantly different at ($p \leq 0.05$).

TI=Urea at 72Kg N/ha + Fish; T2=Urea at 72Kg N/ha + 2ton/ha azolla incorporation + Fish; T3= Urea at 48kg N/ha + 2ton azolla incorporation + Fish; T4= Urea at 72 Kg N/ha + 3ton/ha straw incorporation + Fish; T5= Urea at 48Kg/ha + 3ton/ha rice straw incorporation + Urea 48Kg N/ha + Fish; T6= Fish as the only input.

DISCUSSIONS

Plant height may be determined by the genetic constitution of the cultivar. Additionally, plant height may be influenced by external factors, including status of soil fertility. The latter has been attested to by the experiment results in which higher application of Nitrogen resulted to taller rice crop than in low or no Nitrogen application. A combination of azolla, urea and fish posted higher grain yields even at low N-rates of commercial urea. This was evident when the results showed no significant difference ($P \leq 0.05$) between two urea rates N at 48Kg/ha and at 72Kg/ha in two treatment combination T2 and T3. The findings subsets (Watanabe, 1981; Bohlool et al., 1992), in which incorporation of two crops of azolla led to rice yield increase by about 20-42% accompanied by improvement of soil structure. The yield increase is due to decomposition of the incorporated azolla releasing nitrogen for the rice crop. Bohlool et al. (1992) have shown that azolla fixes N which is made available to rice upon death and decay. According to IRRI (1990), a combined rice-Azolla-fish culture protects the environment and increases the farmer's income through fish production and reduces fertilizers and pesticides.

Yields of the treatments combination (T4 & T5) with straw incorporation were low; this is attributed to immobilization of nitrogen by soil microbe. This has been noted by; immobilization of fertilizer nitrogen and crop residue N is one of the most critical aspects affecting long-term fertility in rice. It has also been shown that increased retention of N in the residue incorporated plots contributes to increased plant N availability in the second crop cycle in a fertilizer ^{15}N study. This can be confirmed by setting up residual experiment in the second season. Although the low N organic compounds will release ammonium ions, they decompose slowly under anaerobic conditions; so only substances with higher N percentages will release appreciable amounts of ammonium over a period of few weeks (FAO, 2006b).

The significantly ($P \leq 0.05$) higher rice yield in treatment with fish alone compared to control was most likely due to improved nutrient availability resulting from the excrements produced by fish as well as aeration of the growth medium as the fish move around. Fertilizer requirement is reduced with the introduction of fish (FAO, 2006b) and a rice field has a higher capacity to produce and capture nitrogen than one without fish. Assimilation of nitrogen in grain and straw is dependent on the N-sources applied to the soils. The nutrient replenishing idea can be explained taking reference to control in which during the experimental season 40.88Kg N was siphoned out without addition of nitrogen. Long term fertility trail in tropical and temperate region have shown that about 50Kg N/ha is absorbed by each rice grown without addition of fertilizer (Koyama & App, 1979).

Singh et al. (1980) have shown that 32-52 Kg N/ha is absorbed by the rice crop in the field without N application. This is a range within which the experiment results fits. Considering that on average fish input for each treatment was approximately 90 kg (15g×6000 fingerling/ha), there was a net gain in fish weights in all treatments at time of harvesting (98 DAS). The gains seem to have been influenced by environment, food supply or both. Little can be clearly explained in this experiment on the two factors and also on their interaction effects. For instance, the insignificant ($P \leq 0.05$) decline in treatment T3 could be due to better environment, i.e. less Urea, Azolla shading, and pH stabilization or N-rich food source Azolla. Isolation of the two factors is subject to research experiment.

Addition of ammonia to the soil is always accompanied by increase in soil pH. Hydrolysis of ammonia liberate OH- ions responsible for increase in soil reaction, this explain the value in treatment T1. Treatments with OMs straw or azolla exhibited a buffering effect and there was no significant difference at ($P \leq 0.05$) when compared to control, mainly due to weak organic acid produced under anaerobic decomposition which tends to counter the increase in soil pH. Urea rich fish droppings was confirmed by increase in soil pH in treatment T6 fish alone compare to control, due to urea dissociation followed by ammonium formation with hydroxyl ion liberation. The addition of organic matter inputs to soil increased soil total carbon a factor confirmed by significant increase in soil total carbon in treatment T2, T3, T4 &T5 compared to the control. OMs inputs addition to soil increased soil carbon was confirmed by significant increase in soil total carbon in treatment T2, T3, T4&T5 compared to control. Significantly ($P \leq 0.05$) higher post-harvest Olsen P in control explain the importance of synergic effect of soil N on uptake of phosphorus, i.e. increase in available N and its higher subsequent uptake increases uptake of phosphorus, and vice versa is true. This means absence of nitrogen input in control resulted into low available nitrogen to boost phosphorus uptake. Azolla application posted the highest residual nitrogen testifying its nitrogen bio-fixing.

CONCLUSIONS AND RECOMMENDATIONS

Rice-Azolla-fish culture exhibits high potential in increasing resource productivity and environmental conservation. Azolla, a cheap nitrogen source, on application showed improvement of soil nutrient status and rice yield. Straw application was accompanied by poor yields, due to N immobilization by microbes to decompose the carbon-rich material, and its viability as nutrient source is to be assets in results residual experiment. There is need to culture fish beyond rice harvest time 98 days after transplanting (DAT) probably for two season to achieve appreciable fish sizes by local who are used huge-sized from the Lake. The experiment testifies viability of rice-fish culture and recommends Urea at 48 N kg/ha + 2ton Azolla +fish (T3) and fish alone (T6) for resource poor farmers of Kano plains.

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BIO-DATA

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