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Effect of Water Management Systems with Different Nutrient Combinations on Performance of Rice on Soils of Mvumi, Kilosa District, Tanzania

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Abstract

A study was conducted on soils of Mvumi Village, Kilosa District, Tanzania to investigate the effect of water and nutrients on performance of rice so as to provide a gateway for improving rice production by manipulating water and nutrients. Pot experiment was laid in a split plot design with water management systems (SRI= Alternate wetting and drying, FLD= Continuous flooding) as main factor and nutrient combinations ($N_0P_0K_0S_0$, $N_{400}P_0K_0S_0$, $N_{400}P_{80}K_0S_0$, $N_{400}P_{80}K_{50}S_0$, $N_{400}P_{80}K_{50}S_{40}$) as sub-factor. $N_{400}P_{80}K_{50}S_{40}$ had significantly (p<0.05) higher number of tillers plant^{-1} (12.44), plant height (98.86 cm), grain yield (26.26 g plant^{-1}) and biomass yield (23.57 g plant^{-1}) as well as total P (0.27%), K (1.07%) and S (0.15%) concentrations in shoot than other treatments. On the other hand, the highest number of tillers plant^{-1} (11 tillers plant^{-1}), grain yield (20.74 g plant^{-1}), biomass yield (17.37 g plant^{-1}) and S (0.13%) concentration in shoot were recorded in SRI while the highest plant height (95.47 cm), N (2.02%), P (0.24%) and K (0.89%) concentrations in shoot were recorded in FLD. The results of interaction of nutrients and water showed that, grain yield increased significantly (p<0.05) from 4.71 g plant^{-1} to 27.37 g plant^{-1} in FLD + $N_0P_0K_0S_0$ and SRI + $N_{400}P_{80}K_{50}S_{40}$, respectively.

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Introduction

Rice (*Oryza sativa* L.) is the third most important food crop in Tanzania after maize and cassava in terms of both area cultivated and production (FAO, 2008). It is a major source of income and employment for the rural poor farmers (Ministry of Agriculture Food Security and Cooperatives (MAFSC, 2009). Rice is grown in almost all regions of the country. The major producers of rice in the country are Coast, Morogoro, Tabora, Mbeya, Mwanza, Shinyanga and Arusha Regions. The national total annual average production of rice was reported to be 1.35 million tonnes (Wilson and Lewis, 2015). This national average is very low and cannot meet the demand of the increasing population of the country. Annual per capita rice consumption increased by 6.15% per annum, rising from 20.5 kg in 2001 to 25.4 kg in 2011 (Wilson and Lewis, 2015). At a lower scale, rice yields in Kilosa are 44 246 ton year^{-1} (Kahimba et al., 2015). The smallholder farmers in Mvumi Village, Kilosa District, depend on pastoralism, rice (as food and cash crop) and maize production for their livelihood. It is therefore important to improve rice production.

The low yields of rice have been attributed to low soil fertility and poor water management (MAFSC, 2009). Low soil fertility is attributed to the type of soil as related to soil parent materials (Msanya et al., 2003) and poor nutrient management practices used by many farmers who tend to apply N fertilizers alone and thereby leading to the depletion of other nutrients (Amuri et al., 2013). Balanced fertilizer application is critical for obtaining optimum yields of rice. Tabar (2012) for instance reported the increase of tiller numbers, fertile fillers, total grain, 1000-grain weight and yield upon application of nitrogen and phosphorus. Potassium application on rice fields leads to the increase in plant height, number of tillers, size of panicles and yield of rice (Uddin et al., 2013). Sulphur has also been reported to influence growth and yield of rice, in which case Resurreccion et al. (2001) reported an increase in the relative growth rate (RGR) due to the increase in the net assimilation rate (NAR) upon the increase of sulphate concentration in soil. Likewise, Jawahar and Vaiyapuri (2010) reported the influence of S on rice growth in terms of plant height, number of tillers per plant and dry matter production as well as yield attributing characters such as number of panicles and number of grain per panicle. Judicious and proper use of fertilizers i.e. balanced application of fertilizers is therefore important so as increase the yield and improve the quality of rice (Alam et al., 2009). Also due to high depletion of nutrients through crop harvest, erosion and leaching, each nutrient should be applied constantly in agricultural field (Amuri et al., 2013). Water is crucial for growth and productivity of rice as it influences the availability of nutrients through its ability to solubilise nutrients making it easy for plants to absorb them from the soil as plants can only take up mineral nutrients dissolved in soil solution (Mengel et al., 2001). Also water can lead to loss of nutrients from soil through its influence on erosion and leaching if not managed properly.

In Tanzania, rice is predominantly produced by smallholder farmers under rain fed conditions. Smallholder farmers belonging to government controlled irrigation schemes have been reported to produce rice on medium sized farms ranging from 2 to 2.5 hectares (Wilson and Lewis, 2015). Due to unreliable rainfall, irrigation remains to be very important as far as rice production is concerned. However, irrigated rice production system has been stated to be the largest consumer of water in the agricultural sector (Uphoff, 2007; Lampayan and Tuong, 2007). Due to climate change and increasing urban and environmental demands on water, water scarcity has increased and this has endangered the sustainability, food production and ecosystem services of rice fields (Lybbert and Sumner, 2010). Hence, there is a need for improving water use efficiency especially in rice fields. Flooding is the commonly used irrigation system in irrigated rice cultivation. In this system water is delivered to the field by ditch, pipe or some other means and simply flows over the ground through the crop. With flood irrigation, large amount of water applied is lost through evaporation, runoff, infiltration of uncultivated areas and transpiration through the leaves of weeds. Due to this fact it is assumed that only half of the water applied actually ends up irrigating the crop. This makes the flooding method to be inefficient for rice production, and as a result, “System for Rice Intensification (SRI)” was developed so as to reduce losses of water and increase the productivity of rice.

SRI is an agro-ecological methodology for increasing the productivity of irrigated rice by changing the management of plants, soil, water and nutrients (SRI online, 2015). This system involves applying small amounts of water regularly or alternating wet and dry field conditions so as to maintain a mix of aerobic and anaerobic soil conditions (Uphoff, 2007). After flowering, a thin layer of water is kept on the field. This practice has been reported to result in higher yields ranging from 6 to 8 ton ha^{-1} with reduction of water consumption by an average of 50% (SRI online, 2015).Other than the report by Honde (2016) which showed the deficiency of some important nutrients for growth and productivity of rice and low yields that do not conform with SRI at Mvumi, there has been no study in Mvumi, Kilosa that has been conducted to investigate the effect of combining N, P, K and S with different water management systems on growth and yield of rice. Therefore, this study was conducted to compare the effect of different nutrient combinations under the two water management systems on the growth and yield of rice on the paddy soils of Mvumi Village, Kilosa District, Morogoro Region in Tanzania.

Specific objectives of this study were to determine: (i) the effect of nutrient combinations on growth, yield and nutrient contents of rice shoot (ii) the effect of water management systems on growth, yield and nutrient contents of rice shoot and (iii) the interaction effect of fertilizer combinations and water management systems on growth, yield and nutrient content of rice shoot.

Materials and methods

Description of the study area

Screen house experiments were conducted at Sokoine University of Agriculture to test the effect of water management systems and fertilizer combinations on the performance of rice. Soils for pot experiment were collected from the well characterized soils of rice growing farms at Mvumi Village, Kilosa District, Morogoro Region, Tanzania. The study site – Mvumi Village lies at latitude06° 35' 48.9" South and longitude 37° 13' 31.5" East with elevation of 413 m above sea level. Salient characteristics of the site are given in Table 1. The parent material of the site is alluvium derived from Gongwe Mountains. The soils are formed from alluvium plain with slope gradient of 0.5%. Surface is characterized by wide deep cracks extending from surface to more than 50 cm depth which implies the presence of Vertisols. No erosion signs were observed in the area but deposition occurs due to flooding during the rainy season. The soils are moderately well drained to somewhat poor drained. Annual rainfall ranges from 532.4 mm to 1536.8 mm. The maximum temperature varies between 29.2°C to 31.8°C and minimum temperature range between 20°C to 24.2°C.

Table 1. Salient characteristics of the studied site.

Attribute	Description
Coordinates	06° 35' 48.9" South and 37° 13' 31.5" East
Altitude	413 (m a. s. l.)
Parent material	Alluvium derived from Gongwe Mountains
Landform	Flat, alluvial plain
Land use	Agriculture mainly rice cultivation under basin irrigation system
Soil moisture regime	Ustic
Soil temperature regime	Isohyperthermic
Mean annual rainfall	1034.6 mm
Soil classification	Flat, Very Deep, Clayey, Mildly alkaline, Isohyperthermic Ustic Endoaquerts (Soil Taxonomy) and Haplic Vertisols (Hypereutric, Gilgaic, Gleyic, Mazic) (WRB)

Pot experiment

About 200 kg of soil were collected from a depth of 0 - 30 cm. The soil were taken to the laboratory, dried, ground to pass through 8 mm sieve and mixed thoroughly to form one uniform composite soil sample for pot experiment. Four kilograms of soil sample portions were weighed into 4.5 litre capacity plastic pots. Before planting in the nursery seeds were prepared by separating the unfilled grains from filled grains using salt water and egg technique and pre–germinating by soaking overnight and Incubated in a warm and shady place for two days. Rice SARO 5 (TXD 306) variety was used as a test crop. Split plot experimental design was used with water management systems in main plot and nutrients combinations in sub plot with three replications. There was two water management systems [SRI= Alternate wetting and drying (SRI technology) and FLD= Continuous flooding] and four nutrients combinations (N, NP, NPK, NPKS) and a control to form ten treatment combinations. The nutrients were applied at these rates: 400 mg N/kg soil, 80 mg P/kg soil, 50 mg K/kg soil and 40 mg S/kg soil. These treatments were designated as follows: $N_0P_0K_0S_0$, $N_{400}P_0K_0S_0$, $N_{400}P_{80}K_0S_0$, $N_{400}P_{80}K_{50}S_0$ and $N_{400}P_{80}K_{50}S_{40}$.

In SRI technology, transplanting was done 10 days after sowing and irrigation was done in alternate wet and dry manner where 2 cm layer of water was introduced followed by letting the pots to dry until cracks become visible then another thin layer was introduced where as in flooding transplanting was done 20 days after sowing and pots were flooded continuously followed by draining of the pots after maturity. In each pot three plants were transplanted. Triple super phosphates, muriate of potash and ammonium sulphate were applied during transplanting. Whereas urea was applied in two splits, one half after three weeks and the second half after 56 days. Data on plant height, number of tillers, grain and biomass yield were collected to test the effect of treatments on the growth and yield of rice. Biomass shoot samples were ground and sieved by using 0.5 mm sieve to form fine powder that was digested by the HNO_3 - H_2O_2 procedure and the digests were analysed for N, P, K and S contents following procedures described by Okalebo et al. (1993).

Statistical analysis

Collected data were subjected to one way Analysis of Variance (ANOVA) using the GenStat (14th edition) statistical software. Multiple comparisons of means for each parameter were performed using Duncan's Multiple Range Test at 5% level of significance. All variables recorded were analysed according to the following statistical model:

$$Yijk = U + Pj + Ti + \delta ij + Sk + (ST)ik + €ijk$$

Where,
Yijk = Response
U = Mean
Pj = Effect of block j (replication)
Ti = Effect of whole plot i (water management systems)
δij = error a
Sk = effect of split plot k (nutrient combinations)
(ST)ik = effect of interaction of water management systems and nutrient combinations
€ijk = error b.

Results and discussion

Effect of nutrient combinations on growth, yield and nutrient contents of rice

Biomass yield

Results of effect of nutrient combinations on the biomass yield are presented in Table 2. It is observed that application of N, P, K and S significantly (p<0.05) increased the biomass yield. The Control had the lowest biomass yield (3.56 g plant^{-1}) whereas the treatment with all nutrients applied together yielded highest biomass (23.57 g plant^{-1}).These results further depict that there was a significant (p<0.05) increase in biomass yield upon application of N over the Control. Also when P was applied in combination with N biomass yield increased significantly. Similarly there was a significant increase in biomass yield when K was combined with N and P, but there was no significant difference (p<0.05) that was observed when S was combined with N, P and K. Little response to the applied S could be due to the medium content of sulphur in the studied soil. Sulphur in the studied soil is 15.92 mg S kg^{-1} soil. According to Horneck (2011) this amount is classified as medium. However, there was the highest biomass yield when all four nutrients were applied in combinations. This agrees with the law of minimum which states that "If two or more factors are limiting or nearly limiting, addition of one will have a little effect on growth and yield, whereas provision of both or all will have much greater influence on yields" (Tisdale et al., 1993).

Number of tillers

Results on the effect of nutrient combinations on the number of tillers are presented in Table 2. Application of nutrients in combination significantly (p<0.05) increased the number of tillers. The lowest numbers of tillers (3.94 tillers plant^{-1}) were recorded in the control and the highest (12.44 tillers plant^{-1}) in the application of all four nutrients together (in combination). The number of tillers per plant increased significantly from 3.94 in the absolute control to 8.28 when N was applied. These results conform to the findings by Chaturvedi (2005) who reported a significance increase in number of tillers upon application of nitrogen. However when P was applied in combination with N the number of tillers increased significantly to 9.83 tillers plant^{-1} but there was no significant (p<0.05) increase in number of tillers when K was applied with N and P in combination. Tabar (2012) similarly reported an increase of number of tiller upon application of N and P together.

Also when sulphur was applied together with N, P and K the number of tillers increased significantly (p<0.05) to 12.44 tillers plant^{-1}. The results of this investigation are in agreement with those by Chaturvedi (2005). The significant increase in number of tillers upon application of these nutrients implies that N, P and S were the limiting nutrients for tiller formation in the studied soil.

Plant height

Plant height is one of the important growth and development indicators of rice. The response of the studied rice variety to the applied nutrient combinations in terms of plant height is presented in Table 2. The plant height increased significantly (p<0.05) from 69.72 cm in absolute control to 90.94 cm when N was applied. The increase in plant height in response to application of N can be attributed to enhanced availability of nitrogen which enhanced more leaf area resulting in higher photo assimilates and thereby in more dry matter accumulation (Chaturvedi, 2005). Similar results were obtained by Chen et al. (2013) who studied the effect of N on seed yield and yield components of *Leymus chinensis*. Also Chaturvedi (2005) and Malik et al. (2014) reported an increase in plant height when N was applied in rice. Plant height increased to 94.36 cm when P was applied in combination with N but slightly decreased to 92.94 cm when K was added in this combination. Tabar (2012) reported the increase in plant height when P is applied together with N to be due to the influence of these nutrients on plant growth and promotion of root development. Decrease in plant height when K was introduced in the combination could be due to reduction of N which is an important nutrient promoting plant growth. However when all four nutrients (N, P, K and S) were applied together plant height increased significantly ($p<0.05$) to 98.86 cm. These results are in close conformity with the findings of Dash et al. (2015).

Grain yield

The response of rice to the applied nutrients in terms of grain yield is presented in Table 2. There was a significant increase ($p<0.05$) in grain yield upon application of nutrients in combination. The lowest grain yield (4.91 g plant^{-1}) was obtained in $N_0P_0K_0S_0$ whereas the highest Grain yield (26.26 g plant^{-1}) was recorded in $N_{400}P_{80}K_{50}S_{40}$. Application of N increased the grain yield significantly from 4.91 g plant^{-1} in absolute control to 20.28 g plant^{-1}. However the yield increased further to 22.28 g plant^{-1} and 23.24 g plant^{-1} when P was applied together with N and K with P and N respectively. Similar results were obtained by Uddin et al. (2013) who found that application of N and N with K increased the grain yield by 1.39 ton ha^{-1} and 2.67 ton ha^{-1} respectively over the control. Tabar (2012) also reported significantly higher yield upon application of N and P in combination.

Significant higher yield of 26.26 g plant^{-1} was obtained in this study when all four nutrients (N, P, K and S) were applied together in combination. These results are in line with the previous study of Kumar et al. (2012) who reported an increased grain and straw yield by 16.2 and 18.5% respectively when S was applied in combination with N, P and K over the treatments without application of S. Also Kalala et al. (2016) reported that sulphur application at 20 mg S kg^{-1} doubled and tripled rice grain yield in paddy soils of Kilombero.

Table 2. Effect of nutrient combinations on growth and yield of rice.

Treatments	Biomass yield (g plant^{-1})	No. of tillers per plant	Plant height (cm)	Grain yield (g plant^{-1})
$N_0P_0K_0S_0$	3.56a	3.94a	69.72a	4.91a
$N_{400}P_0K_0S_0$	13.21b	8.28b	90.94b	20.28b
$N_{400}P_{80}K_0S_0$	18.06c	9.83c	94.36c	22.52bc
$N_{400}P_{80}K_{50}S_0$	23.47d	10.67c	92.94bc	23.24bc
$N_{400}P_{80}K_{50}S_{40}$	23.57d	12.44d	98.86d	26.26c
s.e.	3.99	2.54	0.66	3.05

Means in the same column bearing the same letter(s) are not significantly different at (P=0.05); s.e. = standard error. Treatment abbreviations with subscript numbers indicate the nutrient rates applied in mg kg^{-1}soil.

Nutrient content of rice shoots

Nitrogen

Table 3 presents results of nitrogen content in rice shoot as influenced by nutrient combination. The nitrogen content ranged from 1.18% in absolute control ($N_0P_0K_0S_0$) to 2.33% in treatment with N alone ($N_{400}P_0K_0S_0$). According to Thiagalingam (2000) categorization of N in plant tissue, N was deficiency in absolute control, $N_{400}P_{80}K_{50}S_0$ and $N_{400}P_{80}K_{50}S_{40}$ while in $N_{400}P_0K_0S_0$ and $N_{400}P_{80}K_0S_0$ was sufficiency.

It is further observed that the highest nitrogen content was obtained when nitrogen alone was applied but when nitrogen was combined with phosphorus, nitrogen content in biomass straw decreased from 2.33% to 2.04%, also when K was applied together with N and P and S with N, P and K the Nitrogen content in biomass straw decreased further to 1.83% and 1.93% respectively. These results are in agreement with the findings of Mamunur et al. (2016) who reported an increase in N content in rice plants upon application of Nitrogen fertilizer. Also he reported a decrease in N content in rice plants when K was applied.

Phosphorus

Phosphorus content in the rice biomass straw in respect to the applied nutrient combinations is tabulated in Table 3. The lowest P (0.12%) content was observed in absolute control, whereas as the highest (0.27%) P content was observed in $N_{400}P_{80}K_{50}S_{40}$ which received all nutrients (N, P, K and S) together. When nitrogen alone was applied the P content in the biomass straw increased from 0.12% in absolute control to 0.17%. This implies that N supply increased the ability of the plant to uptake/absorbs P from the soil. Similar results were obtained by Sanga (2013) who was working on sesame. Phosphorus content increased further to 0.25% when phosphorus was applied in combination with N, but when K was applied together with N and P the Phosphorus content decreased to 0.22%. Sanga (2013) reported an increase in P content in plant when phosphorus was applied and a decrease in P content when K was added. Similarly Hakan et al. (2010) reported a decrease in P content upon supply of K. Moreover P content increased to 0.27% when S was added in the combination. The increase or decrease in P content when another nutrient is applied is due to synergism or antagonism effect that a nutrient has with phosphorus.

Potassium

The potassium concentration in rice shoot differed significantly ($p \leq 0.05$) among the applied nutrient combinations (Table 3). The lowest K content (0.38%) was observed in the absolute control. But this concentration increased to (0.99%) and (0.84%) upon application of N alone and N with P, respectively. This implies that these nutrients (N and P) influenced the uptake of K form the soil. These results agree with the findings by Sanga (2013) who reported an increase in K content on sesame leaves from 1.42% to 2.94% and 3.70% after application of N alone and N with P respectively. The above results are also in close conformity with the findings by Dash et al. (2015) who reported a decrease in K concentration by 12.8 - 23% and 12.4 -16.6% in rice grain and straw upon omission of N and P in rice plant.

It is further reported that, in the current study K concentration in rice shoot increased to 1.07% when K was applied in combination with P and N. This observation is in agreement with the findings of Lema (2013) who found least potassium concentration (0.80%) in rice shoots tissues without potassium nutrition and the highest potassium concentration (1.05%) in 50 kg K ha^{-1} potassium treatment. Also the K content of 1.07% in this study was recorded in $N_{400}P_{80}K_{50}S_{40}$ which received all nutrients together.

Sulphur

Results of S content in the rice shoot in respect to the applied nutrients are presented in the Table 3. S content in this study ranged from 0.09% in $N_{400}P_{80}K_0S_0$ to 0.15% in $N_{400}P_{80}K_{50}S_{40}$. Dobermann and Fairhurts (2000) reported the optimum level of S in rice shoot to be 0.15% - 0.30% and the critical level of deficiency to be 0.11% at tillering stage. According to this categorization of S in rice shoot, it is observed in this study that treatment $N_{400}P_0K_0S_0$ had S deficiency whereas the remaining treatments had sufficient S content as they were above the critical level of deficiency. This study further showed that $N_0P_0K_0S_0$ which did not receive any nutrient had sufficient sulphur content. This is due to fact that the soil had medium S content (15.92 mg kg^{-1}) therefore there was some amount of S in the soil for plant uptake. It is also observed in this study that, when N alone was applied the S content decreased from 0.13% to 0.09%. This decrease in S content upon application of N could be due to antagonism effect of N in S, therefore in order to avoid this effect S must be supplied in the soil. However when P was applied in combination with N and K in combination with P and N the S content in rice shoot increased to 0.11% and 0.12% respectively. The highest S content (0.15%) was obtained in $N_{400}P_{80}K_{50}S_{40}$ which received all nutrients (N, P, K and S) together. Similar results were obtained by Sanga (2013) who reported an increase in S content in sesame leaves from 0.06% to 0.28% when S was applied in combination with N, P and K. Also the findings of the present study are in close conformity with the results reported by Rahman et al. (2007) who noted that concentration of S in rice plant increased with application of S.

Table 3. Effect of nutrient combinations on nutrient content of rice shoots.

Treatment	N	P	K	S
$N_0P_0K_0S_0$	1.18	0.12	0.38	0.13
$N_{400}P_0K_0S_0$	2.33	0.17	0.99	0.09
$N_{400}P_{80}K_0S_0$	2.04	0.25	0.84	0.11
$N_{400}P_{80}K_{50}S_0$	1.83	0.22	1.07	0.12
$N_{400}P_{80}K_{50}S_{40}$	1.93	0.27	1.07	0.15

Treatment abbreviations with subscript numbers indicate the nutrient rates applied in mg kg^{-1} soil.

Effect of water management systems on growth, yield and nutrient contents of rice

The response of rice to water management systems applied to the Vertisols of Mvumi Village, Kilosa District in terms of plant height, number of tillers, biomass yield, grain yield and nutrient content are discussed in this section.

Growth and yield of rice

Results on the influence of water management systems (SRI and continuous flooding) on the growth and yield of rice are presented in Fig. 1. It is observed that the straw biomass yield, number of tillers and grain yield were higher in a SRI water management system than in continuous flooding. In contrary plant height was higher in continuous flooding water management system than in SRI. Apart from being irrigated in alternate wet and dry manner also plants in SRI were transplanted early (at 8 days) whereas in continuously flooding seedlings were transplanted conventionally at 18 days. A relative higher straw biomass yield, number of tillers and grain yield in SRI could be due to early transplanting of the seedling which is far more important in preserving plant's potential for tillering and root growth that is reduced by later transplanting, also old seedling results in lower rice yields because they suffer from stem and root injury during pulling (Ashraf et al., 1999). Ali-Elhefnawy (2012) reported an increase in number of tillers and grain yield when seedlings were transplanted with young age. Uphoff and Fernandes (2002) suggested that the use of young seedlings is the single most important component practice of SRI, increasing yield in Madagascar by 2.5 ton ha^{-1}. Similar results were obtained by Ram et al. (2014).

Water management systems had a significant effect on days to flowering and harvest. Days to flowering and harvesting were reduced by 10 days and 14 days respectively in SRI. SRI plants began to flower at 83 days after sowing and harvested after 120 days compared to 93 days and 134 days for flowering and harvest respectively, in continuous flooding. The results of this study are in agreement with a previous study by Chapagain et al. (2011) who reported the reduction of flowering and harvesting days by 8 and 12 days in SRI respectively.

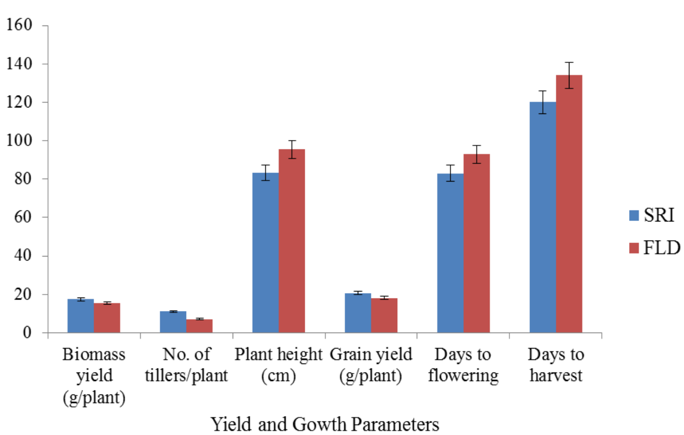

Fig. 1: Effect of water management systems on growth and yield of rice.

Nutrient content of rice shoots

The concentrations of nutrients (N, P, K and S) in rice shoot as influenced by water management systems are presented in Fig. 2. It is observed that N, P and K were higher in flooded than in SRI plants whereas S was higher in SRI plants than in flooded plants. Nitrogen concentration in SRI plants was 1.7% while in flooded plants was 2.02%. High Nitrogen content observed in flooded plants could be due to mineralization of N which led to accumulation of NH_4^+ after few days of flooding (Dobermann and Fairhurts, 2000). Also Zhao et al. (2010) reported higher Ammonium volatilization in SRI than in Traditional Flooding, which implies more intensive N loss under SRI. Early results by Baque et al. (2006) also indicated reduction of N uptake by plant under water stress. On the other hand potassium concentration was 0.86 % and 0.89 % in plants receiving SRI and flooding water treatments respectively. Higher K content in flooded plants could be due to the increased release of exchangeable K into the soil solution and enhanced K diffusion to rice root following the reduction of Fe^{3+} and Mn^{4+} which displaces K^+ from CEC sites (Dobermann and Fairhurts, 2000).

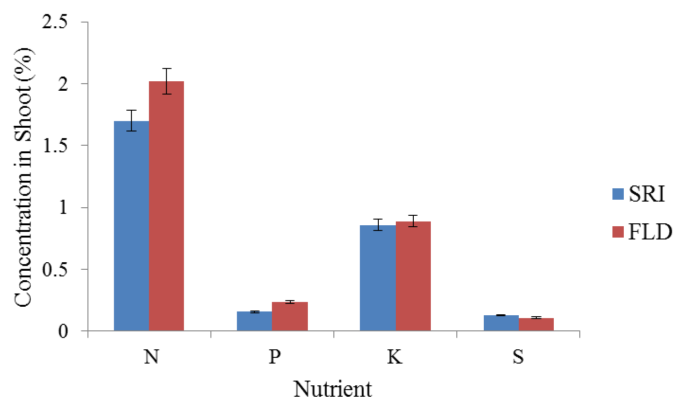

Fig. 2: Effect of water management systems on rice shoot nutrient content.

Phosphorus was higher in flooded plants (0.24%) than in SRI (0.16%) plants. Higher phosphorus in flooded plants could have been influenced by release of sorbed and co-precipitated P following the reduction of Fe^{2+} compounds which increases concentration of P in the soil solution (Dobermann and Fairhurts, 2000). Also flooding enhances diffusion which is the main mechanism of P supply to root (Dobermann and Fairhurts, 2000). These results are in line with the previous findings of Huguenin et al. (2003) who found that in the flooded soil the uptake of P was three times that in the moist soil and there was a sharp decline in P uptake in alternate wet and dry soil because in dried soil P became immobilized in the soil. Sulphur was the only nutrient that was observed to be higher in SRI plants (0.13%) than in flooding (0.11%). Lower S in flooded plants could be due to reduction of SO_4^{2+} to elemental S and the formation of sulphides following Fe reduction in flooded soils. This reduction leads to S deficiency in flooded soils (Dobermann and Fairhurts, 2000).

Interaction effect of fertilizer combinations and water management systems on growth, yield and nutrient content of rice shoot

Growth and yield of rice

The interaction effect of different combinations of fertilizer and water management systems on growth and yield of rice is shown in Table 4. The straw biomass yield, plant height, number of tiller and grain yield was significantly different (p<0.05). The highest biomass yield of rice straw (25.23 g plant^{-1}) was recorded in treatment combination SRI + $N_{400}P_{80}K_{50}S_0$ which was statistically similar to FLD + $N_{400}P_{80}K_{50}S_{40}$ (24.19 g plant^{-1}), on the other hand the lowest biomass yield (3.07 g plant^{-1}) was recorded in SRI+ $N_0P_0K_0S_0$ which was statistically similar to FLD + $N_0P_0K_0S_0$ and FLD + $N_{400}P_0K_0S_0$ treatment combinations. In case of the plant height, the highest plant height (109 cm) was recorded in treatment combinations FLD + $N_{400}P_{80}K_{50}S_{40}$ and the lowest (63.44 cm) was recorded in SRI + $N_0P_0K_0S_0$ treatment combinations. The order of increase in plant height due to interaction effect of nutrients and water management systems was as follows: SRI + $N_0P_0K_0S_0$ < FLD + $N_0P_0K_0S_0$ < SRI + $N_{400}P_{80}K_{50}S_0$ < SRI + $N_{400}P_0K_0S_0$< SRI + $N_{400}P_{80}K_0S_0$ < SRI + $N_{400}P_{80}K_{50}S_{40}$ < FLD + $N_{400}P_0K_0S_0$ < FLD + $N_{400}P_{80}K_{50}S_0$ < FLD + $N_{400}P_{80}K_0S_0$ < FLD + $N_{400}P_{80}K_{50}S_{40}$. On the other hand the highest number of tiller (14.56) was recorded in treatment combination SRI + $N_{400}P_{80}K_{50}S_{40}$ which was not statistically different to SRI + $N_{400}P_{80}K_{50}S_0$ treatment combinations and the lowest number of tillers (3.78) was recorded in FLD + $N_0P_0K_0S_0$ treatment combinations. Grain yield which is the main concern to farmers were significantly higher (27.37 g plant^{-1}) in treatment combinations SRI + $N_{400}P_{80}K_{50}S_{40}$ and low (4.71 g plant^{-1}) in FLD + $N_0P_0K_0S_0$ treatment combinations, a six fold increase.

Nutrient content of rice shoot

The combined effect of nutrients combinations and water management systems on nutrient content of rice shoot was significantly different (p<0.05) (Table 4). The highest nitrogen concentration (2.80%) was recorded in the treatment combination FLD + $N_{400}P_0K_0S_0$ which were followed by FLD + $N_{400}P_{80}K_0S_0$ (2.25%). On the other hand, the lowest nitrogen concentration (1.12%) was observed in the treatment combination FLD + $N_0P_0K_0S_0$ which were not significantly different from SRI + $N_0P_0K_0S_0$.

Table 4. Interaction effect of fertilizer combinations and water management systems on growth, yield and nutrient content of rice.

Treatments	N	P	K	S	Tillers (no./ plant	Biomass yield (g plant^{-1})	Plant height (cm)	Grain yield (g plant^{-1})
	%							
FLD + $N_0P_0K_0S_0$	1.12a	0.12a	0.48a	0.11a	3.78a	4.05a	76 b	4.71a
FLD + $N_{400}P_0K_0S_0$	2.80d	0.21b	0.97bc	0.09a	5.78bc	9.17a	93.72 de	15.65b
FLD + $N_{400}P_{80}K_0S_0$	2.25c	0.30d	0.77b	0.09a	7.33cd	17.76b	100.17f	20.64bc
FLD + $N_{400}P_{80}K_{50}S_0$	1.90bc	0.26c	1.15c	0.12ab	8.11d	21.71c	98.33ef	22.35bc
FLD + $N_{400}P_{80}K_{50}S_{40}$	2.02bc	0.32d	1.08bc	0.13ab	10.33e	24.19bc	109g	25.15bc
SRI + $N_0P_0K_0S_0$	1.24a	0.11a	0.28a	0.15bc	4.11ab	3.07a	63.44a	5.11a
SRI + $N_{400}P_0K_0S_0$	1.86bc	0.13a	1.02bc	0.09a	10.78ef	17.25b	88.17cd	24.90bc
SRI + $N_{400}P_{80}K_0S_0$	1.82bc	0.20b	0.91bc	0.12ab	12.33fg	18.36b	88.56cd	24.40bc
SRI + $N_{400}P_{80}K_{50}S_0$	1.76b	0.18b	0.99bc	0.12ab	13.22gh	25.23bc	87.56c	24.12bc
SRI + $N_{400}P_{80}K_{50}S_{40}$	1.84bc	0.21b	1.07bc	0.17c	14.56h	22.96c	88.61cd	27.37c
CV %	12.3	10.9	18.5	16.4	11.3	22.8	3.5	27.3
s.e.	0.23	0.02	0.16	0.02	1.02	3.73	3.15	5.31

Means in the same column bearing the same letter(s) are not significantly different at (P=0.05); CV = Coefficient of variations; s.e.= standard error; Treatment abbreviations with subscript numbers indicate the nutrient rates applied in mg kg^{-1} soil.

The concentration of phosphorus in rice shoot differed significantly among the treatment combinations. The highest phosphorus concentration in rice shoot (0.32%) was obtained with the treatment combination FLD + $N_{400}P_{80}K_{40}S_{40}$ which were not significantly different from 0.30% in FLD + $N_{400}P_{80}K_{0}S_{0}$. On the other hand, the lowest phosphorus concentration (0.11%) was observed in the treatment combination SRI + $N_{0}P_{0}K_{0}S_{0}$ which were statistically similar with FLD + $N_{0}P_{0}K_{0}S_{0}$ and SRI + $N_{400}P_{0}K_{0}S_{0}$. The highest K concentration in rice shoot (1.15%) was obtained in FLD + $N_{400}P_{80}K_{40}S_{0}$ treatment combination followed by 1.08% in treatment combination FLD + $N_{400}P_{80}K_{50}S_{40}$. The lowest K concentration (0.28%) was recorded in treatment combination SRI + $N_{0}P_{0}K_{0}S_{0}$ which were significantly similar to 0.48% in FLD + $N_{0}P_{0}K_{0}S_{0}$. The highest concentration of sulphur in rice shoot (0.17%) was found in treatment combination SRI + $N_{400}P_{80}K_{50}S_{40}$ followed by 0.15% in SRI + $N_{0}P_{0}K_{0}S_{0}$. The lowest concentration (0.09%) was obtained from FLD + $N_{400}P_{0}K_{0}S_{0}$ which were statistically similar to FLD + $N_{0}P_{0}K_{0}S_{0}$ and SRI + $N_{400}P_{0}K_{0}S_{0}$.

Conclusion

It was concluded from the results of this study that N, P, K and S were the major nutrients limiting growth and yield of rice in the study area as application of these nutrients together led to better growth and higher yields of rice. System of Rice Intensification (SRI) was the best in promoting growth and yield of rice while the traditional method of rice farming had positive effects on nutrient availability and uptake. Moreover, adoption of SRI together with application of all four nutrients in combination resulted in higher yields. Two pertinent recommendations were made from the results of the study: (1) N, P, K and S should be applied to improve rice productivity (2) Since the study was conducted in a pot experiment under controlled environment, further research needs to be conducted under field conditions to validate and clarify further nutrient patterns in soil and response of rice plants under field conditions.

Conflict of interest statement

Authors declare that they have no conflict of interest.

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