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ANALYSIS OF GRAIN YIELD COMPONENTS OF SELECTED UPLAND RICE GROWN IN VALLEY BOTTOM SOIL UNDER RATES OF FOLIAR ORTHO-SILICATE ACID FERTILISER

S.O. OLAGUNJU, O.S. SAKARIYAWO[1], M.O. ATAYESE[1], E.O. DARE[2], A.L. NASSIR and E.H. ADESINA

Department of Crop Production, College of Agricultural Sciences, Olabisi Onabanjo University, P.M.B. 0012, Ayetoro Campus, Ayetoro, Ogun State, Nigeria
[1]Department of Plant Physiology and Crop Production, Federal University of Agriculture, Abeokuta (FUNAAB), P.M.B. 2240. Alabata, Ogun State, Nigeria
[2]Department of Chemistry, Federal University of Agriculture, Abeokuta (FUNAAB), P.M.B. 2240, Alabata, Ogun State, Nigeria
Corresponding author: solomondwiseman@yahoo.com, olagunju.solomon@oouagoiwoye.edu.ng

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ABSTRACT

Attainment of potential yield (PY) of upland rice grown in valley bottom (VB) soil is limited by inadequate supply of beneficial nutrients. Previous study revealed that VB soil increase grain weight plant^{-1} (GWP) in upland rice by 70%, which is still far below its PY. Application of ortho-silicate acid (OSA) fertiliser, as silicon source at optimum rate, could help to boost the yield of upland rice. Five upland rice cultivars, comprising of three medium maturing (NERICA 1,4,7) and late maturing (MOROBEREKAN and OFADA), were grown in pots filled with VB soil. Four rates of foliarly applied OSA fertiliser (0, 250, 500, and 750 ml ha^{-1}) were imposed across stages of growth of rice cultivars. OSA fertiliser increased GWP significantly (P<0.01) with application of 500 ml ha^{-1} having the best effect. At 250 ml ha^{-1}, 1000 grain weights was more associated with number of branches panicle^{-1} and number of grains branch^{-1} panicle^{-1}; while at 500 ml ha^{-1}, GWP was closely associated with % number of fertile spikelets panicle^{-1} plant^{-1} (%NFSPP), total weight of panicle plant^{-1} (TWPP) and length of panicle plant^{-1} (LPP). Total number of spikelets plant^{-1} was more associated with total number of panicle plant^{-1} at 750 ml ha^{-1}. The highest significant (P<0.01) GWP was observed in MOROBEREKAN (9.27 g plant^{-1}); while the lowest was in Ofada (4.79 g plant^{-1}). Application of 500 ml ha^{-1} of the fertiliser is recommended for these rice cultivars. Further improvement in yield of upland rice grown on VB soil under foliarly applied silicon should focus on % NFSPP, TWPP, and LPP.

Key Words: Foliar application, OSA fertiliser, upland rice, yield components

RÉSUMÉ

L'atteinte d'un rendement potentiel (RP) de riz pluvial cultivé dans le sol de fond de vallée (FV) est limitée par un apport insuffisant de nutriments bénéfiques. Une étude précédente a révélé que le sol de fond de vallée (VB) augmente le poids de grain par plante (PGP) dans le riz pluvial de 70%, ce qui est encore bien en dessous de son rendement potentiel (RP). L'application d'engrais d'acide orthosilicate (AOS), comme source de silicium à un taux optimal, pourrait aider à augmenter le rendement du riz pluvial. Cinq cultivars de riz pluvial, comprenant trois à maturation moyenne (NERICA 1,4,7) et à maturation tardive (MOROBEREKAN et OFADA), ont été cultivés dans des pots remplis de terre FV. Quatre taux d'engrais AOS appliqués par voie foliaire (0, 250, 500 et 750 ml ha^{-1}) ont été imposés à tous les stades de croissance des cultivars de riz. L'engrais AOS a augmenté PGP de manière significative (P <0,01) avec l'application de 500 ml ha^{-1} ayant le meilleur effet. À 250 ml ha^{-1}, 1000 poids de grain étaient davantage associés au nombre de branches par panicule et au nombre de grains par branche et par panicule; alors qu'à 500 ml ha^{-1}, PGP était étroitement associé au% nombre d'épillets fertiles par panicule et par plante (% NEFPP), au poids total de la panicule par plante (PTPP) et à la longueur de la panicule par plante (LPP). PGP significatif le plus élevé (P <0,01) a été observé à MOROBEREKAN (9,27 g $plante^{-1}$); tandis que le plus bas était à Ofada (4,79 g de $plante^{-1}$). L'application de 500 ml ha^{-1} d'engrais est recommandée pour ces cultivars de riz. Une amélioration supplémentaire du rendement du riz pluvial cultivé sur le sol FV sous silicium appliqué par voie foliaire devrait se concentrer sur le% NEFPP, PTPP et LPP.

Mots Clés: Application foliaire, engrais OSA, riz pluvial, composants de rendement

INTRODUCTION

Silicon is a trace element that is beneficial to plants, though its absence does not prevent plants from completing their life cycles (Liang *et al.*, 2005). The beneficial role of silicon is linked to its ability to alleviate both biotic and abiotic stresses, such as moisture stress, and pest and disease attacks, eventually leading to improvement in growth and yield (Guntzer *et al.*, 2012; Luyckx *et al.*, 2017). The element, though abundant in soil, is usually not available in the form that plant can easily absorb. Nonetheless, differences in silicon uptake ability of plant roots have resulted in differential ability of plant to absorb silicon into plant tissue (Hernandez-Apaolaza, 2014).

In the family of Poaceae to which rice, sugarcane, wheat, maize and other cereal belong, rice is the second largest accumulator of silicon with rates, as high as 130 g kg^{-1} in straw, to about 350 g kg^{-1} in joints (Currie and Perry, 2007). Despite the preference of rice for silicon absorption, it still benefits from silicon application as fertiliser as expressed through increased grain yield.

Silicon supply to plant is usually achieved in the form of soil or foliar application. The inability of some plants to absorb the element from soil has made it necessary to make it available in liquid form that can easily be incorporated into plant tissues. Indeed, Jamal *et al.* (2006) observed that in many cases, foliar applied nutrients gives quicker and better results, and are preferred to soil applied nutrients. This is because they are more effective and economical than soil applied fertiliser (Fageria *et al.*, 2009). Formulation of silicon as liquid fertilisers has been an alternative way of improving silicon absorption, leading to increase in effectiveness of the element in plants. The benefits that upland rice can derive in terms of grain yield increase from this form of application; however, this needs to be further explored in order to further reduce the yield gap between potential and actual yield of upland rice cultivars.

Silicon increases grain yield of rice through reduced loss of water to transpiration, improvement in photosynthesis, erectness of leaf which allows penetration of more light into the crop canopy, among others (Gao *et al.*, 2006; Ma and Yamaji, 2006; Chen *et al.*, 2011). The increase in biomass achieved through improvement in these physiological and morphological features of rice, results in increased proportion of biomass allocated to both vegetative and reproductive structures such as panicles (Etesami and Jeong, 2018). Increased allocation of biomass to reproductive organs could be the first step in achieving higher grain yield increase in upland rice. An earlier study conducted on upland rice grown on valley bottom soil of a toposequence, established higher grain yield, association with increase fraction of biomass to reproductive organs (Olagunju *et al.*, 2018). The understanding of grain yield and yield components association that lead to higher grain yield in rice cultivars grown on this soil, and the benefit that OSA fertiliser can bring offers insights into both varietal development and management towards further ensuring higher yields. Grain yield is a product of improvement in total number of panicles, total number of spikelets, percentage fertile spikelets per hill, as well as 1000 grain weight (Yoshida, 1981). Some of these components can be influenced by foliar applied silicon.

Reducing the yield gap between potential and actual yield in upland rice requires meeting the nutrient demand of crops since about 30 to 50% increase in yield has been attributed to nutrient input alone, in places within temperate climate such as USA and England (Stewart and Roberts, 2012). Although silicon fertiliser has been applied to soil for possible increase in yield of rice, little is known about the effect of foliar ortho-silicate acid (OSA) fertiliser on grain yield of upland rice. An attempt has also been made to study the correlations among these various components and grain yield, but the influence of OSA fertiliser rates on these correlations is yet to receive attention. This study, therefore, addressed the effect of OSA fertiliser rates on panicle and grain yield characteristics of selected upland rice cultivars grown on valley bottom soil; and to identify the components of yield that mostly contribute to increased grain yield of upland rice under this condition.

MATERIALS AND METHODS

Experimental site. A pot experiment was conducted at the Teaching and Research Farm of College of Agricultural Sciences, Olabisi Onabanjo University, Ayetoro in Nigeria. The topography of the area from which the soil was collected, slopes towards a river with variations in soil physical and chemical properties. The soil used in the study was collected from valley bottom soil of the toposequence and is loamy-sand according to USDA soil textural triangle calculator.

Soil samples and laboratory analyses. Soil in valley bottom of a toposequence was scooped from 0-15 cm depth, and homogenised through thorough mixing with a shovel on site. Samples of the soil were collected before potting, air dried and sieved with 2-mm sieve; before being subjected to laboratory analyses. Soil pH was determined using a glass electrode pH meter in 1:2 soil water ratio (McLean, 1982). Using the hydrometer method, particle size distribution was determined as described by Gee and Bauder (1986). Ammonium acetate method was used to extract exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) in the soil (Thomas, 1982); while Buck Scientific 210 VGP model, Atomic Absorption Spectrophotometer (AAS) was used to determine Ca^{2+} and Mg^{2+}; following extraction of exchangeable bases. Potassium and sodium were read on flame photometer.

Exchangeable acidity was determined by the titration method proposed by Anderson and Ingram (1993). Exchangeable bases and exchangeable acidity were summed to estimate Effective Cation Exchange Capacity (ECEC) (Anderson and Ingram, 1993).

The Kjeldahl method was used to determine the total nitrogen (Bremner, 1996). Organic carbon was determined by the wet oxidation method as described by Walkley-Black (Nelson and Sommer, 1996). Available phosphorus was also determined using Bray-1 method (Bray and Kurtz, 1945).

Experimental methods. The experiment comprising of four rates of OSA fertiliser 0, -250, 500 and 750 ml ha^{-1}, five upland rice cultivars, namely early maturing (NERICA 1,4,7) and late maturing (MOROBEREKAN and OFADA), with three replications was established in an open field in sixty 5-liter pot size. Each of the pots was filled with 5 kg of the homogenised soil. The pots were later arranged in a completely randomised design. Seeds of five upland rice varieties were each nursed in pots which were nurtured for 21 days, then the seedlings were transplanted into already prepared pots at one seedling per pot.

At one week after transplanting (WAT), N:P:K 15:15:15 fertiliser, was applied at the rate of 30 kg ha^{-1}; while the remaining dose of nitrogen (80 kg ha^{-1} N) fertiliser was applied at seventh WAT using urea. At two WAT, application of Ortho Silicate Acid (OSA) as foliar fertiliser commenced through spraying of the rice cultivars with well-prepared solution of the fertiliser, which continued till grain filling stage. The OSA fertiliser was applied four times based on the recommended spray schedule by the manufacturer. The first application was carried out at the beginning of second week after transplanting (WAT); while second, third and fourth applications of the fertiliser were done at two weeks interval.

Watering of potted plants was by rainfall; while irrigation water of 40 mm day^{-1} pot^{-1}, equivalent to daily rainfall for the area (Nassir and Adewusi, 2011; Olagunju *et al.*, 2018), was supplied during periods when potted soil was observed to be drying based on the principle that soil drying starts from the surface (Yoshida, 1981).

Rice panicles were harvested at maturity when grains were hard to touch and when the milky assimilates could not be forced out of the spikelets (Motuzaite-Matuzeviciute *et al.,* 2012).

Data collection. Data on yield variables were taken at harvest maturity from the rice plants. All the panicles on each plant were harvested and each of the panicle was assessed for grain yield components. The total number of panicle $plant^{-1}$ (TNPP) was taken by counting all panicles on each plant. Weight of each panicle was obtained with sensitive Electronic Compact Scale (ATOM A-110C), China, after which all the weights were summed to obtain total weight of panicle $plant^{-1}$ (TWPP). The length of each panicle $plant^{-1}$ (LPP) was taken by measuring the length from the panicle neck to the tip of the panicle. Number of branches on each panicle were also counted to obtain number of branches $panicle^{-1}plant^{-1}$ (NBPP).

The number of grains on terminal, middle and basal branches were counted and averaged across the three branches to obtain number of grains $branch^{-1}$ $panicle^{-1}$ $plant^{-1}$ (NGBPP). The total number of the spikelets $panicle^{-1}$ $plant^{-1}$ (TNSPP) was estimated by multiplying the number of branches by the number of grains per branch on each panicle. The number of unfilled spikelets on each panicle was also counted and deducted from the total number of spikelets to obtain total number of filled spikelets.

Percentage number of fertile spikelets $panicle^{-1}$ $plant^{-1}$ (%NFSPP) was determined from the proportion of filled grains in the total spikelets of each panicle. These yield components were later averaged across panicles on each plant to obtain respective reading per plant. The panicles were threshed and the empty grains, usually white in colour (Kobata *et al.,* 2013), were blown off after threshing manually to obtain the weight of filled grains. Grain weight $plant^{-1}$ (GWP) was determined after threshing all panicles and removing the rachis. One thousand grain weights (1000GW) were determined by counting 1000 grains and weighing them.

Statistical analyses. Data collected were subjected to Analyses of Variance (ANOVA); while significant means were separated using Fischer's Protected Least Significant Difference (LSD) test at 5% level of significance. All count data that violated the assumptions of ANOVA were transformed using square root transformation. Correlation and principal components analyses (PCA) bi-plot were conducted to assess the interrelationships among the grain weight and yield components and rates of the fertiliser; as well as the rice cultivars. Data for both correlation and PCA bi-plot were logarithm transformed before analyses to normalise the data. The statistical package used was GenStat 12th edition (Payne *et al.*, 2009).

RESULTS

The result of analyses conducted on the soil used in the study is presented in Table 1. The percentage of sand in the soil was higher (83.60%) than that of silt (8.80%) and clay (7.60%) which classified the soil as loamy-sand. The pH of the soil is near neutral (6.40). The exchangeable Ca and Mg contents of the soil 7.78 and 2.26 cmol kg^{-1}, respectively were moderately higher while the potassium level (0.07 cmol kg^{-1}) in the soil was very low compared to critical potassium level of 0.15 cmol kg^{-1}. Exchangeable sodium (0.17 cmol kg^{-1}) was also low while the ECEC (10.35 cmol kg^{-1}) was higher than the critical level of 8.0 cmol kg^{-1} for low soil fertility in tropical soils. The exchangeable acidity (Al and H) was low (0.07 cmol kg^{-1}) while the percentage base saturation of 99.32% is very high. Total nitrogen (0.09 g kg^{-1}) and organic carbon (0.69 g kg^{-1}) were very low. The available phosphorus of 3.25 mg kg^{-1} is low when compared with the critical level of 8.0 mg kg^{-1} in non-degraded soil.

TABLE 1. Physicochemical properties of the valley bottom soil of the toposequence before the study.

Physicochemical properties	Soil composition
pH	6.40
Sand (g kg^{-1})	83.60
Silt (g kg^{-1})	8.80
Clay (g kg^{-1})	7.60
Texture	Loamy-sand
Ca (cmol kg^{-1})	7.78
Mg (cmol kg^{-1})	2.26
K (cmol kg^{-1})	0.07
Na (cmol kg^{-1})	0.17
Al+H (cmol kg^{-1})	0.07
ECEC (cmol kg^{-1})	10.35
Base Saturation (%)	99.32
Total N (g kg^{-1})	0.09
Organic Carbon (g kg^{-1})	0.69
Av_P (mg kg^{-1})	3.25

ECEC = Exchangeable Cation Exchange Capacity; Av.P = Available phosphorous

The effect of OSA rates and cultivars on grain weight and yield components of selected rice cultivars under foliar applied silicon was significant for all the variables among the cultivars (Table 2). A significant ($P<0.01$) effect of OSA fertiliser rates was only observed on percentage number of fertile spikelets (%NFSPP) and grain weight plant^{-1} (GWP). The least %NFSPP (48.8%) and GWP (4.67g) were obtained with the control.

Significant differences in grain weight and its components were observed among the cultivars, with OFADA maintaining the lowest ($P<0.01$) values for all, except TNPP and 1000 GW. The lowest TNPPP (2.50) and 1000 GW (21.8 g) were observed in MOROBEREKAN and NERICA 1, respectively. The highest TNPP (3.92) and TWPP (9.47 g) were observed in NERICA 1 and 4, respectively; while MOROBEREKAN maintained the longest LPP (26.74 cm), NBPP (13.29) and %NFSPP (78.60%). The highest NGBPP (11.02) and TNSPP (472) were observed in NERICA 1; while highest 1000 GW (29.10 g) and GWPP (8.52 g) were observed in NERICA 4. No significant interaction between OSA fertiliser rates and cultivars was observed for grain

TABLE 2. Effect of rates of Ortho-Silicate Acid fertiliser and cultivar on grain weight and its attributes of selected upland rice cultivar

Sources of variation	Levels of variation (ml ha^{-1})	Total number panicle plant^{-1} (TNPP)	Total weight of panicle plant^{-1} (TWPP)	Length of panicle plant^{-1} (LPP)	Number of branches panicle^{-1} (NBPP)	Number of grains branch^{-1} plant^{-1} (NGBPP)	Total number of spikelet panicle^{-1} plant^{-1} (TNSPP)	Percentage number fertile spikelets panicle^{-1} plant^{-1} (%NFSPP)	One thousand grain weight-1000 GW (g)	Grain weight plant^{-1} GWP (g)
OSA	0	3.20^{a}	6.18^{a}	21.85^{a}	10.87^{a}	9.07^{a}	318^{a}	48.80^{b}	26.0^{a}	4.67^{b}
Fertiliser	250	3.53^{a}	7.64^{a}	22.98^{a}	10.98^{a}	9.03^{a}	356^{a}	69.30^{a}	27.7^{a}	7.58^{a}
Rates (R)	500	3.73^{a}	9.06^{a}	23.12^{a}	10.80^{a}	9.46^{a}	387^{a}	71.30^{a}	26.1^{a}	8.51^{a}
(ml ha^{-1})	750	3.80^{a}	8.47^{a}	22.49^{a}	10.68^{a}	8.96^{a}	410^{a}	66.70^{a}	25.2^{a}	7.17^{a}
	LSD (0.05)	0.18^{t}	2.50	1.69	0.17^{t}	0.20^{t}	2.79^{t}	0.63^{t}	2.5^{a}	2.21
	Significance	ns	ns	ns	ns	ns	ns	**	ns	**
Cultivars (C)	NERICA 1	3.92^{a}	7.60^{a}	20.69^{c}	9.74^{c}	11.02^{a}	472^{a}	58.30^{bc}	21.8^{c}	6.62^{ab}
	NERICA 4	3.83^{a}	9.47^{a}	22.58^{b}	10.56^{bc}	9.25^{b}	387^{ab}	63.40^{b}	29.1^{a}	8.52^{a}
	NERICA 7	3.75^{a}	8.68^{a}	23.31^{b}	11.10^{b}	9.45^{b}	399^{ab}	66.60^{ab}	26.9^{ab}	7.42^{a}
	MOROBEREKAN	2.50^{b}	9.05^{a}	26.74^{a}	13.29^{a}	9.46^{b}	337^{bc}	78.60^{a}	28.5^{a}	7.54^{a}
	OFADA	3.83^{a}	4.39^{b}	19.74^{c}	9.48^{c}	6.48^{c}	245^{c}	53.70^{c}	24.8^{b}	4.81^{b}
	LSD	0.20^{t}	2.80	1.89	0.19^{t}	0.22^{t}	3.12^{t}	0.70^{t}	2.8	2.48
	Significance	**	**	**	**	**	**	**	**	*
R × C		ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)		12.1	43.2	10.1	6.8	8.8	20.1	10.7	13.1	43.0

**,* = significant at 1% and 5% level of probability; ns = non-significant; LSD = Least significant difference. LSD values with superscript 't' are obtained from transformed data weight and all the yield components. Among the variables, coefficient of variation (CV) was below 20%, with the exception of TWPP; and GWP that recorded 43% each.

Linear correlation coefficients among GWP and yield components of selected upland rice cultivars show strong (P<0.01) and direct relationship among the variables; with inverse but significant relationship observed between total number of panicle and length of panicle and number of branches panicle^{-1} (Table 3). The highest significant relationship (r=0.94**) was observed between GWP and TWPP; while the lowest (r=0.27*) was between TNPP and LPP.

Figure 1 shows the principal component analyses (PCA) bi-plot showing the relationships among grain weight and yield components, with rates of OSA fertilisers applied. The first principal component (PC-1) accounted for 62% variations in grain yield components, attributed to rates of OSA applied; while the second principal component (PC-2) accounted for additional 26%. In all, 88% of the total variation was captured by the two components. The association among the grain yield components was related with the rates of OSA fertiliser applied. Closer association among 1000 GW, average number of branches panicle^{-1} and average number of grains branch^{-1} were observed at 250 ml ha^{-1} of the fertiliser; while at 500 ml ha^{-1}, GWP was closely associated with percentage number of fertile spikelets, total panicle weight and average length of panicle. At 750 ml ha^{-1}, however, total number of spikelets plant^{-1} and total number of panicle were closely related.

The principal component bi-plot among cultivars and the grain weight and grain yield components revealed varying associations among the variables with each cultivar (Fig. 2). The first principal component (PC-1) accounted for 64% of the total variation in yield components of the cultivars; while the second principal component (PC-2) accounted for additional 27%. In all, a total of 91% of the total variation was accounted for by the first two principal components. MOROBEREKAN was identified to have the longest LPP, the most NBPP and 1000 GW. A very close association was observed between GWP and TWPP in NERICA 4 and NERICA 7. These two yield components were more related with NGBPP, TNSPP and TNPP than any other yield components for the NERICAs. OFADA was observed to perform poorly for all the yield components.

DISCUSSION

Upland rice sprayed with different rates of fertiliser gave generally better grain weight through increase in %NFSPP than the control (Table 2). This revealed the important role of OSA fertiliser in boosting grain weight increase in upland rice. The non-interaction of OSA fertiliser rates and cultivars suggest similarity and predictability in rice cultivar response to foliar OSA fertiliser application rates. Possibly, the application of the fertiliser elicited similar physiological reaction among the upland rice cultivars. Consequently, plant grain weight and yield components of all the rice cultivars responded similarly to OSA fertiliser rates. However, grain weight and %NFSPP varied among the upland rice cultivars, indicating that the cultivars differ in their expression of traits for grain weight and thus yield components; and that expect grains per plant depend on the cultivars chosen and at a given rate of OSA fertiliser. The grain yield components of OFADA responded poorly to the fertiliser rates applied, which may be responsible for the lowest grain output of the cultivar.

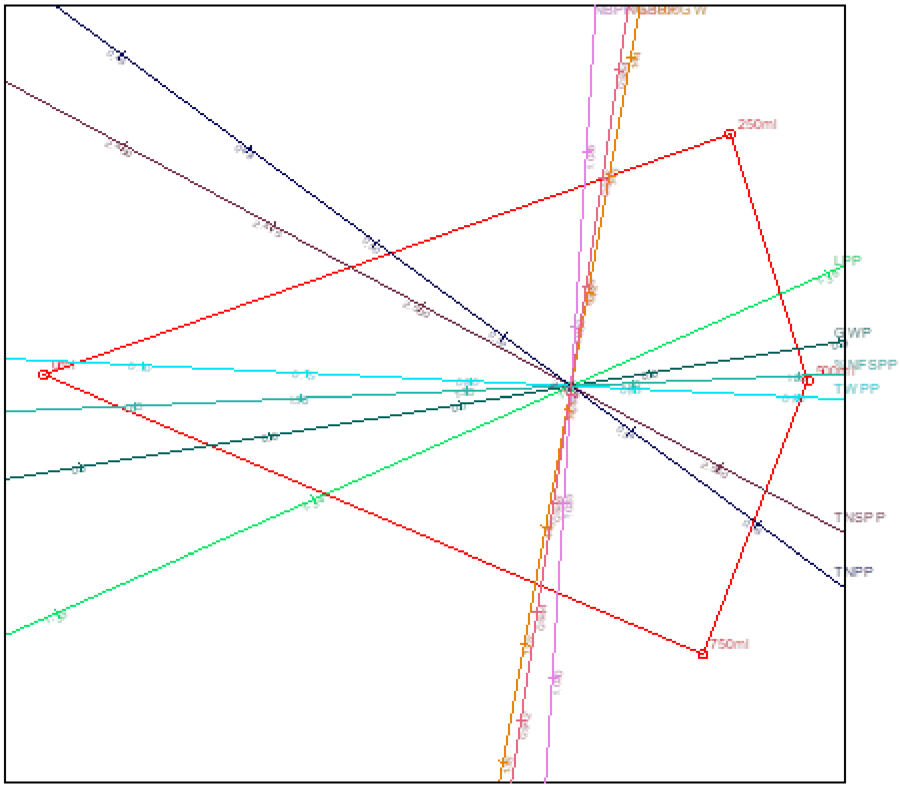
The understanding of grain weight association with its components is one fundamental way of manipulating yield towards grain yield increase in upland rice cultivars (Araus *et al.*, 2008). As observed in this study, management practice such as OSA fertiliser application as silicon source ensured grain weight increase in all the rice cultivars, with the exception of OFADA, mainly through increase in percentage number of filled

TABLE 3. Linear correlation coefficients among grain weight and yield component variables of selected upland rice cultivars

Variables	Total number panicle plant^{-1} (-TNPP)	Total weight of panicle plant^{-1} (- TWPP)	Length of panicle^{-1} plant^{-1} (- LPP)	Number of branches panicle^{-1} (-NBPP)	Number of grains branch^{-1} plant^{-1} (-NGBPP)	Total number of spikelet panicle^{-1} plant^{-1} (-TNSPP)	Percentage number fertile spikelets panicle^{-1} plant^{-1} (- %NFSPP)	One thousand grain weight -1000 GW (g)	Grain weight plant^{-1} (-GWP (g))
TNPP									
TWPP	0.42**								
LPP	**-0.27***	0.61**							
NBPP	-0.44**	0.34**	0.78**						
NGBPP	0.01^{ns}	0.57**	0.42**	0.29*					
TNSPP	0.65**	0.81**	0.29*	0.19^{ns}	0.65**				
%NFSPP	0.08^{ns}	0.68**	0.51**	0.25^{ns}	0.24^{ns}	0.30*			
1000 GW	-0.19^{ns}	0.32*	0.56**	0.41**	-0.06^{ns}	-0.02^{ns}	0.15^{ns}		
GWP	0.42**	**0.94****	0.56**	0.26*	0.42**	0.68**	0.80**	0.35*	

**,* = significant at 1% and 5% level of probability; ns= non-significant. Values in bold are the highest and lowest significant correlation values for the variables involved

PCP biplot (87.99%)



PC-2 (26.04%)

PC-1 (61.95%)

Figure 1. Principal component analyses bi-plot showing the relationship among the grain weight and yield components and rates of ortho-silicate fertiliser.

TNPP = Total number panicle plant^{-1}; TWPP = Total weight of panicle plant^{-1}; LPP = Length of panicle plant^{-1}; NBPP = Number of branches panicle^{-1}; NGBPP = Number of grains branch^{-1} plant^{-1}; TNSPP = Total number of spikelet panicle^{-1} plant^{-1}; %NFSPP = Percentage number fertile spikelets panicle^{-1} plant^{-1}; 1000 GW = One thousand grain weight; GWP = Grain weight plant^{-1}.

spikelets. This is evidence of increased sink demand and stimulation of source capacity as posited by Detmann *et al.* (2012). Decrease in number of filled grains has also been associated with reduced sink strength in wheat (Rajala *et al.,* 2009). Though the effect of OSA fertiliser rates, as silicon source to upland rice cultivars was not significant on panicle weight, its closer relationship and length of panicle with grain weight and percentage number of filled spikelets indicates the potentiality of these variables as the next influential traits to yield increase in upland rice under OSA fertiliser application. The main components of yield such as total number of panicle plant^{-1}, total spikelets panicle^{-1}, percentage fertile spikelets and 1000 GW earlier reported by Yoshida (1981),Nassir and Ariyo (2006), and Fageria (2007) to be the main determinant of grain weight in rice could only ensure maximum yield if the proportion of biomass allocated to the reproductive part is increased. Laza *et al.* (2004) had posited that attainable yield can be achieved through breeding of rice cultivars with larger panicle sizes. The closer association of TWPP with 500 ml ha^{-1} of OSA fertiliser in

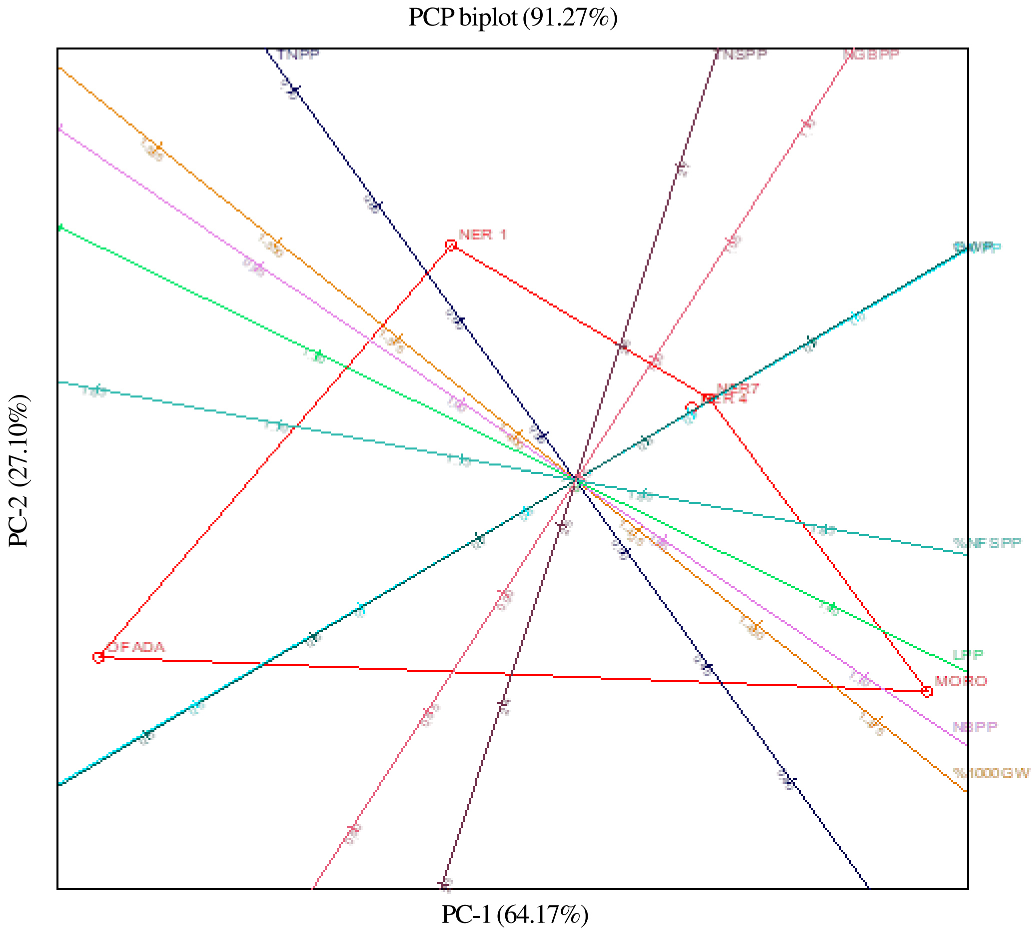


Figure 2. Principal component analyses (PCA) bi-plot showing the relationship among the grain weight and yield components and selected upland rice cultivars.

TNPP = Total number panicle plant^{-1}; TWPP = Total weight of panicle plant^{-1}; LPP = Length of panicle plant^{-1}; NBPP = Number of branches panicle^{-1}; NGBPP = Number of grains branch^{-1} plant^{-1}; TNSPP = Total number of spikelet panicle^{-1} plant^{-1}; %NFSPP = Percentage number fertile spikelets panicle^{-1} plant^{-1}; 1000 GW = One thousand grain weight; GWP = Grain weight plant^{-1}.

the biplot of Figure 1 could implied that the role of this rate of fertiliser towards grain yield increase lies not only in increase in percentage fertile spikelets but also in its potential ability to influence panicle weight increase.

The positive and significant relationship observed between the grain yield components and grain weight explain the positive influence that grain yield components can have in determining grain weight increase in upland rice (Table 3). This was confirmed as the OFADA cultivars that maintained relatively low grain weight were observed to have had relatively low values of length, weight and number of panicle; as well as number of branches pancle^{-1}. However, the trade-off established between total number of panicle plant^{-1}and total number of branches panicle^{-1}, total weight and length of panicle explains the effect of limited amount of assimilates to accommodate both the number and weight increase at the same time, in which case weight was more favoured at the expense of number, especially in situation of moisture stress. The increased grain weight observed under OSA fertiliser application in the study, that was associated with increased percentage fertile spikelets, at the expense of number of spikelets, could have contributed to the trade-off observed. Since pleiotropic genetic control of these traits has not been reported, the possibility of developing cultivars with higher values of the traits under silicon application is not ruled out.

Different rates of OSA fertiliser maintained differing relationships with different component of grain weight of upland rice (Fig. 1). Higher 1000 GW association with 250 ml ha^{-1} and not with higher rates of the fertiliser confirmed the limit to which the size of the grain can be increased towards increasing yield in upland rice. One thousand grain weight has been reported to be less influenced by environment than other yield components (Kamara *et al.*, 2017). In addition, grain sink size has been reported to be the main yield limiting factor in wheat and rice, and that sink capacity needs to be improved if improvement in yield is to be exploited (Foulkes *et al.*, 2011). This could inform the closer association of number of spikelets, a trait that has been reported to be more plastic than grain size (Sadras and Slafer, 2012; Gonzalez-Navarro *et al.*, 2016), with higher doses (750 ml ha^{-1}) of the fertiliser. This yield component could serve as an alternative way to increase grain weight, through application of OSA fertiliser at higher doses. The trade-off between number and size of spikelets had earlier been observed in wheat (Rebetzke *et al.*, 2016), which could imply that grain weight increase through application of OSA fertiliser was achieved through increase in number of spikelets and the proportion of spikelets that are filled. However, the association of grain weight with percentage number of filled spikelets at 500 ml ha^{-1} of OSA fertiliser could imply that moderate application rate (500 ml ha^{-1}) of the fertiliser is required to ensure maximum yield production through increased percentage of filled spikelets. This could also explain the limit to which further increase in OSA application rates may become counterproductive and uneconomical with respect to the trait.

The lower coefficient of variation (< 20%) in yield components and the eventual significant variation in plant grain weight indicated the cumulative effect of OSA fertiliser rates even when the effect appeared not to be major for most of the yield components. The relatively higher coefficients of variation observed for TWPP and GWP are, however, indicators that other factors not considered in this study also contributed to panicle weight and grain weight of the rice cultivars. This could, otherwise imply that wider gap exist in responses of the TWPP and GWP of the cultivars to silicon fertiliser applied. Further studies to assess the effect of other screen house management practices such as watering regimes, variation in nitrogen fertiliser application rates, and pot size among others on total panicle weight and grain weight of the rice cultivars may be instructive.

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