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Urea-supergranules and phosphorus application increases irrigated rice yields and agronomic use efficiency in Burkina Faso

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Abstract

Nitrogen and phosphorus deficiencies are some of the main factors restricting irrigated rice (*Oryza sativa* L.) productivity in Burkina Faso. Urea supergranules (USG) have been proven to increase rice yield but this increased productivity is likely to be constrained because P is becoming limiting in irrigated rice systems. Field experiments were carried out with rice variety Nerica 62N in Sourou valley in the wet season of 2012 and in the dry season of 2013. The effect of two sizes (1.8 and 2.7 g) of USG and five levels of phosphorus (0, 20, 30, 40 and 50 kg P ha^{-1}) were studied in a split plot design on rice yields. The use of USG 2.7 g did not significantly increase rice yields compare with USG 1.8 g in both seasons. P application significantly increased rice yields. The 1.8 g USG significantly increased the agronomic efficiency (AE) by 48.9% over the USG 2.7 g in the 2012 wet season while the increase in AE was 24.4% in the 2013 dry season. The best AE 42 kg kg^{-1} in 2012 and 25 kg kg^{-1} in 2013 were obtained with 50P and 30P. This study suggests that USG can be used by farmers in small rate (USG 1.8 g) to improve nitrogen use efficiency and the application of 30 kg P kg^{-1} seems to be adequate to increase yield in irrigated rice cropping system.

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Introduction

Low soil fertility, particularly induced by nitrogen (N) and phosphorus (P) deficiencies, is one of the main factors restricting increasing agricultural productivity in sub-Saharan Africa (Smalling *et al.*, 1997; Sanchez *et al.*, 1997). Nitrogen and P are fundamental to crop development because they form the basic component of many organic molecules, nucleic acids and proteins (Lea and Miflin, 2011). One key issue in Burkina Faso as in most of Africa is that the urban population is shifting from traditional African staple foods towards rice. So, rice cultivation is becoming more and more important in Burkina Faso (Badolo and Traoré, 2015). Rice production reached 347501 tons in 2014/2015 cropping season and the increase in rice production was 13, 8 % higher compared to last season (MARHASA, 2015). However, this increase is insufficient to meet the national demand as evidenced by the rising imports.

Global food security is at stake since the demand for rice is exceeding production yet local rice production may only meet 42 percent of the demand (CEFCOD, 2013). Irrigated rice is a production system that can be accessed at high levels of economic returns, but nitrogen is the main factor limiting yields of these systems (Segda, 2006). It has been shown that for nitrogen efficiency to be particularly high the plant must access sufficient phosphorus and potash. If one of these two elements becomes limiting, nitrogen efficiency drops steeply (Marc, 2001).

Consequently, phosphorus application is recommended especially for rice cultivation (Mokwunye *et al.*, 1996; Sahrawat, 2003). In Burkina Faso, numerous research reports have shown that the soils are becoming more and more limiting in phosphorus (Lompo *et al.*, 2009) and this has to be taken into account when assessing NUE. Phosphorus replenishment must usually be accompanied by N replenishment in order to be effective, because most P-deficient soils also are deficient in N (Roland *et al.*, 1997).

Accurate assessment of P availability in soils and precise prediction of P fertilizer requirements is increasingly important for sustainable agriculture and protection of the environment from the detrimental effect of excess P (Wang *et al.*, 2001). Judicious and proper use of fertilizer can markedly increase the yield and improve rice quality (Yoshida, 1981). Therefore application of nitrogen fertilizer either in excess or less than optimum rate will affect both the yield and quality of rice (Song *et al.*, 2013). Nitrogen fertilizer is mainly subjected to volatilization and denitrification (Prasad *et al.*, 2015). Consequently, any method of fertilizer application which can minimize losses would be of great importance in rice cultivation. There is therefore, the need to determine the desired quantity of nitrogen and phosphorus fertilizer needed for boosting rice yield per unit area while avoiding increase in production cost. The objective of this study was to determine the optimal rates of USG and P for increasing yields and nutrient use efficiency under irrigated rice system.

Materials and methods

Experimental site

The experiment was carried out in Sourou Valley in the wet season of 2012 and in the dry season of 2013 to investigate the effect of USGs and P on yield and NUE. The experimental site was located at 13°00' latitude North 03°20' longitude west. The region of Sourou is generally characterized by a north Soudanian Sahelian climate with an average rainfall below 900 mm. Temperatures are stable and between a minimum of 17°C in coolest season and maximum of 41°C in hottest season. The soils in Sourou Valley are mainly brown, poorly developed, hydromorphic soils and Vertisols with fine texture, high water retention capacity, low permeability, poor ventilation of subsurface horizons and strong compaction (Faggi and Mozzi, 2000). Soil physical and chemical analysis classified the soil used for the experiment as neutral and predominantly sandy clay. Soil showed very low contents in organic carbon, total nitrogen and low available phosphorus (Table 1).

Table 1. Selected initial soil chemical and physical characteristics of the experimental field.

Soil properties	Value	
	0 – 20 cm	20 – 40 cm
Clay (%)	41.2	49.6
Silt (%)	23.5	17.7
Sand (%)	35.3	33.3
Organic carbon (%)	0.93	0.45
Total N (%)	0.07	0.04
C/N	13.0	11.0
pH(1:2.5 H_2O)	7.2	7.3
Avail P (mg/kg)	1.3	3.7

Experimental design

A split plot design was used for this experiment. Two sizes of USG (1.8 and 2.7 g corresponding to 52 kg N ha^{-1} and 78 kg N ha^{-1}) were randomized in the main plots and 5 levels of P (0, 20, 30, 40 and 50 kg P ha^{-1}) were arranged in the sub-plots. Recommended basal rates of potassium (24 kg of K_2O ha-1) were applied uniformly to all the plots except the control at transplanting. One variety of rice (Nerica 62N) that has cycle duration of 118 days was used in this experiment. Thirty (30) day old seedlings of Nerica 62N that were previously planted in the field were used and two seedlings were transplanted per hill at a spacing of 20 cm x 20 cm geometry. Each plot (25 m^2) had independent drainage and irrigation ditches, so as to prevent the spread of water and fertilizers between adjacent plots. Prilled urea was split in two and one applied at 14 days after transplanting and the other at panicle initiation after weeding. The USG granular was deep placed at 10 cm into the soil after water drainage at 7 days after transplanting only once during the season. One granular of USG was placed deeply in soil between four (4) hills. Irrigation was applied when necessary throughout the cropping seasons.

Data collection

After harvest, grain and straw of a 4 m^2 sub-plot was weighed and dried at 65°C for 48 hours, grounded and sieved through a 0.2 mm mesh for the total N, P and K analysis. Total N and P were analysed by using automatic colorimeter method and total K was analysed by using flame photometric method. The assessment of yield components (total number of tillers and number of panicle) was made on 1m² in each plot. Thousand grains were taken randomly from each sub plot and the weight (g) recorded. The Agronomic N use Efficiency (AE) was used to evaluate the nitrogen use efficiency (NUE) and was determined using the equation by Craswell and Godwin (1984) as follows:

$$AE = \frac{(GYN - GYO)}{Nr}$$

Where

Nr is the amount of N fertilizer applied (kg N ha^{-1});

GYN is the dry grain yield with applied N fertilizer;

GYO is the dry grain yield without N fertilizer applied;

Statistical and data analysis

Data analyses were conducted on individual year data. The analysis of variance was conducted using Genstat package 9th edition to determine the significance of the effects of N and P fertilizer application on rice yields. Treatment means were compared with the least significant different (LSD) at the probability level of 0.05.

Results and discussion

Rice plant N, P and K uptake Grain and straw N, P and K uptake varied significantly ($P < 0.05$) with increasing P levels, in both seasons (Table 2). Grain N uptake increased with the increasing P rates up to 74.3 kg ha^{-1} in the 2012 wet season at P50. Grain P uptake was highest at P40 and the least uptake was observed at P0. Grain P uptake ranged from 0.7 to 1.7 kg ha^{-1}. The amount of K partitioned into rice grain ranged from 14.6 – 35.0 kg ha^{-1} with higher rate obtained at P50 in the wet season. Phosphorus application improved N, P and K uptake nutrient in the experiment resulting to better nutrient translocation to rice plant in the wet season 2012. The N, P and K uptake ranged from 51.1 to 69.0 kg ha^{-1}, 0.96 to 1.68 kg ha^{-1} and 12.9 to 22.56 kg ha^{-1} respectively in 2013 dry season with the highest N and K uptake being recorded from plots that received 50 kg P ha^{-1}. P application significantly increased nutrient uptake during the experiment. This results can be explained by the fact that P is becoming a limiting nutrient in Burkina Faso, it availability may increase other nutrients uptake. Rabat (2003), reported that interdependence between N and P. Also, the increase in N, P and K uptake was most likely due to a better plant establishment due to an early root development induced by availability of P in soil solution at earlier stage (Grant *et al.*, 2001).

Table 2. Effect USG and phosphorus on N, P and K uptake.

Treatment	Grain (kg ha^{-1})			Straw (kg ha^{-1})		
	N	P	K	N	P	K
Wet 2012						
Type of fertilizer						
1.8 USG	58.00	1.32	26.37	23.32	0.22	100.60
2.7 USG	63.10	1.45	25.60	31.57	0.32	103.70
Lsd (5%)	6.10	0.17	3.04	4.18	0.03	15.98
Fpr	0.075	0.080	0.477	0.008	0.002	0.581
Phosphorus rate (kg ha^{-1})						
0	36.50	0.73	14.58	24.41	0.15	82.10
P20	57.80	1.25	24.07	25.54	0.20	103.00
P30	66.30	1.70	32.06	26.62	0.30	105.90
P40	67.80	1.73	24.17	29.60	0.32	106.60
P50	74.30	1.52	35.03	31.07	0.38	113.10
Lsd (5%)	10.30	0.23	4.92	5.65	0.06	21.70
Fpr	0.001	0.001	0.001	0.113	0.001	0.068
Fpr USG×P	0.884	0.122	0.001	0.027	0.001	0.006
CV (%)	16.4	15.9	18.3	19.9	21.0	20.6
Dry 2013						
Type of fertilizer						
1.8 USG	58.0	1.31	18.06	60.1	0.56	139.00
2.7 USG	65.2	1.27	18.05	54.6	0.77	150.30
Lsd (5%)	14.8	0.31	4.68	20.8	0.23	54.10
Fpr	0.22	0.68	0.99	0.47	0.07	0.55
Phosphorus rate (kg ha^{-1})						
P0	51.1	0.96	12.90	66.6	0.50	156.90
P20	64.1	1.32	17.75	61.4	0.45	139.30
P30	61.6	1.22	18.79	57.7	0.56	147.20
P40	62.0	1.26	18.27	41.9	0.57	124.20
P50	69.0	1.68	22.56	59.1	1.24	155.60
Lsd (5%)	6.8	0.30	2.01	9.6	0.12	23.41
Fpr	0.001	0.001	0.001	0.001	0.001	0.048
Fpr USG×P	0.641	0.417	0.001	0.001	0.001	0.408
CV (%)	10.30	10.10	10.80	16.3	17.80	15.70

USG= Urea Supergranule, Lsd= Least significant difference, Urea supergranule application significantly ($P < 0.05$) increased only rice straw N and P uptake in the 2012 wet season with the highest uptake being associated with USG 2.7 g during the experiment. The increases in N and P uptake over USG 1.8 g were 35% and 45%, respectively. Increasing P rate significantly ($P < 0.05$) increased straw P uptake up to 0.38 kg ha-1 in the wet season. However, P levels significantly affected N, P and K uptake. The highest P uptake was associated with the P50 treatment (1.24 kg ha^{-1}). These results are in agreement with the findings of Khan *et al.* (2007) who reported that phosphorus application to rice increased P accumulation because flooding decreased soil P sorption and increased P diffusion resulting in higher P supply to rice. The highest N (66.6 kg ha^{-1}) and K (156.9 kg ha^{-1}) uptake were however obtained from control plots (P0). This result can be explained by rice plant root development due to nutrient deficiency in soil. Fageria (1992, 2010) reported that at nutrient deficient levels, root length is higher compared to high nutrient levels because tendency of plants to tap nutrients from deeper soil layers. A large rooting zone can be explored by plant root and increased N uptake.

Yield components, grain and straw yields

The number of panicles was significantly influenced by phosphorus application in 2012 wet season. The application of phosphorus at the rate of 40 kg P ha^{-1} produced the highest number of tillers (275 tillers m^{-2}) and panicles (245 panicles m^{-2}). This result can be explained by the fact that phosphorus availability influences plant growth, cell division and tillering (Dobermann and Fairhust, 2000). The results support the work of Khan *et al.* (2007) who found that the application of P fertilizer significantly increased yield components of rice. The application of USG did not significant increase the number of tillers and panicles during this season. The response of 1000 seed weight to USG and phosphorus was also not significant. Unlike the wet season of 2012, no significant differences were observed in the number of tillers and panicles in response to P application in the dry season 2013 but yield components were generally high at 50 kg P ha^{-1} application rate. In contrast, 1000 seed weight was significantly ($P < 0.05$) increased by the application of USG. The highest and the lowest weights were observed with USG 1.8 g and USG 2.7 g, respectively (Table 3). Increase in grain weight at higher nitrogen rates might be primarily due to increase in chlorophyll content of leaves which led to higher photosynthetic rate and ultimately plenty of photosynthates available during grain development (Bhowmick and Nayak, 2000).

Table 3. Effect of USG and phosphorus on rice yield components.

Treatment	Wet 2012			Dry 2013		
	Tiller m^{-2}	Panicle m^{-2}	1000 seed weight (g)	Tiller m^{-2}	Panicle m^{-2}	1000 seed weight (g)
Type of urea						
1.8 g USG	235	196	22.8	227	227	25.1
2.7g USG	253	206	23.1	238	238	24.2
Lsd (5%)	22	40	1.3	18	18	0.7
Fpr	0.087	0.417	0.455	0.149	0.149	0.031
Phosphorus rate (kg ha^{-1})						
P0	207	168	22.7	234	233	24.3
P20	252	206	22.1	229	229	24.4
P30	243	199	23.2	230	230	24.7
P40	275	245	23.3	228	228	24.5
P50	243	190	23.3	240	240	25.4
Lsd (5%)	35	38	1.3	31	31	0.8
Fpr	0.010	0.006	0.257	0.925	0.925	0.067
Fpr USG x P	0.287	0.959	0.647	0.487	0.487	0.833
CV	13.9	18.4	5.4	12.8	12.8	3.2

Grain and straw yields were significantly influenced ($P < 0.001$) by phosphorus fertilizer but no significant effect was observed with the two sizes of USG in both seasons (Table 4). The increase in yield with phosphorus can be explained by the increase in N, P and K uptake with the application of phosphorus. Slaton *et al.* (1998) also, reported significant yield increase with phosphorus fertilization. Phosphorus application increased nutrient uptake in both seasons which contributed to yield increase. The P20 and P50 rates increased grain yield by 62% to 102%, respectively over the control (P0) in 2012 wet season. Straw yields increased with incremental rate of P to 50 kg ha^{-1} in 2012 wet season. Increase in rice straw yield ranged from 40 to 58 % over P0. Differences between straw yield obtained from P20 treatment plots and those of the higher P rates were not statistically significant. Similar results were obtained in 2013 dry season on grain yields when the same rates of P were applied. These results can be explained by the low mobility of P in soil and plant characteristic. Also, phosphorus efficiency is very low due to P fixation in soil (Mac Donald *et al.*, 2011). The highest grain yield (4094 kg ha^{-1}) was recorded with P50 while the lowest grain yield (2967 kg ha^{-1}) was observed with P0. Grain yield from P50 plots was 38% higher than that of the control (P0) plots. The increase in grain yield with phosphorus application over the control ranged from 15 - 38%. The yield responses to the two levels of USG were not significant during the two seasons. These results indicate that the small amount of USG (1.8 g) could supply sufficient nutrients to satisfy rice plants' demand for N. This result can also be attributed to the fact that application of higher rates of N fertilizer makes plants susceptible to lodging (Islam *et al.*,

2007) and low productivity. Singh *et al.* (2011); Murtaza *et al.* (2014) reported that farmers targeting higher yields tend to use higher rates of N. However, such high rates do not always leading corresponding higher yields. It can be deduced from the results of the P trials, that application of P to rice becomes apparently significant in as much as the soils of the areas are inherently low in P (Sedogo, 1993). P fertilizers need to be applied to obtain optimum plant growth and crop yields.

Table 4. Effect of USG and phosphorus on rice grain and straw yield.

Treatment	Grain yield ($kg\ ha^{-1}$)	Straw yield ($kg\ ha^{-1}$)	Grain yield ($kg\ ha^{-1}$)	Straw yield ($kg\ ha^{-1}$)
	Wet 2012		Dry 2013	
Type of urea				
1.8g USG	3767	3475	3502	6496
2.7g USG	3825	3900	3626	7385
Lsd (5%)	4.6	553.1	861.5	2507.1
Fpr	0.670	0.092	0.679	0.341
Phosphorus rate ($kg\ ha^{-1}$)				
P0	2250	2625	2967	6625
P20	3636	3688	3688	6428
P30	4250	3938	3400	7212
P40	4188	4031	3673	6725
P50	4556	4156	4094	7712
Lsd (5%)	643.2	792.6	367.0	1088.9
Fpr	0.001	0.004	0.001	0.137
Fpr USG × P	0.661	0.087	0.133	0.473
CV (%)	16.4	20.8	10.0	15.2

Agronomic use efficiency

In the 2012 wet season, significant differences ($P<0.05$) in agronomic efficiency were associated with the use of the 2 sizes of USG (Table 5). The highest AE was observed for plots that received 1.8 g of USG with the increase in AE over that of USG 2.7 g representing 49%. This finding is supported by the work of Song *et al.* (2013) who obtained higher NUE with low application of nitrogen. Application of additional unit weight of N led to a reduction or gave almost similar unit weight of rice grain. Muhammad *et al.* (2015) reported that paddy yield increases significantly with the increase in nitrogen rate but after a certain limit yield starts decreasing. There is therefore much advantage to be derived from using economic rate that enhances higher nitrogen use efficiency and maximize grain production. Unlike the wet season of 2012, no significant difference was observed with the use of USG during the dry season but higher AE was recorded for treatments that received 1.8 g of USG. This result shows that USG application can be effective even at small rates. Phosphorus levels significantly improved ($P < 0.05$) agronomic efficiency. The AE values ranged from 3.5 to 42.0 $kg\ kg^{-1}$. The highest AE was associated with the P50 treatments and the mean value was significantly different with those of the other P treatments. Phosphorus levels also significantly improved ($P < 0.05$) the AE in the dry season of 2013 which ranged from 8.66 to 34.62 $kg\ kg^{-1}$, with the highest AE being recorded from P30 treatment plots (Table 5). This result is in agreement with the finding of Janssen *et al.* (1990), who reported that other nutrients such as P influence the efficient use of nitrogen.

Table 5. Effect of phosphorus on rice nitrogen agronomic efficiency.

Treatment	AE ($kg\ kg^{-1}$) wet 2012	AE ($kg\ kg^{-1}$) Dry 2013
Type of urea		
1.8 USG	34.00	25.00
2.7 USG	22.80	17.20
Lsd (5%)	7.70	17.52
Fpr	0.019	0.252
Phosphorus rate		
P0	3.50	10.48
P20	26.60	23.44
P30	35.90	25.12
P40	33.90	22.04
P50	42.03	24.43
Lsd (5%)	10.20	4.77
Fpr	<0.001	<0.001
Fpr USG × P	0.216	0.001
CV (%)	34.8	21.9

Conclusion

This study was conducted across two cropping seasons. The results indicate need of using USG as source of nitrogen in small rate for rice production.

Grain yield showed no advantage with respect of the size of USG even though nitrogen use efficiency was increased by the use of USG 1.8 g. The study suggests that USG can be efficient at small rate of 1.8 g for rice cultivation. Phosphorus application increase rice grain yield but no interaction effect was observed between USG and phosphorus. The results suggest that USG 1.8 g can be used with P at 30 P kg ha-1 that correspond to the recommender rate to increase rice grain yield in irrigated system of Sourou valley.

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