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Effects of rate of phosphorus fertilizer on crop growth and yield in rice-soybean intercropping system

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Abstract

The study was aimed at investigating the effects of rate of phosphorus fertilizer on growth and yield in rice-soybean intercropping system. Phosphorus fertilizer was applied at the rate of 0, 45, 60 and 75 kg P ha^{-1} while the three cropping patterns were sole rice, sole soybean and rice + soybean intercrop. Phosphorus and cropping patterns were combined in a 4 x 3 factorial and laid out in a randomized complete block design with three replicates. Results showed that increasing rate of P fertilizer significantly (P<0.05) increased growth parameters in both rice and cowpea. All components of yield of soybean were found to show significant (P<0.05) phosphorus and cropping pattern interactions. Application of P at 45, 60 and 75 kg ha^{-1} enhanced rice yield by 23%, 57.4% and 88.3% respectively, while soybean yield was increased by 28.5%, 65.7% and 73.5% at same respective P fertilizer rates. Interactive effects of phosphorus and cropping pattern for yield of both rice and cowpea were found to be significant (P<0.05). LER increased with P rate ranging from 42% to 71%. SPI showed a linear trend with P fertilizer rate. Agronomic efficiency of P fertilizer was generally higher in the cereal crop (rice) relative to the legume (soybean) at all levels of application. The results of this study have shown that to achieve a positive interspecific competition between rice and soybean in the rice-soybean intercropping system it is more appropriate to apply phosphorus 60 kg P ha^{-1}.

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Introduction

One of the major effects of a rapidly growing population is the great demand on agricultural lands which are usually continuously cropped. The aftermath of continuous cropping without appropriate soil management practices is a decline in soil nutrients. Rice is among the most important food crops cultivated in tropical Africa. The major constraint to rice farmers is the decrease in yield due to soil degradation occasioned by continuous cultivation. Ahmed *et al.* (2009) observed that erosion washes away soil nutrients in most farmlands, while some other nutrients are taken out of the field through harvested products (such as residues of crops). The application of mineral fertilizers and intercropping of legumes with cereals are viable options for maintaining soil fertility under continuously cropped rice fields.

In several crop production systems, phosphorus has been established as the next element after nitrogen (Choudhury *et al.*, 2007; Massawe and Mrema, 2017). In other to produce a ton of paddy rice (plus straw), rice (*Oryza sativa*) crops need about 3-4 kg phosphorus (Sahrawat, 2000). Phosphorus is also involved in certain biochemical processes in rice such as supply and transfer of energy. Phosphorus is the most important nutrient which determines soybean yield. Its relevance is seen in biological nitrogen fixation, pulling about 28 kg P ha^{-1} from the soil and is known to have a greater contribution to soybean yield than other plant nutrients (Goswami, 2016). Intercropping is common practice in tropical environments of Africa. Besides the yield advantage and insurance against crop failure, intercropping of cereals with legumes also results in enhanced soil fertility through increased soil nitrogen from biological nitrogen fixation (Gosh *et al.*, 2006; Abate and Getachew, 2018).

In a related study on different levels of phosphorus application, Shahid *et al.* (2009) observed significantly enhanced vegetative growth and number of pods of soybean at 75 and 100 kg P_2O_5 ha^{-1}. Malik *et al.* (2006) also reported a significant soybean seed yield of 1911.12 kg ha^{-1} with application of phosphorus at 90 kg P_2O_5 ha^{-1}. Field observations on effects of phosphorus on rice yield in Bangladesh indicated increased grain yield with increasing soil phosphorus (Saleque *et al.*, 1998). Olufajo (1992) reported LER value of 1.55 in a soybean/maize intercrop. Danmaigoro and Ibrahim (2014) also observed LER greater than unity in rice/soybean intercrop.

Most crop farmers who practice intercropping in Africa do not have an in-depth understanding of fertilizer requirements or crop combination that will maximize yield and gains under the intercropping system. The study is therefore aimed at evaluating the effects of rate of phosphorus fertilizer and cropping pattern on growth and yield in rice-soybean intercropping systems.

Materials and methods

Two field experiments were conducted in the 2016 and 2017 cropping seasons in the Faculty of Agriculture Research and Teaching Farm, Delta State University, Asaba Campus, Nigeria. Asaba is located on a latitude of 60° 12´ N and longitude 60° 45´ E with annual rainfall between 1800 and 3000mm and a temperature range of 27.5°C to 39.9°C. Five core soil samples were randomly collected from the experimental area. These were bulked, thoroughly mixed, air-dried and analyzed for the physical and chemical properties based on standard procedures described by IITA (1979). Particle size distribution (Bouycous method): 78.6%, sand 9.0% silt and 12.4% clay indicating a sandy loam textural class. Other properties of the soil were as follows: pH in water = 5.3; 0.067% total nitrogen (Kjedahl method) and 4.93% organic carbon, 0.36% phosphorus and 0.53% potassium. The soil belongs to the Ultisol order. The two factors studied were nitrogen and cropping pattern. Phosphorus fertilizer in form of ammonium phosphate was applied at the rate of 0, 45, 60 and 75 kg P ha^{-1} while the three cropping patterns were sole rice, sole soybean and rice + soybean intercrop. Phosphorus and cropping patterns were combined in a 4 x 3 factorial and laid out in a randomized complete block design with three replicates.

Crop cultivars used were early maturing varieties of rice (cv. ITA 150) and soybean (cv. TGx-1908-8F). Both rice and soybean were planted at a spacing of 30cm × 30cm in both sole and intercrops. Each plot size measured 3.6m x 3.6m ($12.9m^2$); with 1m between and within plots to give a total land area of $220m^2$. Additive intercropping was practiced in this experiment where the population of crops under sole crop was maintained in intercrops while an intercrop ratio of 1:1 was maintained in all intercrops.

Data was collected for vegetative parameters such as plant height, leaf number, leaf area index for both crops, while branch number and tiller number m^{-2} were obtained for only soybean and rice respectively. Yield parameters for rice were number of panicles, panicle weight, 1000 grain weight and grain yield, while for soybean were number of pods per plant, pods weight per plant, 1000 seed weight and seed yield.

Productivity of the intercrop was assessed using Land Equivalent Ratio and System productivity index and Competition Ratio. The formula for each of the indices is as stated:

(a) Land Equivalent Ratio (LER) = (Z_{ab}/Z_{aa}) + (Z_{ba}/Z_{bb}), where Z_{aa} and Z_{bb} are corresponding yields of sole rice (*a*) and soybean (*b*) while Z_{ab} and Z_{ba} are the corresponding yields of intercrops of a and *b*. Values of LER that are above unity are considered advantageous.

(b) System productivity index (SPI), as earlier described by Lithourgidis *et al.* (2011) standardizes the yield of the secondary crop (soybean), *b*, in terms of the primary crop (rice), *a*. It was computed as:

SPI = $(Z_a/Z_b * Y_b) + Y_a$; where Z_a and Z_b are yield of rice and soybean respectively in sole crop and Y_a and Y_b are the yield of rice and soybean, respectively in intercrop.

(c) Competition Ratio (CR): As described by Yang *et al.* (2013), competition ratio is an indicator ratio that is used to assess the degree of competition between component crops in the intercropping system. It was computed thus:

$CR_{rs} = [Y_{rs}/(Y_{rr} \times A_r)]/ Y_{sr}/(Y_{ss} \times A_s)]$; where CR_{rs} is the competitive ratio of rice relative to soybean, Y_{rs} and Y_{sr} are the respective yield of rice and soybean under intercropping while Y_{rr} and Y_{ss} are the respective yields of rice and soybean under monocrop r, and Ar and As are the ratios of the area occupied by rice and soybean under the intercropping system relative to that of the corresponding monocrop.

(d) Rice Equivalent Yield (REY_{rs}) was obtained by converting yield of intercrop into rice yield based on the market prices of rice and soybean at the time of the study. The formulae are below:

$REY_{rs} = [Y_r + \{Y_s \times (P_s/P_r)\}]$; Where REY_{rs} = Rice equivalent yield (kg ha^{-1}), Y_s and Y_r respective yields of soybean and rice, while P_r and P_s are the respective prices of rice (USD 0.58 kg^{-1}) and soybean (USD 0.52 kg^{-1}).

Agronomic efficiency (AE_P) of P fertilizer was obtained from the ratio of the difference in grain yield between P fertilizer treatments and control to the P rate applied in Kg.

Year effect of treatments was not intended to be part of the study; hence data presented are as means of the two years. All data were subjected to analysis of variance (ANOVA) procedure described by Snedecor and Cochran (1982), while significant means were separated with LSD (least significant difference).

Results and discussion

Vegetative growth

The vegetative growth characteristics of rice as influenced by phosphorus fertilizer and cropping pattern are as shown in Table 1. An increasing rate of P fertilizer significantly ($P<0.05$) increased all vegetative growth parameters. Maximum plant height (98.32cm), number of leaves (4.03), LAI (4.65) and number of tillers m^{-2} (122.33) were achieved at 75 kg

P ha^{-1}. Massawe and Mrema (2017) also observed significant positive effects of growth parameters and yield components of rice when P application was raised from 0 to 60 kg ha^{-1}. Intercropping with soybean significantly (P<0.05) reduced number of leaves and number of tillers of rice by 15.4% and 9.4% respectively. Interactive effects of P and cropping pattern were significant for all vegetative characters indicating that with increasing rate of applied phosphorus, plant height, leaf number, leaf area index and number of tillers were enhanced.

Table 1. Effects of rate of phosphorus fertilizer and cropping pattern on vegetative growth of rice in rice-soybean intercropping.

	Plant height (cm)	No. of leaves	Leaf area index	No. of tillers (m^{-2})
Rate of P (kg ha^{-1})				
0	76.33	2.96	2.97	87.87
45	86.14	3.23	3.25	100.63
60	94.15	3.71	4.18	118.57
75	98.32	4.03	4.65	122.33
LSD	3.43	1.25	0.57	4.67
Cropping pattern (CP)				
Sole rice	90.62	3.77	3.85	112.67
Rice-soybean	86.65	3.19	3.67	102.03
LSD	ns	0.34	ns	3.84
P × CP	*	*	*	*

*Significant at 1% level of probability.

The data regarding vegetative growth of soybean as influenced by phosphorus fertilizer and cropping pattern are as presented in Table 2. Phosphorus fertilizer significantly increased (P<0.05) all vegetative attributes of soybean relative to the control. Compared to the control, application of at 45, 60 and 75 kg P ha^{-1} increased plant height of soybean by 27.4%, 39.3% and 41.3% respectively. Plant height and number of leaves of soybean were significantly (P<0.05) depressed by intercropping with rice, however soybean LAI and branching were not influenced by the rice component crop.

Results agree with that of Yadav *et al.* (2013) who observed enhanced growth parameters of soybean with increased phosphorus application rates.

Table 2. Effects of rate of phosphorus fertilizer and cropping pattern on vegetative growth of soybean in rice-soybean intercropping.

	Plant height (cm)	No. of leaves	Leaf area index	No. of branches (plant^{-1})
Rate of P (kg ha^{-1})				
0	26.41	41.83	3.21	1.32
45	33.65	56.42	5.40	2.93
60	36.80	66.28	6.08	3.40
75	37.33	69.33	6.21	3.56
LSD	2.88	2.58	1.76	1.83
Cropping pattern (CP)				
Sole rice	35.18	60.67	5.81	2.98
Rice-soybean	31.92	56.25	4.63	2.62
LSD	2.32	3.05	ns	ns
P × CP	*	*	*	*

*Significant at 1% level of probability.

Components of yield

The components of yield of rice and soybean as influenced by phosphorus fertilizer and cropping pattern are as presented in Tables 3 and 4. Rate of P fertilizer indicated a significant (P<0.05) increase in number of panicles, panicle weight and 1000 grain weight in rice. Application of P at 45, 60 and 75 kg ha^{-1} significantly increased number of panicles by 19.1%, 20.5% and 50.3% respectively. Maximum panicle weight (3.15g) and 1000 grain weight (37.32g) were obtained in 75 kg P ha^{-1}. Sole rice plants had a significantly higher number of panicles (87.05), panicle weight (2.91g) and 1000 grain weight (28.35g) than their corresponding intercrops. Interaction of P and cropping pattern was significant (P<0.05) for all the components of yield for rice.

Table 3. Effect of rate of phosphorus fertilizer and cropping pattern on components of yield of rice in rice-soybean intercropping.

	No. of panicles (plant^{-1})	Panicle weight (g)	1000 grain weight (g)
Rate of P (kg ha^{-1})			
0	65.62	1.98	18.75
45	78.15	2.35	21.55
60	83.05	2.80	26.07
75	98.65	3.15	37.32
LSD	5.57	1.17	2.33
Cropping pattern (CP)			
Sole rice	87.05	2.91	28.35
Rice-soybean	75.69	2.23	23.49
LSD	4.66	0.34	3.53
P × CP	**	*	*

**Significant at 1% level of probability; *Significant at 5% level of probability.

Number of pods, pod weight and 1000 seed weight of soybean were significantly (P<0.05) increased by phosphorus fertilizer with maximum values of 80.02 (number of pods plant^{-1}), 36.18g (pod weight) and 131.33g (1000 seed weight) at 75 kg P ha^{-1}. All components of yield of soybean were found to show significant (P<0.05) phosphorus and cropping pattern interactions except for number of panicles which was highly significant (P<0.01).

Table 4. Effect of rate of phosphorus fertilizer and cropping pattern on components of yield of soybean in rice-soybean intercropping.

	No. of pods (plant^{-1})	Pod weight (g)	1000 seed weight (g)
Rate of P (kg ha^{-1})			
0	51.64	17.91	107.21
45	65.33	20.47	121.26
60	78.14	27.15	130.15
75	80.02	36.18	131.33
LSD	2.86	3.45	4.33
Cropping pattern (CP)			
Sole rice	70.21	26.47	125.26
Rice-soybean	67.35	24.39	119.72
LSD	2.33	2.11	3.01
P × CP	*	*	*

*Significant at 5% level of probability.

Crop yield

From the data presented in Table 5, P fertilizer and cropping pattern significantly affected ($P<0.05$) rice yield. Relative to the control, application of P at 45, 60 and 75 kg ha^{-1} enhanced rice yield by 23%, 57.4% and 88.3% respectively, while soybean yield was increased by 28.5%, 65.7% and 73.5% at same respective P fertilizer rates. Interactive effects of phosphorus and cropping pattern for yield of both rice and cowpea were found to be highly significant ($P<0.01$) indicating increasing rates of phosphorus fertilizer and intercropping affects the final yield of component crops. Similar results were observed in maize-soybean intercrop (Wandahwa *et al*., 2006).

Table 5. Effect of rate of phosphorus fertilizer and cropping pattern on yield of rice and in rice-soybean intercropping.

		Rice			Soybean	
Rate of P (kg ha^{-1})	Sole rice	Intercropped rice	Mean	Sole soybean	Intercropped soybean	Mean
0	1520.52	1100.36	1410.44	1002.43	697.99	850.21
45	1982.00	1682.46	1832.23	1207.33	979.52	1093.45
60	2765.42	2157.92	2461.67	1506.83	1312.49	1409.66
75	2903.80	2406.76	2655.28	1566.25	1384.47	1475.36
Mean (CP)	2292.94	1836.88		1320.71	1093.62	
LSD (P)	31.56			98.74		
LSD (CP)	40.28			70.09		
P × CP	**			**		

**Significant at 1% level of probability

Intercrop productivity indices

The LER for P fertilizer treatments was above unity, indicating that the resource use efficiency of the land was maximized with intercropping compared with the corresponding sole cropping (Table 6). LER increased with P rate ranging from 42% to 71%. This implies that the sole cropping of each crop requires 42 to 71% more land than the intercrop in other to achieve same yields indicating more land-use efficiency of mixtures than sole crops. Similar results were reported for intercropping in barley/faba bean (Agegnehu *et al*., 2006), maize/soybean (Margarida *et al*., 2018).

Table 6. Effect of rate of phosphorus fertilizer and cropping pattern on productivity indices in rice-soybean intercropping.

	LER	SPI (kg ha^{-1})	CR	REY (kg ha^{-1})
Rate of P (kg ha^{-1})				
0	1.42	2370.54	1.04	1726.14
45	1.50	3741.51	1.05	2560.46
60	1.65	5272.83	0.90	3583.48
75	1.71	5846.54	0.94	3590.84

The SPI values indicate the productivity advantage from intercropping based on yield of the component crops. SPI showed a linear trend with P fertilizer rate, which when compared with the control increased by 57.8%, 55.0% and 146% at 45, 60 and 75 kg P ha^{-1}. The increased productivity of the intercrops of sorghum and soybean compared to each sole crop can be attributed to enhancing utilization of nutrients, solar radiation and space over time which allowed for more photosynthetic efficiency of the crops (Belel *et al.*, 2014; Zhang *et al.*, 2015). The competition ratio of rice relative to soybean (CR_{RS}) in the rice-soybean intercropping system was greater than unity at control and 45 kg P ha^{-1}, indicating a positive interspecific competition between the two-component crops. However, at 60 and 75 kg P ha^{-1} values of the competition ratio (CR_{RS}) were below unity ranging from 0.90 to 0.94 which shows a negative interspecific interaction between the two-component crops in the rice-soybean intercropping system. Previous researches (Yang *et al.,* 2013; Chen *et al.,* 2017) have shown that interspecific competition for nutrient resources influences growth and seed yield of component crops in intercropping systems.

Table 7. Effect of rate of application on agronomic efficiency of P (AE_P) fertilizer in rice-soybean intercropping.

	Rice		Soybean	
	Sole rice	Intercropped rice	Sole soybean	Intercropped soybean
Rate of P (kg ha^{-1})				
0	-	-	-	-
45	10.26	12.94	4.55	5.41
60	20.75	17.63	8.41	9.32
75	18.44	17.42	7.52	8.33

Agronomic efficiency of P fertilizer

The results of agronomic efficiency of phosphorus fertilizer (AE_P) as presented in Table 7 indicate the significant role of phosphorus nutrition in the growth of the two-component crops in the rice-soybean intercropping. In this study, AE_P was at its maximum with application of 60 kg P ha^{-1} in both sole and intercrops of rice and soybean. Agronomic efficiency of P fertilizer was generally higher in the cereal crop (rice) relative to the legume (soybean) at all levels of application.

The lower agronomic efficiency values of soybean compare to rice may be due to more nutrient demand from the rice relative to the leguminous soybean. Midmore (1973) and Blade *et al.* (1997) had earlier noted that the addition of nutrients to a cereal-legume system appears to favour the cereal at the expense of the legume.

Conclusion

Based on the results of this study, the application of phosphorus fertilizers increased crop yields at all levels both in sole cropping and intercropping. The results of this study have shown that to achieve a positive interspecific competition between rice and soybean in the rice-soybean intercropping system it is more appropriate to apply phosphorus 60 kg P ha^{-1}.

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