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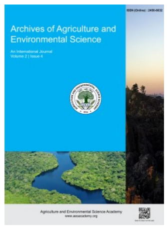

ORIGINAL RESEARCH ARTICLE

CrossMark

Evaluation of crop arrangement and phosphorus rate on performance of maize-common bean intercropping in western Kenya

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ABSTRACT

The effect of phosphorus (P) rate and crop arrangement on the performance of component crops in maize-bean intercropping systems was investigated at two sites; Malanga and Bugeng'i in western Kenya. A split plot design with five crop arrangements in the main plots i.e., one row of maize alternating with one row of beans (conventional), maize and beans planted in the same hole, two rows of maize alternating with two of beans (Mbili), sole maize and sole beans, in a factorial combination with three P rates; 0, 30, and 60 kg ha^{-1} in the subplots, was used. Bean yields were low (< 1 t ha^{-1}) but they increased with increasing P rate at both sites. Response of maize to P fertilizer was however poor at Malanga mainly due to *Striga* weed infestation. Yields of beans did not significantly differ among crop arrangements at both sites. At Bungeng'i, there was a significant interaction between P rate and crop arrangement. At this site, the maize yield in the conventional arrangement increased with increasing P rate but for the Mbili arrangement, the grain yield from application of 30 kg P ha^{-1} was significantly higher than that at 0 kg P ha^{-1} and similar to that 60 kg P ha^{-1}. Therefore, it is not beneficial to fertilize beyond 30 kg P ha^{-1} at this site with the Mbili arrangement. Intercropping was beneficial in all crop arrangements (Land equivalent ratio >1) and can therefore be practiced, except for maize and beans planted in the same hole with no P application at Bugeng'i.

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INTRODUCTION

Depleted soil fertility coupled with unsustainable cropping practices in western Kenya are serious constraints to production of most food crops despite the regions favorable climatic conditions. Yield of the staple food crop maize is on average only 1t ha^{-1} against a potential of 5 ha^{-1} (Ngome *et al.*, 2011) while that of beans, another popular crop in the region, is 0.5 t ha^{-1} against a potential of 2 t ha^{-1} (Namugwanya *et al.*, 2014). The situation is aggravated by the small land sizes, with individual farms rarely exceeding 1.5 ha, due to continuous land subdivision occasioned by rapid population increase (Lunze *et al.*, 2002). As a mitigation measure, intercropping of maize and common bean is often practiced as a means of maximizing land use and improving soil fertility on smallholder farms (Lunze *et al.*, 2007; Agegnehu *et al.*, 2006). This cropping system leverages on complementarity of the physiological and morphological characteristics of maize and beans in the use of growth resources (Arash *et al.*, 2016). In particular, beans may improve soil fertility through biological nitrogen fixation (Attar *et al.*, 2012; Rotaru and Sinclair, 2009) and hence reduce the need for nitrogen fertilizers (Giller, 2001; Latati *et al.*, 2016). The ability of common beans to fix nitrogen on most soils in western Kenya is however low because of P deficiencies (Beebe *et al.*, 2011). Plant available P in soil is important for sufficient nodulation of legumes and therefore nitrogen fixation because nitrogen fixing bacteria require high energy in form of ATP. Consequently, legumes require more phosphorus to achieve maximum function and must therefore be supplied with adequate P in form of fertilizers.

A major limitation in intercropping systems is the competition of component crops for growth resources such as light, moisture and nutrients, which lead to general yield reduction of the component crops (Cheng-dong *et al.*, 2019; Ijoyah and Jimba, 2012). It is however now recognized that the arrangement of component crops in intercropping systems, which defines the pattern of distribution of plants over the ground, may create different micro climates in the crop stands and therefore influence the efficiency with which the growth resources are utilized (Mal´ezieux *et al.*, 2009). Therefore, spatial arrangement of the component crops has been recognized as one of the management factors that determine the advantage or otherwise of an intercropping system (Mvubu, 2015).

In western Kenya, beans and maize are often planted in the same hole to minimize the labour requirement which is often in limited supply on smallholder farms. Another common practice is to alternate a row of beans with maize. These practices are however thought to accentuate the effects of competition because of inappropriate spatial crop arrangement (Woomer *et al.*, 2004). A newer staggered crop arrangement consisting of two rows of maize alternating with two rows of beans (called 'Mbili' in the local language) has therefore been proposed (Tungani *et al.*, 2003; Matusso *et al.*, 2014). In this system, the legume crops are not as strongly shaded by the maize in the intercrops, compared to the current crop arrangements and it is therefore hypothesized that its yields will be higher. There is however little understanding of how these crop arrangements interacts with fertilizer inputs to affect crop performance. The objective of this study was therefore to evaluate the effects of crop arrangement and P fertilizer rates on performance of maize and beans in western Kenya.

MATERIALS AND METHODS

Site description

The study was conducted for one season in 2015 at two sites; Bugeng'i and Malanga in western Kenya. Both sites receive a bimodal rainfall that ranges between 1500 and 1900 mm per year. The long rains season occurs from February to July and short rains from August to November. The initial soil properties at the sites are presented in Table 1.

Experimental design and treatments

A split-plot design consisting of 15 treatments with three replications was used. The crop arrangements were imposed in main plots at five levels of as follows; (i) conventional arrangement consisting of one row of maize alternating with one row of beans (ii) maize and beans planted in the same hole (iii) a staggered arrangement consisting of two rows of maize alternating with two rows of beans (Mbili) (iv) sole maize and (v) sole beans. These were combined in a factorial arrangement with three P fertilizer levels *i.e.* 0, 30 and 60 kg P ha^{-1} in the sub-plots.

Crop establishment and management

Land was prepared to a medium seedbed tilth and plots measuring 4.5 m × 3 m demarcated. Sole maize (variety Western Hybrid 505) and common bean (Rose coco variety) were planted at 75 cm by 30 cm (44, 444 plants ha^{-1}) and 30 × 15 cm (202,020 plants ha^{-1}), respectively at the onset of the rains. In all crop arrangements, two beans per hill were planted and thinned to one except for maize and beans in the same hole where three bean seeds were planted and later thinned to two to give a population of 88, 888 plants ha^{-1} in all the intercrops. Triple superphosphate (TSP), the P source, and calcium ammonium nitrate were evenly broadcast in the appropriate plots and incorporated into the soil at planting. However, only a third of N fertilizer (20 kg N ha $^{-1}$) was applied at planting. The rest was applied using spot application to all maize treatments at 6 weeks after planting (WAP). Sole bean treatments were not top dressed with N fertilizer because the beans were inoculated and were therefore expected to fix N for their growth. The crops were managed using the recommended agronomic practices for the area.

Soil sampling and analysis

Soils for site characterization were obtained at a depth of 0-20 cm at each site by randomly auguring several spots in the field and then bulking the soil to get one composite at the beginning of the study. The samples were air-dried and analysed for pH, organic C, total N, exchangeable calcium, magnesium potassium and available P using standard laboratory procedures (Okalebo *et al.*, 2002). Soil were again sampled at 6 WAP and analysed for plant available soil P.

Table 1. Soil properties at the Malanga and Bugeng'i. study sites.

Soil property	Malanga	Bugeng'i
pH (1:2.5 Soil:H_2O)	5.0	4.8
Total organic carbon (%)	0.63	1.10
Total nitrogen (%)	0.10	0.12
Available P (mg kg^{-1})	8.00	10.00
Exchangeable Ca (Cmol kg^{-1})	5.30	4.22
Exchangeable Mg (Cmol kg^{-1})	0.24	0.01
Exchangeable K (Cmol kg^{-1})	0.66	0.29
Sand (%)	30.00	34.00
Silt (%)	10.00	40.00
Clay (%)	60.00	26.00
Textural class	Clay	Clay loam

Estimation of leaf area index, height and yields of maize and beans

The leaf area of maize was estimated by direct measurements on single leaves for cross-sectional lengths and widths using a standard metre rule and the leaf area calculated using the formulae.

$$\text{Leaf area } (m^2) = \text{Length (L) in meters x Width (W) in meters}$$

Leaf area for beans was also determined at 6 WAP by obtaining ten fully expanded leaves from a sample of three bean plants randomly selected from each sub-plot. Their leaf area was determined using the graphical method. Leaf area index for both crops was calculated using the formulae of Blanco and Folegatti (2003) as follows.

$$\text{LAI} = \frac{\text{Leafarea } (m^2)}{\text{Total ground area } (m^2) \text{ ofsampled plants}}$$

Maize and beans were harvested at physiological maturity and their grain yields determined at moisture content of 13.5%.

Land equivalent ratio

Land Equivalent Ratio (LER) was used to compare yield advantage of intercropping and was calculated as follows.

$$LER = \frac{Yab}{Yaa} + \frac{Yba}{Ybb}$$

Where *Yaa* and *Ybb* are yields of the sole crops and *Yab* and *Yba* are yields in intercrops (Mead and Willey, 1980).

Data analysis

Analysis of variance (ANOVA) was performed on all data using GenStat software (Genstat Release 7.22, 2010) and treatment means separated by the Least Significant Differences of means (LSD) at $p<0.05$.

RESULTS AND DISCUSSION

Available P in the soil

Table 2 illustrates effects of treatments on soil available P. There was no interaction between P fertilizer rate and crop arrangement on soil available P at both sites. At Malanga soil available P ranged between 6.7 and 30 mg kg^{-1} under maize and beans planted in the same hole at 0 kg P ha^{-1} and sole maize at 60 kg P ha^{-1}respectively. Although available P increased with increasing P rate at this site, statistical significance was not attained. Crop arrangement however, had a significant effect, with sole maize and sole bean crops having similar but higher amounts of available P than other crop arrangements. This was likely due to lower uptake of P in the sole crops where the plant population was lower than in the intercrops.

At Bugeng'i, available P ranged from 10.47 to 12.87 mg kg^{-1} under conventional arrangement at 0 kg P ha^{-1} and sole maize at 60 kg P ha^{-1}respectively. Soil available P was not affected by crop arrangement at this site but was significantly affected by P fertilizer rate where it increased with increasing P rate within a crop arrangement. This is attributed very soluble nature of TSP. Consequently higher rates of fertilizer released higher quantities of P in soil solution. Similar findings were reported by Opala *et al.* (2012).

Leaf area index of beans and maize

The LAIs of beans ranged from 0.29 to 1.51 (Table 3). These were very low when compared to the optimum value of 4 reported by Mengel and Kirkby (2001). The low LAIs are partly attributed to adverse weather conditions during the study period. Excessive rainfall (1065 mm and 820 mm at Bungeng'i and Malanga, respectively received in only 3 months) partly damaged the bean leafs. There was no interaction between P fertilizer rate and crop arrangement on LAI of beans at both sites (Table 3). Effects of crop arrangements and P rates on LAI of beans were also not significant. This is ascribed to the fact that maize had low LAI and hence did not shade the beans. The competition for light was therefore not a major factor among the crop arrangements as would have been expected.

There was no interaction between P fertilizer rates and crop arrangements on LAI of maize at both sites (Table 4). The LAI of maize was also not significantly affected by crop arrangement at both sites. This is attributable to the fact that maize, which was the main crop in the intercrop, was taller than the beans and therefore was not affected by the beans in competition for light. Similarly, Worku (2008) reported that bean arrangement didn't influence growth of maize in Ethiopia and attributed this to the less aggressive nature of bean over maize. Leaf area index of maize at Malanga ranged from 1.09 under sole maize at 0 kg P ha^{-1} to 1.80 under Mbili at 60 kg P ha^{-1}. At Bugeng'i, LAI of maize ranged between 0.10 under maize and beans planted in the same hole at 0 kg P ha^{-1}and 1.93 under conventional at 60 kg P ha^{-1}. These LAIs were however low compared to the optimum of 5 for maize (Mengel and Kirkby, 2001). High LAI is responsible for higher absorption rates of solar radiation due to larger leaf surface area and therefore highly influences biomass accumulation (Tsubo *et al.*, 2001). The low LAIs in this study therefore adversely affected the final yields of both crops. The LAI due to application of 60 and 30 kg P ha^{-1}did not differ significantly at this Malanga but both had significantly higher LAI than 0 kg P ha^{-1}. The general increase in LAI with P rate confirms that P was limiting in these soils and demonstrates the importance of P fertilization on these soils.

Bean yields

Effects of treatments on bean yields are presented in (Table 5). The average bean yields (0.37 t ha^{-1} at Malanga, 0.45 t ha^{-1}at Bungeng'i) were lower than the reported potential yield of 2 t ha^{-1} (Namugwanya *et al.*, 2014). These poor yields, as earlier explained for the low LAIs, are attributed to the generally adverse weather conditions during the study period. In addition, bean growth is likely to have been limited by the low initial levels of soil N (< 0.2%) at both sites (Table 1). It was assumed that beans would fix N to support their growth and hence they were not top-dressed. However, due to high acidity of these

Table 2. Available soil phosphorus (mg kg^{-1}) at both the study sites.

Crop arrangement	Phosphorus rate							
	Malanga				Bugeng'i			
	0	30	60	Means	0	30	60	Means
Conventional	8.0	12.7	15.3	12.0	10.47	11.33	12.43	11.41
Mbili	7.3	16.3	24.0	15.9	11.13	12.03	12.60	11.92
Maize + beans (SH)	6.7	11.3	17.3	11.8	10.57	11.23	11.80	11.20
Sole beans	20.0	22.7	29.3	20.7	11.30	11.97	12.23	11.83
Sole maize	20.0	26.7	30.0	25.6	11.53	11.90	12.87	12.10
Means	12.4	17.94	23.18	17.2	11.00	11.69	12.39	11.69
Probabilities of the F test for the ANOVA for system and P rate								
CA	0.001				NS			
P rate	NS				<0.001			
CA × P rate	NS				NS			
LSD								
CA	5.2				NS			
P rate	NS				0.29			
CA × P rate	NS				NS			

Table 3. Effects of different phosphorus rate on leaf area index of beans.

Crop arrangement	Phosphorus rate							
	Malanga				Bugeng'i			
	0	30	60	Means	0	30	60	Means
Conventional	1.03	0.99	1.51	1.18	0.49	0.49	0.51	0.50
Mbili	0.76	0.79	1.27	0.94	0.48	0.48	0.54	0.50
Maize + beans (SH)	0.78	1.32	1.42	1.17	0.50	0.52	0.56	0.52
Sole beans	0.80	0.92	1.22	0.98	0.47	0.52	0.61	0.53
Means	0.84	1.01	1.36	1.07	0.48	0.51	0.55	0.51
Probabilities of the F test for the ANOVA for system and P rate								
CA	NS				NS			
P rate	NS				NS			
CA × P rate	NS				NS			

Table 4. Effects of different phosphorus rate on leaf area index of maize.

Crop arrangement	Phosphorus rate							
	Malanga				Bugeng'i			
	0	30	60	Means	0	30	60	Means
Conventional	1.27	1.54	1.70	1.50	0.93	1.80	1.93	1.55
Mbili	1.40	1.59	1.80	1.60	1.13	1.32	1.33	1.26
Maize + beans (SH)	1.30	1.49	1.67	1.49	0.10	1.17	1.22	0.83
Sole maize	1.09	1.24	1.74	1.36	1.18	1.45	1.57	1.40
Means	1.27	1.47	1.73	1.49	0.84	1.43	1.51	1.26
Probabilities of the F test for the ANOVA for system and P rate								
CA	NS				NS			
P rate	<0.001				0.01			
CA × P rate	NS				NS			
LSD								
CA	NS				NS			
P rate	0.170				0.16			
CA × P rate	NS				NS			

soils, the generally low soil P levels coupled with the fact that beans are inherently poor N fixers (Attar *et al.*, 2012), it is unlikely that the beans fixed enough N for their use.

There was no interaction between P fertilizer rate and crop arrangement on yields of beans at both sites. At Malanga, effect of crop arrangement on bean yields was not significant but the yields increased with increasing P rate. At Bugeng'i, conventional arrangement at 0 kg P ha^{-1} had the least (0.09 t ha^{-1}) while sole beans at 60 kg P ha^{-1} had the highest (1.8 t ha^{-1}) yields. The effect of crop arrangement was significant at this site. When averaged across all P rates, sole bean crop had significantly higher yield than the other crop arrangements mainly because they had higher plant population (202,020 plants ha^{-1}) compared the intercrops (88, 888 plants ha^{-1}). There was also less competition for growth resources in the sole bean crop than in the intercrops. Other crop arrangements did not differ significantly in bean yields. This is consistent with the lack of significant differences in LAI observed earlier.

The effect of P fertilizer on bean yields was significant at both sites with higher P rates generally giving higher yields. This response to P application corroborates the fact that the initial available soil P at these sites (8 mg kg^{-1} at Malanga and 10 mg kg^{-1} and Bungeng'i) was wanting. This is buttressed by the significant positive linear relationship between available soil P and bean grain yields at Malanga (r = 0.86) which indicates that P was important in determining yields at these sites.

Similar positive responses of beans to P fertilizer have been reported (Fageria and Baligar, 2016). Phosphorus fertilization improves early root formation and therefore facilitates increased nodulation and enhanced common bean productivity (Vongai *et al.*, 2018).

Maize yields

There was no interaction between P fertilizer and crop arrangement on maize grain yield at Malanga (Table 6). The effect of crop arrangement was also not significant. Maize grain yields ranged between 0.27 t ha^{-1} under maize and beans planted in the same hole at 0 kg P ha^{-1} and 0.69 t ha^{-1} under conventional arrangement at 60 kg P ha^{-1} (Table 6). These very low yields are attributed to parasitic *Striga* weed at this site. *Striga* has been reported to decrease yields of maize by as much as 100% in western Kenya (Atera *et al.*, 2013; Vanlauwe *et al.*, 2008). In addition, soil acidity (pH 5.0 at Malanga and 4.8 at Bungeng'i) is likely to have been a problem at both sites. Under such low pH (pH < 5.5), Al toxicity limits root growth and crops do not adequately respond to applied fertilizer inputs (Kisinyo *et al.*, 2014; Marschner, 1985).

Application of 60 kg P ha^{-1} gave significantly higher maize grain yields than at 0 and 30 kg P ha^{-1} at Malanga. The difference in yield between 0 and 30 kg P ha^{-1} was however not significant. Similar increases in maize yield with increasing P rate have been demonstrated in many other studies in western Kenya (Nziguheba *et al.*, 2016; Opala *et al.*, 2014; Opala *et al.*, 2010). At Bugeng'i, maize yields ranged between 1.55 t ha^{-1} under sole maize at 0 kg P ha^{-1} and 5.84 t ha^{-1} under conventional at 60 kg P ha^{-1}. There was a significant interaction between P rate and crop arrangement on maize yields at this site. The grain yield for conventional crop arrangement followed the order: 60 kg P ha^{-1} > 30 kg P ha^{-1} > 0 kg P ha^{-1}. However, for the Mbili arrangement, the grain yield due to application of 0 kg P ha^{-1} was significantly lower than that at 30 kg P ha^{-1} but the yields 30 and 60 kg P ha^{-1} for this arrangement did not differ significantly. Therefore, it is not beneficial to apply P fertilizer beyond 30 kg P ha^{-1} for the Mbili arrangement at this site. There were no significant differences in maize yields as affected by P rates in the sole maize or when maize and beans were planted in the same hole at Bugeng'i. When averaged across P rates, the mean yields for conventional and Mbili arrangements were statistically similar but significantly higher than those of maize planted in the same hole as beans at Bugeng'i. This was attributed to the advantages of appropriate crop arrangements in these systems, resulting in reduced competition between maize and beans consequently leading to better nutrient absorption and utilization. Similar results were reported by Mattuso *et al.* (2014) and Mucheru-Muna *et al.* (2010) in the central highlands of Kenya and Woomer *et al.* (2004) in western Kenya.

Land equivalent ratio

The LERs ranged from 0.88 for maize and beans planted in the same hole at 0 P kg ha^{-1} at Bugeng'i to 2.41 for conventional crop arrangement at 60 P kg ha^{-1} at Malanga (Table 7). The LER within a cropping arrangement generally increased with increasing P rate at both sites but statistical significance was not attained. The LER at both sites was > 1 irrespective of crop arrangement, except for maize and beans planted in the same hole at Bugeng'i when no P fertilizer was applied. The better performance of the intercrop is credited to better utilization of nutrients and other growth factors such as moisture, and light interception by the component crops in the intercrop (Matusso *et al.*, 2014; Tsubo *et al.*, 2001; Chowdhury and Rosario, 1994). The poor performance of the maize and beans planted in the same hole, especially when no phosphate fertilizer was applied is attributed to the higher competition for growth resources because of the close proximity of the component crops.

Table 5. Effects of different phosphorus rate on bean yields.

Crop arrangement	Phosphorus rate							
	Malanga				Bugeng'i			
	0	30	60	Means	0	30	60	Means
Conventional	0.24	0.30	0.38	0.31	0.09	0.14	0.22	0.15
Mbili	0.21	0.28	0.35	0.28	0.14	0.17	0.25	0.19
Maize + beans (SH)	0.22	0.28	0.39	0.30	0.13	0.13	1.23	0.50
Sole beans	0.48	0.54	0.81	0.60	0.42	0.60	1.80	0.94
Means	0.29	0.35	0.48	0.37	0.20	0.26	0.87	0.45
Probabilities of the F test for the ANOVA for system and P rate								
CA	NS				0.010			
P rate	<0.001				0.001			
CA × P rate	NS				NS			
LSD								
CA	NS				0.240			
P rate	0.054				0.070			
CA × P rate NS					NS			

Table 6. Effects of different phosphorus rate on maize yields.

Crop arrangement	Phosphorus rate							
	Malanga				Bugeng'i			
	0	**30**	**60**	**Means**	**0**	**30**	**60**	**Means**
Conventional	0.40	0.41	0.69	0.50	2.43	4.13	5.84	4.02
Mbili	0.36	0.45	0.55	0.45	2.13	5.40	5.50	4.35
Maize + beans (SH)	0.27	0.32	0.45	0.35	1.82	2.32	3.33	2.49
Sole maize	0.37	0.43	0.45	0.42	1.55	2.24	3.18	2.32
Means	0.35	0.40	0.54	0.43	1.98	3.52	4.37	3.29
Probabilities of the F test for the ANOVA for system and P rate								
CA		NS				0.001		
P rate		0.004				<0.001		
CA × P rate		NS				0.005		
LSD								
CA		NS				0.75		
P rate		0.10				0.46		
CA × P rate		NS				0.98		

Table 7. Land equivalent ratios in relation to phosphorus rate during maize-bean intercropping.

Crop arrangement	Phosphorus rate							
	Malanga				Bugeng'i			
	0	30	60	Means	0	30	60	Means
Conventional	1.79	1.81	2.41	2.00	1.25	1.31	2.09	1.55
Mbili	1.23	1.64	2.22	1.58	1.18	1.63	1.85	1.55
Maize + beans (SH)	1.47	1.59	1.62	1.56	0.88	1.15	1.33	1.16
Means	1.50	1.68	1.96	1.71	1.10	1.36	1.76	1.42
Probabilities of the F test for the ANOVA for system and P rate								
CA		NS				NS		
P rate		NS				NS		
CA × P rate		NS				NS		

Conclusion

There was no significant interaction between P rate and crop arrangement for all parameters under consideration at Malanga. At this site maize yields were very low due to effects of *Striga* weed that confounded the effects of the applied fertilizer and crop arrangement. Bean yields however increased with increasing P rate at both sites. At Bungeng'i, there was significant interaction between P rate and crop arrangement where the maize yield in the conventional arrangement increased with increasing P, but for the Mbili arrangement, the grain yield due to application of 0 kg P ha^{-1} was significantly lower than that at 30 kg P ha^{-1}, but the yields at 30 and 60 kg P ha^{-1} did not differ significantly. Based on economic considerations, the lower P fertilizer rate (30 kg P ha^{-1}) for the Mbili arrangement should be used at this site. Intercropping was beneficial in all crop arrangements (LER > 1) except for maize and beans planted in the same hole with no P fertilizer application at Bugeng'i and can therefore be practiced at these sites as long as adequate fertilizer is provided and *Striga* weed controlled.

Conflict of interests

The authors have declared no conflict of any interests.

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