African Journal of Agricultural Research

Full Length Research Paper

Agronomic and economic evaluation of phosphate fertilizer use in maize-bean cropping systems in Western Kenya

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Effects of phosphorus rate and crop arrangement on yields and economic benefits in maize-bean cropping systems were investigated for two seasons: Short rains (SR) of 2015 and long rains (LR) of 2016 in Western Kenya. A split plot design with five crop arrangements in the main plots; one row of maize and beans alternating (conventional), maize and beans planted in the same hole (SH), two rows of maize alternating with two of beans (Mbili), sole maize and sole beans, and three P rates; 0, 30, and 60 kg ha^{-1} in the subplots was used. There were no significant effects of crop arrangement on maize and bean yields in LR but bean yields increased with increasing P rate in both seasons. Within a crop arrangement, maize yields also increased with P rate in the SR. Conventional and Mbili arrangements had similar yields for both beans and maize which were superior to SH at 60 kg P ha^{-1} in SR. Sole beans significantly out-yielded intercropped ones. Intercropping was only beneficial (LER > 1) with adequate rainfall in SR but financial returns were too low for all the tested practices because of low yields coupled with high production costs and low producer prices.

Key words: Crop arrangements, intercropping efficiency, phosphorus.

INTRODUCTION

In western Kenya, increased population pressure has reduced per capita area of cropping land and most small scale farmers therefore own less than 0.2 ha of land (Vanlauwe et al., 2011). The key to increasing crop yields in this region, in order to feed the growing population, therefore lies with intensification that is, increasing yields per unit area rather than expansion of the cropping area. However, most of these lands have over the years been depleted of plant nutrients especially nitrogen (N) and phosphorus (P) and crop yields are therefore low (Sanchez et al., 1997). Developing sustainable cropping systems to better exploit soil nutrients resources such as N and P in these soils is one of the research challenges. Therefore intercropping of cereals with legumes has been considered as one of the efficient cropping systems that increase use of such nutrients and as a means of

maximizing land use (Lithourgidis et al., 2011; Matusso et al., 2014). Intercropping is not a new concept, but because of the current threat to food security, there has been a renewed interest to better productivity of such systems in tropical agriculture (Mal´ezieux, 2009).

Intercropping maize (*Zea mays* L.) and common bean (*Phaseolus vulgaris* L.) is widely practiced on small scale farms in western Kenya. In such systems, beans are supposed to fix N and therefore secure the nitrogen economy while increasing yield of maize (Giller, 2001). However widespread phosphorus deficiencies in western Kenya limit nitrogen fixation by beans consequently negating their usefulness as a component of maize-bean intercropping systems. For efficient nitrogen fixation by the legume, adequate phosphorous must be supplied in form of fertilizers because nitrogen fixing bacteria require high energy in the form of ATP (Attar et al., 2012).

Crop productivity in intercropping systems depends on many factors including the crop variety used, plant density, cropping seasons and agricultural practices like irrigation, fertilization etc. (Tsubo et al., 2003). One aspect that has received little attention in intercropping research is the spatial arrangement of crops within the cropping system yet it is one of the most important agronomic factors that determine whether an intercrop system will be advantageous or not with regard to yield gains (Natarajan and Shumba, 1999). Since plants stand still in the land, the way they are distributed greatly influence the ability of a crop to capture and use environmental resources (radiation, water, and nutrients), which are necessary for growth and yield (Satorre, 2013). There is evidence that crop arrangements may create different microclimates in the stands and therefore influence the efficiency with which the growth resources are utilized (Dolijanovic et al., 2013). An ideal spatial arrangement is the one which maximizes the complementarity between the component crops and enhances physiological efficiency of the intercropping system in a given environment (Natarajan, 1990). Hence agronomic manipulation of the spatial arrangements of the component crops can strongly affect growth and yields of the crops and hence determine whether an intercrop system will be advantageous or not with regard to yield gains (Natarajan and Shumba, 1999). There is however little understanding on how crop arrangements interact with fertilizer inputs to affect crop yield in intercropping systems (Mal´ezieux, 2009). There are also concerns that even when the agronomic effectiveness of certain technologies is well established, adoption of such technologies by farmers is sometimes dismal (Opala et al., 2010). A fact that is often overlooked is that adoption of any technology by a farmer is not only based on yield returns but also on the accruing economic benefits (Odendo et al., 2007; Tungani et al., 2003). The objective of this study is therefore to assess the interactive effects of crop arrangement and P fertilizer rates and associated economic benefits.

MATERIALS AND METHODS

Site description

The study was conducted at Bugeng'i (0°7'N, 34°24'E) in Busia County in western Kenya, at an altitude of 1298 m above sea level. The area has two rainy seasons with long rains (LR) from March to July while short rains (SR) are from August to December; the mean annual rainfall ranges between 1270 and 1790 mm. The mean annual maximum temperatures range from 26 to 30°C while the mean minimum temperatures vary between 14 and 18°C. The dominant soil types are the highly weathered ferrasols (Jaetzold et al., 2009).

Soil sampling and analysis

Soils for site characterization at the beginning of the study were obtained at a depth of 0 - 20 cm by randomly auguring several spots in the field and then bulking the soil to get one composite. The soil was analysed using standard laboratory procedures (Okalebo et al., 2002). Soil pH was determined in a soil-water (1:2.5) suspension with a pH meter. Organic carbon was determined by Walkley-Black method while exchangeable calcium, magnesium potassium and extractable P were determined by Mehlich double acid method. Total soil N was determined by Kjeldahl acid digestion method.

Experimental design and treatments

The study was conducted for two consecutive cropping seasons; the SR in September 2015 and LR in March 2016. A split-plot design with 15 treatments replicated three times was used. The main plots consisted of five levels of maize-bean cropping arrangement as follows; (i) one row of maize alternating with one row of beans (conventional) (ii) maize planted in the same hole with beans (iii) 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, that is, 0, 30 and 60 kg P ha^{-1} in the subplots.

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 beans (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 each season. Maize was planted at two seeds per hill and later thinned to one plant. 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 bean population of 88, 888 plants ha^{-1} in all the intercrops. Triple superphosphate 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 40 kg N ha^{-1} 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

Table 1. Values used for cost- benefit analysis in both seasons.

Parameter	Value
	Ksh kg^{-1}
Input costs	
Rose cocoa grains: Sole beans	250
WH 505 maize grains	200
TSP fertilizer	70
CAN fertilizer	60
Bio fix	1250
Labour costs	
Ploughing	9000
Harrowing	6000
1st and 2nd weeding sole maize	10000
1st and 2nd weeding sole beans and intercrops	15000
Top-dressing	2000
Harvesting sole crops	7500
Harvesting intercrops	12500
Output prices	
Maize grain	35
Bean grain	75
Maize stover	3

Ksh is Kenya Shilling.

their growth. The crops were managed using the recommended agronomic practices for the area and harvested at physiological maturity. The yields of both crops were determined at moisture content of 13.5%.

Land equivalent ratio

Land Equivalent Ratio (LER) was used to compare yield advantage obtained from different intercropping arrangements. It was calculated as follows:

LER= Partial LER maize + Partial LER beans   (1)

$$LER = \frac{Yab}{Yaa} + \frac{Yba}{Ybb}$$
                                                                                             (2)

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

Economic analysis

Economic analysis was conducted using cost-benefit analysis (CIMMYT, 1988). The prices of the fertilizer and seed inputs were determined through a market survey of the area (Table 1) while the labour cost was determined by observing how long it took to perform specific activities and valued using the mean market wage rates within the study area. Economic benefits were calculated by multiplying the crop yields with prevailing market prices. To evaluate the economic benefits of the treatments under consideration,

the benefit: cost ratios (BCRs), calculated as the net benefit due to the treatment divided by the total cost associated with that treatment was used.

Data analysis

Yield data were subjected to analysis of variance using Genstat software (Genstat Release 7.22, 2010) and treatment means separated by Least Significant Differences of means (LSD) at p < 0.05.

RESULTS AND DISCUSSION

Soil physical and chemical properties

Soil properties prior to establishment of the experiments at the site are presented in Table 2. The soil was very acidic with a pH of 4.8. This is to be expected in this high rainfall area because most of the basic cations have been leached (Kisinyo et al., 2014). This is confirmed by the low levels of Mg and K at the site. However, Ca was not limiting. Available P was below the critical value of 20 mg kg^{-1} that is considered adequate for most crops therefore justifying the need for application of P fertilizers at this site. Similar low P levels across many parts of western Kenya have been reported (Opala et al., 2014; Nziguheba et al., 2002) and attributed mainly to the high

Table 2. Initial soil properties at Bugeng'i.

Soil property	Value
pH (1:2.5 Soil:H_2O)	4.8
Total Organic Carbon (%)	1.1
Total Nitrogen (%)	0.12
Available P (mg kg^{-1})	8
Exchangeable Ca (Cmol kg^{-1})	4.22
Exchangeable Mg (Cmol kg^{-1})	0.01
Exchangeable K (Cmol kg^{-1})	0.29
Sand (%)	34
Clay (%)	26
Silt (%)	40
Textural class	Clay Loam

Table 3. Bean yields as affected by crop arrangement and phosphorus rate at Bugeng'i.

	Phosphorus rate kg ha^{-1}							
	Short rains seasons			Mean	Long rains season			Mean
Crop arrangement	0	30	60		0	30	60	
Conventional	0.09	0.14	0.22	0.15	0.18	0.33	0.34	0.28
Mbili	0.14	0.17	0.25	0.19	0.23	0.4	0.42	0.35
Maize + beans (SH)	0.13	0.13	1.23	0.5	0.17	0.34	0.34	0.28
Sole beans	0.42	0.6	1.8	0.94	0.5	0.88	0.99	0.79
Mean	0.2	0.26	0.87	0.45	0.27	0.49	0.52	0.43
Probabilities of the F test for the ANOVA for system and P rate								
CA	0.01				NS			
P rate	0.001				0.03			
CA × P rate	NS				NS			
LSD								
CA	0.24				NS			
P rate	0.07				0.02			
CA x P rate	NS				NS			

SH = same hole; LSD = Least significant difference of means; N.S = not significant; CA= crop arrangement.

P-fixation capacity of these soils and cropping with little or no P inputs which has depleted soil P stock (Buresh et al., 1997). Organic C and N were below the optimum values of 2 and 0.2% respectively (Okalebo et al., 2002) likely again due to continuous cropping with no appropriate soil fertility replenishment measures.

Bean yields

Effects of treatments on bean yields are presented in Table 3. There was no significant effect of crop arrangement on bean yields in the LR. However in the SR,

when averaged across all P rates, sole bean crop had significantly higher grain yields than the other crop arrangements. The effect of P fertilizer on bean yield was significant in both seasons. In the SR, application of 60 kg P ha^{-1} gave significantly higher bean yields than at 0 and 30 kg P ha^{-1} while in the LR bean yields at application of 30 and 60 kg P ha^{-1} did not differ significantly but were however significantly higher than at 0 kg P ha^{-1}. This response to P application confirms that the initial available soil P (8 mg kg^{-1}) at these sites was deficient. These results are consistent with those of Kajumula and Muhammad (2012) in Tanzania who observed that under Low P availability, beans suffer from reduced rate of

Table 4. Maize yields as affected by crop arrangement and phosphorus rate at Bugeng'i.

	Short rains season				Long rains season			
	Phosphorus rate kg ha^{-1}							
Crop arrangement	0	30	60	mean	0	30	60	mean
Conventional	2.43	4.13	5.84	4.02	0.26	0.55	0.59	0.46
Mbili	2.13 1.82		5.4	5.5	0.18	0.49	0.51	0.39
Maize+ beans (SH)	1.55	2.32	3.33	2.49	0.4	0.46	0.49	0.45
Sole maize		2.24	3.18	2.32	0.67	0.77	0.78	0.74
Mean	1.98	3.52	4.37	3.29	0.41	0.56	0.57	0.51

Probabilities of the F test for the ANOVA for system and P rate		
CA	0.001	NS
P rate	<0.001	NS
CA x P rate	NS	NS
LSD		
CA	0.75	NS
P rate	0.46	NS
CA x P rate	0.98	NS

SH = same hole; LSD = Least significant difference of means; N.S = not significant; CA= crop arrangement.

photosynthesis therefore impacting negatively on yield.

The average bean yields (0.45 and 0.43 t ha^{-1} in the SR and LR respectively) were lower than the potential yield of 3 t ha^{-1} that was reported by Namugwanya et al. (2014). These poor yields are attributed to the adverse weather conditions during the study period. In the SR season, heavy rain physically damaged the bean leaves. In the LR, there was severe drought with no rain received during the critical flowering period. The highest bean yields were obtained in the sole bean crops mainly because of their higher plant population (202,020 plants ha^{-1}) compared the intercrops (88, 888 plants ha^{-1}) but also due to reduction in yields per plant due to competition in the intercrops. Other crop arrangements did not differ significantly in bean yields.

Maize grain yields

Maize grain yields were higher in the SR (mean of 3.29 t ha^{-1}) than the LR (mean of 0.51 t ha^{-1}) at (Table 4). The variation in maize grain yield observed between the two seasons is attributed mainly to the differences in rainfall. In the SR season, the rainfall was unusually high 1065 mm compared to 137.50 mm, the normal long term means and well distributed during the growing period of maize. However, in the LR season the rainfall was low and poorly distributed. Only 529 mm of rainfall was recorded in this season, with only 30 mm being received in the month of June at the critical stage when the maize was tasselling and no rainfall was recorded in July. There were no significant treatment effects on maize grain

yields in the LR (Table 4) mainly due to severe drought. In the SR, there was no significant interaction between P rate and crop arrangement on maize grain yield but maize yields generally increased with increasing P rate within a crop arrangement (Table 4).

Crop arrangement significantly affected maize yields in this season where the mean yields for conventional and Mbili arrangements were statistically similar but were significantly higher than those of maize planted in the same hole with beans and sole maize. The better performance of these two intercropping arrangements compared to maize and beans planted in the same hole is attributed to the appropriateness of these crop arrangements that reduced interspecies competition for growth resources between maize and beans. 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. While competition for nutrients and water is expected to be severe in maize and beans planted in the same hole therefore contributing to low maize yields, the low yield of sole maize compared to the other intercrops of Mbili and conventional was unexpected. Many other studies have reported that maize yields are usually depressed or not affected by the intercropped beans (Nassarya et al., 2020; Morgado and Willey, 2008).

Application of 60 kg P ha^{-1} gave significantly higher maize yields than at 0 and 30 kg P ha^{-1} during the SR season, when rainfall was not limiting, for most crop arrangements confirming. Since phosphorus was limiting at this site, the response to P was not entirely unexpected. Similar increases in maize yield have been

Table 5. Land equivalent Ratios for the intercrops at Bugeng'i.

Treatment	SR	LR
Conventional 0P	1.23	0.81
Conventional 30P	1.33	1.21
Conventional 60P	2.09	1.41
Mbili 0P	1.18	0.71
Mbili 30P	1.76	0.9
Mbili 60P	2.05	2.15
Maize, bean 0P	0.88	0.77
Maize, bean 30P	1.22	0.95
Maize, bean 60P	0.7	1.05

Table 6. Cost, benefits and cost - benefit ratios of treatments.

Treatment	Costs (Ksh)	Net benefits (Ksh)		BCR	
		SR	LR	S R	LR
Sole bean 0P	84069	-52069	-76569	-0.62	-0.91
Sole bean 30P	94520	-59471	-57020	-0.63	-0.6
Sole bean 60P	104971	-65373	-38971	-0.62	-0.37
Maize, bean 0P	94566	32484	-62836	0.34	-0.66
Maize, bean30P	105017	30042	-67887	0.29	-0.64
Maize, bean 60P	115468	59910	-71768	0.52	-0.62
Conventional 0P	98816	58374	-67546	0.59	-0.68
Conventional 30P	109276	97182	-63017	0.89	-0.58
Conventional 60P	119718	148400	-67868	1.24	-0.57
Mbili 0P	98816	51894	-73106	0.53	-0.74
Mbili 30P	109267	151892	-56087	1.39	-0.51
Mbili 60P	119718	161760	-62928	1.35	-0.53
Sole maize 0P	69333	4437	-37753	0.07	-0.54
Sole maize 30P	79784	-235	-43714	0	-0.55
Sole maize 60P	90235	23643	-52855	0.26	-0.59

demonstrated in many other studies in western Kenya (Nziguheba et al., 2016; Opala et al., 2012).

Land equivalent ratio

The total LER during the SR season showed yield advantage (LER >1) of intercropping maize and beans over component sole crops for all the intercropping arrangements and fertilizers rates except for maize and beans planted in the same hole at 0 kg P ha^{-1} (Table 5). However in the LR, only the conventional arrangement at P rates of 30 and 60 kg ha^{-1} and Mbili at 60 kg ha^{-1} had total yields of the intercrops being greater than the monocrops (LER >1). The better performance of the intercrop in the SR is attributed to more efficient resource use and resource complementarity under the prevailing favourable rainfall compared to sole cropping. Similar

results were reported by Latati et al. (2013) and Tsubo et al. (2001). However, when fertilizer was applied and maize and beans planted in the same hole, the nutrients became limiting due to severe competition. The low LERs in the LR are attributed to competition for water by the component crops. The intercrops had higher plant water requirements and hence consumed more water than sole crops. The sole crops therefore performed better under the water stress than the intercrops in this season that received below average rainfall.

Cost - benefit analysis

Results of cost-benefit analysis for the 2015 SR and 2016 LR are shown in Table 6. The costs for the two seasons are similar because the same treatments were repeated. In both seasons, sole maize at 0 kg P ha^{-1} recorded the

least cost (Ksh 69, 333) while conventional and Mbili both at 60 kg P ha^{-1} recorded the highest costs (Ksh 119,718) because of higher labour costs in these crop arrangements. There were negative financial returns across all the treatments in the LR mainly due to high costs of production that could not be compensated through the sale of the low yields of maize and beans in that season. However positive financial returns were recorded in the SR with Mbili arrangement at 60 kg P ha^{-1} recording the highest financial returns (Ksh 161,760). This was attributed to better yields that were achieved by this crop arrangement in this season. Similar results were reported by Mucheru-Muna et al. (2010) and Nekesa et al. (2005) in Central Kenya. However, all treatments recorded BCR values of < 2 with the highest BCR (1.27) obtained with Mbili at 30 kg P ha^{-1}. The general rule is that a BCR of at least 2 is attractive to farmers (FAO, 2006). None of the treatments in the present study is therefore likely to be adopted by rational farmers in the study area if the prevailing climatic and economic conditions prevail. Similar results that showed technologies having agronomic effectiveness but being economically unattractive have been reported by other workers in western Kenya (Nyambati and Opala, 2014; Jama et al., 1997).

Conclusion

The yields of component crops generally did not significantly differ among crop arrangements and P rates in the LR under drought conditions which limited growth. However, when rainfall conditions were more favourable, both bean and maize yields generally increased with increasing P rate in this P deficient soil. Among the crop arrangements, conventional and Mbili arrangements had similar yields but were superior to maize and beans planted in the same hole. In addition, during the SR season, sole beans recorded significantly higher bean yields than the intercropped ones. None of the treatments was economically attractive because of high costs of production coupled with low yields and low prices offered for the crops. Therefore, unless smallholder farmers are assisted by subsidizing fertilizer inputs and/or offered higher prices for their produce, the vicious poverty cycle prevailing in the region will continue as they must till their land to eke a living.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

The authors are grateful to the Humid Tropics Projects for providing financial support for Dorcas Ofuyo's Msc research and thank Charles Okara, for his technical assistance in the field and the farmer at Bugeng'i who provided his land for the study.

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