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Article *in* Journal of Experimental Agriculture International · November 2018

DOI: 10.9734/JEAI/2018/30636

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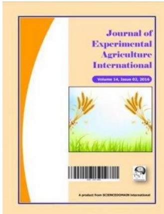

Journal of Experimental Agriculture International

27(6): 1-9, 2018; Article no.JEAI.30636
ISSN: 2457-0591
(Past name: American Journal of Experimental Agriculture, Past ISSN: 2231-0606)

Agronomic and Economic Performance of Maize-Soybean Intercrop under Rhizobia and Soil Amendments in Western Kenya

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Authors' contributions

This work was carried out in collaboration between all authors. Author MAO designed the experiment, collected the data, performed the statistical analysis and wrote the first draft under the supervision of authors BD and MO. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JEAI
Editor(s):
(1) Dr. Renata Guimarães Moreira-Whitton, Professor, Departamento de Fisiologia - Instituto de Biociências-USP, Cidade Universitária, Brazil.
Reviewers:
(1) T. Pullaiah, Sri Krishnadevaraya University, India.
(2) Shelley Gupta, India.
(3) Hamza Abdulmajeed, University of Ibadan, Nigeria.
Complete Peer review History: http://www.sciencedomain.org/review-history/27388

Original Research Article

Received 22 October 2016
Accepted 22 December 2016
Published 05 November 2018

ABSTRACT

Low crop responses to N and P fertilizer application among small holder farms are common phenomena in degraded acidic soils of western Kenya. An on-farm trial was established in Shianda sub-location in Mumias District, Western Kenya during two seasons in 2011 to determine the effect of inoculation (*Bradyrhizobium japonicum)*, lime ($CaCO_3$) and inorganic P (Single Super Phosphate) on soil chemical properties and yield components of soybean (*Glycine max* L.) and maize (*Zea mays* L.). The experiment was a 2^3 factorial with 4 replicates laid out in a randomized complete block design giving a total of 32 plots. Experimental treatments were Lime (0 and 2.5 tons lime ha^{-1}), P fertilizer (0 and 30 kg P ha^{-1}) and Inoculation (soybean inoculation and no inoculation). Lime application at 2.5 t ha^{-1} led to a significant increase in soil pH from 4.85 to 5.58 (*P* =.05) after two cropping seasons. Increase in soil available P was in the order of lime > P > inoculation (9.35>6.50>5.10 $mgkg^{-1}$). A combination of Lime + P + inoculation recorded the highest maize

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(4490 kgha^{-1}, 3470 kgha^{-1}) and soybean (970 kgha^{-1}, 830 kgha^{-1}) grain yields during the long rain (1st) and short rain (2nd) seasons respectively. Sole P treatment gave higher average number of nodules per plant and average plant biomass, (7.7 and 21.8 g) respectively than both sole inoculation (4.3 and 19.2 g) and sole lime treatments (2.3 and 16.8 g) during the 1st cropping season. On average, across the treatments during the two seasons benefit-cost analysis indicated that the lime + P + inoculation treatment gave the highest net benefit (Ksh. 107,518.60) with a benefit-cost ratio of 1.7. These results indicate that a combination of lime + P + inoculation offers a better option for increasing maize and soybean grain yields in the degraded soils of western Kenya.

Keywords: Inoculation; inorganic P; lime; net benefit.

1. INTRODUCTION

Maize is a major staple food which accounts for approximately 35% of consumed calories in Kenya. Western province accounts for up to 20% of Kenya's total maize production. However, there is a shortfall of 500,000 tonnes between production and consumption with imports increasing from 200,000 in 2013 to 500,000 tonnes in 2014 [1-3]. This implies that Kenya will continue to rely on imports and this dependence will increase over the coming years. Soils of western Kenya are highly weathered, leached and are mainly acidic with a pH range of 4.9 to 5.4 and widespread evidence of nitrogen (N) and phosphorous (P) deficiencies [4]. Consequently, continuous growing of maize without commensurate soil nutrient replenishment coupled with application of acidifying fertilizers, especially Di-ammonium Phosphate (DAP) and Sulphate of ammonia (SA) have aggravated the soil acidity problem, and caused decreased maize yields averaging less than 1 ton ha^{-1} against a potential of 4 tons ha^{-1} in smallholder farms of western Kenya [5].

Past studies have shown that maize productivity is very low in western Kenya; the typical output from a 'good' rainy season is less than 1 Mg/ha of maize, although the potential lies between 4 to 5 Mg/ha on small scale farmers' fields [6,7]. Phosphorus deficiency in these soils is largely due to low occurrence of P-containing minerals [8] and P-fixation [6]. On the other hand, low mineral nitrogen (N), is attributed to low SOM, while nitrates released due to organic matter mineralization may be taken up by plants, immobilized by microbes, lost from the soil system through soil erosion, leaching and denitrification or retained in the soil profile [9].

In Africa, relying on the biological nitrogen fixation (BNF) of grain legumes is a strategy to ease the burden that commercial fertilizers exert on resource limited smallholder farmers. Soybean (*Glycine max*) a popular legume grown as intercrop with maize in western Kenya, has the ability to fix between 44 to 103 kg N ha^{-1} annually which can be used directly by the host plant [10]. Currently, about 500-7000 metric tons (MT) of soybean is produced in Kenya against an annual local demand which exceeds 100, 000 MT, the highest in the East African region [11]. Unlike most other legumes that contain about 20% protein, soybean contains 40% protein. However, several reports have highlighted low fixation capability of soybean especially if symbiotic association is constrained by various factors including inefficient strains capable of initiating the N-fixation process [12,13]. This constraint could be alleviated through seed and/or soil inoculation with the proper Rhizobium coupled with inorganic P and lime application in the acid soils of Western Kenya. The general objective of this study therefore was to determine the effects of inoculation, lime, inorganic P and their combinations on soil chemical properties and grain yields of maize and soybean on small holder farms of Western Kenya.

2. MATERIALS AND METHODS

2.1 Study Site

Field experiments were carried out for two seasons in 2011, in Shianda sub-location, East Wanga division in Mumias district, Western Kenya. The district lies between (34° 29' and 21° E and 0° 20' and 11° N) in the lower midland agro-ecological zones (LM_{1-2}) with an altitude of 1300 – 1500 m above the sea level. The district receives mean annual rainfall between 1650-2000 mm with mean temperatures of 20.8-22°C. The dominant soil types are Humic Acrisols [14]. On-farm trials were set up on two farmers' fields at the beginning of the first season, 2011. Seeds of maize (*Zea mays* L, var. DK8031) and soybean (*Glycine max* L, var. Gazelle) were obtained from Kenya Agricultural Research Institute, Kakamega. Peat-based culture of

Bradyrhizobium japonicum USDA 110C, licensed by University of Nairobi and produced by MEA Ltd branded BIOFIX was used for soybean inoculation.

2.2 Experimental Treatments and Design

A 2^3 factorial field experiment was laid out in a randomized complete block design (RCBD) with the following treatments:-

1. Control (no lime, no inoculation and no inorganic P application)
2. Lime (2.5 tha^{-1}) applied to both maize and soybean
3. Inoculation of soybean
4. Inorganic P (30 $kgha^{-1}$ P) applied to both maize and soybean
5. Lime (2.5 tha^{-1}) applied to both maize and soybean and soybean inoculation
6. Lime (2.5 tha^{-1}) applied to both maize and soybean and inorganic P (30 $kgha^{-1}$ P) applied to both maize and soybean
7. Inorganic P (30 $kgha^{-1}$ P) applied to both maize and soybean and soybean inoculation
8. Lime (2.5 tha^{-1}) applied to both maize and soybean, inorganic P (30 $kgha^{-1}$ P) applied to both maize and soybean and soybean inoculation.

Each treatment was replicated four times.

2.3 Field Establishment and Management

The crops were planted in 32 plots each measuring 4.5 m by 4 m. The test crops were maize (*Zea mays* L.) intercropped with soybean (*Glycine max* L.). Soybean was inoculated with *Rhizobium japonicum* bacterial strain). The inoculum solution was prepared 20 minutes before planting at the planting site. 30 kg P /ha of Single Super Phosphate was applied on both crops at planting. 2.5 t/ha of agricultural lime was applied 2 weeks before planting. Maize spacing was 75 cm by 30 cm, while soybean crops were planted between the maize rows at intra-row spacing of 10 cm. Two seeds of maize were planted per hill and thinned to one when the crop was 30-40 cm high. Weeding was done twice and harvesting done after crop maturity and leaf senescence. Soil sampling using zigzag random sampling was carried out at 0-20 cm depth before planting and after harvesting in each season.

Five soybean plants per plot were uprooted carefully at 8 weeks after planting (WAP) keeping the nodules intact. Roots were washed carefully; all nodules were separated, counted and fresh weight determined. The soybean plant tissues were dried separately at 80°C to a constant weight and dry biomass obtained. At maturity, maize and soybean samples for grain yield determination were obtained from the harvest area of each plot. The grains from the plots were taken to the lab; oven-dried to a constant weight after shelling and dry matter yield obtained. The grain yields were expressed on hectare basis.

2.4 Soil Analysis

Soil pH was measured using the pH meter with soil: water ratio of 1:2.5. The hydrometer method was used in soil particle analysis, Total soil organic carbon was determined by modified Walkley-Black method, exchangeable calcium, magnesium and potassium were determined using the Ammonium acetate extraction method and total N was determined by Kjeldahl digestion method. Extractable soil phosphorous was determined using Olsen method [15-19].

Table 1. Chemical and physical characteristics of soils from Shianda, Western Kenya

Soil property	Mean
pH (1:2.5 Soil:H_2O)	4.90
Total Organic Carbon (%)	1.30
Total Nitrogen (%)	0.16
Available P (mg kg^{-1})	8.1
Exchangeable Ca ($mgkg^{-1}$)	340
Exchangeable Mg ($mgkg^{-1}$)	34
Exchangeable K ($mgkg^{-1}$)	117
Sand (%)	80
Silt (%)	5
Clay (%)	15
Textural class	loamy sand

2.5 Statistical Data Analysis

The measured soil and plant parameters were subjected to analysis of variance (ANOVA) using Genstat Statistical Package. The treatment means were compared using the least significant difference (LSD) test at 5% probability level [20,21].

2.6 Economic Analysis

Data on input prices, labour wage rates and market prices of maize and soybean grains was collected from 10 farmers and three agro-input stockists randomly selected from the study area. The information used for cost-benefit analysis in this study was collected at specific time for each activity in the course of each season. Labour was measured in terms of person-days using the mean prevailing market wage rates from the study area as opportunity cost for labour provided by household members. All costs and benefits were calculated on per hectare basis in Kenya shillings (KShs. ha^{-1}) using the concepts defined in economic analysis [22].

3. RESULTS AND DISCUSSION

3.1 Soil Properties

At the end of the 2nd season, the highest pH (5.58) was recorded in plots treated with sole lime at 2.5 t ha^{-1} followed by lime + inoculation + P (5.52) (Table 2). Lime reduces soil acidity by changing some of the H+ into water and carbon dioxide (CO2). The Ca2+ ion from the lime replaces two H+ ions on the cation exchange complex while the carbonate (CO3-) reacts with water to form bicarbonate (HCO3-). These react with H+ to form H2O and CO2, which leads to a reduction in soil pH. As shown from Table 2 below, the highest soil available P content was recorded in the lime + P (12.22 mg kg^{-1}) followed by lime + P + inoculation (11.05 mg kg^{-1}) then sole lime treatments (9.35 mg kg^{-1}). The increase in soil available P could be due to quick action of lime in improving soil acidity and hence phosphorus availability [5] and the effect of P fertilizer in increasing P in the soil solution [23]. Sole inoculation treatment recorded the lowest soil available P content of (5.10 mg kg^{-1}). This could be due to the fact that P is a key requirement for ATP production during the process of biological nitrogen fixation. Sole lime treatment recorded higher soil available P content (9.35 mg kg^{-1}) than sole P treatment (6.50 mg kg^{-1}). However, combined applications of lime + P and P + lime + inoculation led to an increase in soil available P which is significantly different from the control. In a study in western Kenya, [5] pointed out that both lime and P fertilizer applications are important to enhance soil available P in acid and P deficient soils. He reported mean soil available P increments of 92% and 209% following the application of lime and P fertilizer after 7 months of sesbania growth, respectively. There was no significant difference in the effect of lime, inorganic P and inoculation on both total N and organic C contents of soil at the end of the 2nd season (Table 2). Lime + P + inoculation and lime + P treatments gave significantly high concentrations of Ca^{2+} (617.5 mg kg^{-1} and 875.8 mg kg^{-1}), respectively (Table 2). A combination of P + inoculation and Lime + P + inoculation recorded the highest concentrations of Mg^{2+} (51.4 mg kg^{-1}) and K^{+} (104.5 mg kg^{-1}), respectively (Table 2). These results are in line with the observations of [24], who reported increased concentration of Ca^{2+} and Mg^{2+} from 154 to 314 mg kg^{-1} and from 66 to 93 mg kg^{-1} respectively due to liming. In another study, [25] reported an increase in soil pH from 5.45 to 6.54, and exchangeable Ca^{2+} from 12.42 mg kg^{-1} to 29.21 mg kg^{-1} soil due to liming.

3.2 Maize Grain Yield

The mean maize grain yield ranged from 1860 to 4490 kg ha^{-1} and from 1650 to 3470 $kgha^{-1}$ in the 1st and 2nd season, respectively (Table 3). Lime + P + inoculation treated plots produced the highest grain yields (4490 kg/ha and 3470 kg/ha) in the 1st and 2nd seasons, respectively. Sole P, sole lime and sole inoculation treatments

Table 2. Effect of different treatments on soil chemical properties at the end of 2nd season

Treatment	pH (H_2O)	Available P ($mgkg^{-1}$)	Ca (mgkg-1)	Mg (mgkg-1)	K (mgkg-1)	OC (%)	Total N (%)
Control	4.85	5.23	320.0	21.6	83.50	0.81	0.135
Lime	5.58	9.35	531.9	43.4	97.25	1.22	0.143
Inoculation	4.64	5.10	136.2	42.2	92.03	0.83	0.148
P	4.72	6.50	450.1	39.0	79.53	0.98	0.137
P + Lime	5.28	12.22	875.8	35.0	78.27	1.28	0.143
P + Inoc	4.68	6.28	139.1	51.4	83.00	0.91	0.145
Lime + Inoc	5.37	6.35	399.8	43.6	83.55	0.95	0.144
Lime + Inoc + P	5.52	11.05	617.5	39.0	104.50	1.20	0.151
Mean	5.08	7.76	433.8	39.4	87.70	1.023	0.143
$LSD_{0.05}$	1.15	5.78	432.8	15.2	17.21	NS	NS

Values in the same column followed by the same letter are not significantly different at P=.05 recorded average maize grain yields of 3380, 3385 and 1755 kg/ha, respectively (Table 3). This could be due to the ability of lime to effectively neutralize soil acidity which raises pH, thus stimulating crop growth. The low maize grain yields obtained from the sole soybean inoculation plots could be as a result of the intercrop effect due to competition in soil moisture and by the legume-cereal component. The results from this study agree with the results of [6], who obtained maize grain yield of 4620 kg/ha from TSP + lime treatment and 580 kg/ha from the control in a maize- groundnut intercrop. In his study, [26] obtained maize grain yields of 550 and 3260 kg/ha from the control and combined lime + fertilizer P treatments, respectively in acidic soils of Western Kenya. According to Reddy et al. [27], intercropping advantage depends on net effect in trade-off between inter-specific competition and facilitation in which one plant species enhances the survival, growth, or fitness of another.

3.3 Soybean Grain Yield

Lime + P + inoculation treatment gave the highest grain yields of soybean (970 and 830 kg/ha), whereas the control plots gave the lowest grain yields of soybean (477 and 351 kg/ha) in the 1st and 2nd seasons, respectively (Table 4). Sole lime treatment gave a mean soybean grain yield of (610 kg/ha) followed by sole P (535 kg/ha) then sole inoculation treatments (505 kg/ha) (Table 4). The increase in soybean grain yield under inoculation treatment could be attributed to improved N status in the soil due to enhanced biological nitrogen fixation (BNF). Enhanced nodulation and number of pods per plant in lime + P + inoculation treatments contributed to observed higher soybean yields. Phosphorus is an important element in legume establishment and its deficiency limits legume production in most of agricultural soils. Similarly, combined application of fertilizer P and legume inoculation has also led to increased growth, yield and nitrogenase activity as well as improved soil fertility as shown in various studies [28]. Other studies have obtained soybean seed yield range between 1200 and 2180 kg/ha with inoculation against 1050 kg/ha in un-inoculated plants [29].

3.4 Nodulation

Highest average number of nodules per plant was obtained in the P + inoculation treatment (10.7), whereas the lowest average number of nodules plant per plant was obtained from the control (1.3) (Table 5). Sole P application recorded (7.7) average number of nodules per plant. However, when combined with inoculation, significantly higher (10.7) average number of nodules per plant was obtained (Table 5). The highest average nodule fresh weight (0.23 g) was obtained in lime + P + inoculation treatment, whereas the lowest average nodule fresh weight (0.09 g) was obtained from the control (Table 5). Sole lime treatment recorded average nodule fresh weight of 0.10 g which was not statistically different from the control (0.09 g). Sole P and inoculation treatments gave the same average nodule fresh weight per plant of 0.16 g (Table 5). Lime application led to an increase in nodule number due to its effect on increasing soil pH, which in turn enhances the survival of Rhizobial population responsible for nitrogen fixation [30]. Inorganic P plays a major role the process of symbiotic N2 fixation because it facilitates signal transduction and membrane biosynthesis for generation of ATP for nitrogenase function [31]. [12] also showed that number of nodules per plant of soybean was significantly influenced by addition of 25 kg P/ha; moreover, he reported that nodule fresh weight of soybean across fields and varieties increased by 112.5% when fertilizer application was increased from 10 kg P/ha to 25 kg P/ha. Similarly, [13] also observed higher nodule fresh weight of soybean with inorganic P application at 60 kg P/ha as compared to the control.

3.5 Plant Biomass and Pod Production

The highest average biomass per plant (22.7 g) was obtained from the inoculation + P treatment (Table 5). Sole P, sole inoculation and sole lime treatments recorded 21.8 g, 19.2 g and 16.8 g average biomass per plant, respectively. Lime + P + inoculation treatment recorded the highest number of pods per plant (19.3) while the lowest average number of pods per plant (9.8) was recorded in the control. Inorganic P enhances ATP production which is a key requirement for nodule development and functioning. The results in this study are in line with the observations of [12], who reported increased plant biomass by 10% in soybean crop with addition of 25 kg P/ha. In another study, [25] reported a significant (P < .05) increase in plant biomass as a result of Sinorhizobium inoculation in lucern. The increase in number of pods per plant after P application might be due to enhanced pod and seed formation resulting from increased ribulose-1-5-diphosphate carboxylase activity caused by increased P supply from fertilizer P [32]. Previous studies have also reported 67% increase in number of effective pods per plant and 21% increase in seed yield of soybean with application of fertilizer P + inoculation [33].

3.6 Economic Analysis

Benefit-cost analysis (BCA) during the 1st and 2nd seasons indicated that although some treatments had higher net benefit (NB), they

Table 3. Effect of different treatments on maize grain yield during the 1st and 2nd seasons

Treatment	Grain yield (Kg/ha)		
	1st season	2nd season	Means
Control	2530	2060	2295
Lime	3760	3010	3385
Inoculation	1860	1650	1755
P	3810	2950	3380
P + Lime	4350	3230	3790
P + Inoculation	2650	2320	2485
Lime + Inoculation	3730	2500	3115
Lime + Inoculation + P	4490	3470	3980
Mean	3398	2649	
$LSD_{0.05}$	1320	1150	

Values in the same column followed by the same letter are not significantly different at P=.05

Table 4. Effect of different treatments on soybean grain yield during the 1st and 2nd seasons

Treatment	Grain yield (Kg/ha)		
	1st season	2nd season	Means
Control	477	351	414
Lime	670	550	610
Inoculation	540	470	505
P	560	510	535
P + Lime	720	590	655
P + Inoculation	740	610	675
Lime + Inoculation	710	580	645
Lime + Inoculation + P	970	830	900
Mean	673	561	
$LSD_{0.05}$	240	170	

Values in the same column followed by the same letter are not significantly different at P=.05

Table 5. Effect of different treatments on average nodule number, nodule fresh weight, plant biomass and pod number per of soybean during the 1st season

Treatment	Average nodule number per plant	Average nodule fresh weight per plant (g)	Average plant biomass (g)	Average pod number per plant
Control	1.3	0.085	14.4	9.8
Lime	2.3	0.103	16.8	12.8
Inoculation	4.3	0.155	19.2	13.5
P	7.7	0.157	21.8	13.8
P + Lime	4.0	0.138	18.8	13.8
P + Inoculation	10.7	0.205	22.7	15.3
Lime + Inoculation	9.7	0.198	17.3	17.5
Lime + Inoculation + P	9.7	0.228	19.7	19.3
Mean	6.2	0.159	18.8	14.5
$LSD_{0.05}$	5.7	0.08	4.7	4.2

Values in the same column followed by the same letter are not significantly different at P=.05

Table 6. Benefit-cost ratios of average maize-soybean yields obtained in the two cropping seasons under different treatments

Treatment	Gross benefit (Kshs.ha^{-1})	Total cost (Kshs.ha^{-1})	Net benefit (Kshs.ha^{-1})	Benefit-cost ratio
Control	87765.93	19970.00	67795.93	3.4
Lime	129396.15	40381.00	89015.15	2.2
Inoculation	83275.20	21700.00	61575.20	2.8
SSP	122849.55	41212.00	81637.55	2.0
SSP + Lime	142477.65	61623.00	80854.65	1.3
SSP + Inoculation	114478.20	42962.00	71516.20	1.7
Lime + Inoculation	126250.20	42131.00	84119.20	2.0
Lime + Inoc. + SSP	170891.55	63373.00	107518.55	1.7

respectively had a lower benefit-cost ratio (BCR) as exemplified by results in Table 6 (above). For example lime + P + inoculation had a net benefit of Ksh 107, 518.60 and a benefit-cost ratio of 1.7 compared to sole lime treatment with a net benefit of Ksh 89,015.20 and a benefit-cost ratio of 2.2 thus, considering net benefit alone could be misleading as far as cost effectiveness of the different soil fertility amendment inputs is concerned, therefore, BCR seems to be the most appropriate economic tool for determining the most economical soil fertility amendment technologies as it shows the return per shilling invested.

4. CONCLUSION

Application of lime at 2.5 t/ha significantly increased soil pH from 4.9 to 5.58, this confirms the superiority of liming as an effective method of controlling soil acidity in western Kenya. Maximum soil available P (12.22 mg kg^{-1}) was obtained with lime + P treatment. A similar trend was observed on increased levels of exchangeable Ca^{2+} with lime + P treatment recording the highest level of exchangeable Ca^{2+} (875.8 mg kg^{-1}). This shows that application of both lime and inorganic P is a more effective remedy to the low levels of P and exchangeable bases in the soils of western Kenya. Inorganic P and inoculation are highly effective in enhancing soybean nodulation and biomass production which leads to improved crop yield. Sole lime and P application proved to be more effective in increasing soybean and maize yields than inoculation. The highest mean maize grain yields of 3980 kg/ha and soybean yields of 900 kg/ha were obtained with lime + P + inoculation treatment. These results indicate that a combination of lime + P + inoculation offers an economically feasible as well as a better option for increasing maize and soybean grain yields for the degraded soils of western Kenya.

ACKNOWLEDGEMENT

The authors thankfully acknowledge KARI Kakamega field officers in the AGRA-Maize Project for their support during field work, Ms. Lea Munala for her assistance during field data collection and sample measurements. Funding for my course work, research activities and laboratory analyses was provided by Bill and Melinda Gates Foundation through the AGRA-Soil Health Program of Kenyatta University.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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