

Managing Soybean for Enhanced Food Production and Soil Bio-Fertility in Smallholder Systems through Maximized Fertilizer Use Efficiency

Ezekiel Mugendi Njeru^{1,2,*}, John Muthini Maingi¹, Richard Cheruiyot¹, Gitonga Nkanata Mburugu³

¹Department of Plant and Microbial Sciences, Kenyatta University, P.O. Box, 43844-00100, Nairobi, Kenya

²Institute of Life Sciences, Sant'Anna School of Advanced Studies Piazza Martiri della Libertà n.33 – 56127, Pisa, Italy

³Meru University of Science and Technology, P.O. Box, 972-60200, Meru, Kenya

Abstract The production of promiscuous soybean by smallholder farmers in Kenya would improve soil fertility through biological nitrogen fixation (BNF), boost food security, and contribute to generation of cash. The present study was conducted to determine the effects of soil amendments on growth and yields of promiscuous soybean cultivars under varying soil carbon levels. Field experiments using early maturing SB 19 and late maturing SB 20 promiscuous soybean cultivars and different levels of phosphorus (P), potassium (K) and sulphur (S) fertilizers were conducted in two sites in the south-eastern slopes of Mt. Kenya, approximately 1500 m above sea level. The soybean cultivars were observed for phenology, plant biomass production, pod fresh weight, 1000 seed weight and haulm weight. Significant differences were observed on most yield components due to field carbon level, soybean cultivar and fertilizer amendments, while the plant height was only affected by fertilizer application and soy bean cultivar. However, the effects due to the interaction of these factors were not significant. Therefore, the benefits of combined use of BNF by soybean and application of PKS fertilizers could be a promising entry point into maximized fertilizer use efficiency by smallholder systems in Kenya.

Keywords Promiscuous Soybean, Soil Amendments, Biological Nitrogen Fixation, Smallholder Farmers

1. Introduction

Soybean (*Glycine max* (L.) Merrill) is an important source of high quality, inexpensive protein and oil, presently cultivated worldwide under varying climatic conditions[1]. Compared to other foods that are rich in proteins such as animal meat, fish, eggs, and milk, soybean is by far the cheapest source of protein for smallholders in Africa. The amount of soybean protein consumed by humans worldwide is currently low, although there is increasing public and commercial interest since the crop could be a major source of dietary protein for the future. Another advantage of soybean is that it improves soil fertility by fixing atmospheric nitrogen through biological nitrogen fixation (BNF)[2-3]. This would be a major benefit to smallholder farming systems in Kenya where soil degradation and nutrient depletion have gradually increased and now pose serious threats to sustainable food production.

There has been a slow growth in production of soybeans by smallholders in Kenya over the years. Although soybean forms a major alternative source of proteins and cooking oil,

local production in Kenya is still low at 4335 tons in year 2011[4]. The main reasons for slow growth are postulated to be lack of awareness about soybean management (production, processing, and use), low yields and few markets[5]. Soybean production in Kenya can further be improved by increasing the output from the land presently under cultivation and expanding production to the land yet unexploited. Most parts of Western, Central and Eastern Kenya regions receive adequate rainfall, have well drained soils of moderate to high fertility with a pH range of 5.5–7.5, and are hence considered to have a high potential for soybean production and future expansion[6].

Similar to many parts of Kenya, crop yields in Meru South are presently low mainly due to declined soil fertility status mainly attributed to continuous cropping without addition of fertilizers or manure[7-8], nutrient loss through soil erosion and leaching. Moreover, the cropping sequences are poorly planned thus do not maximize on agroecological soil nutrient cycles. Being resource poor, most smallholder farmers in Meru South like their counterparts in the rest of sub-Saharan Africa (SSA) typically apply negligible amounts of mineral fertilizers. Despite repeated demonstrations of the usefulness of green manures in enhancing soil fertility in Meru South[8] the practice of using green manure is still limited.

Proven district-level recommendations of fertilizer rates based on several years' field investigation are now in place

* Corresponding author:

njeruezek@gmail.com (Ezekiel Mugendi Njeru)

Published online at <http://journal.sapub.org/ijaf>

Copyright © 2013 Scientific & Academic Publishing. All Rights Reserved

[9]. However, they rely on blanket application approaches that are often not readily adoptable by smallholder farmers because they are based on optimizing yield, rather than maximizing the efficient use of scarce inputs. It is therefore essential to develop appropriate technologies to improve and manage soil fertility based on judicious use of organic and inorganic fertilizers while at the same time taking measures that will enhance preservation of the land resource base by smallholder farmers.

Soybean farming is one of the most cost-effective ways in which smallholder farmers can maintain soil fertility and yet reap other benefits from the crop. They are among legumes known for their high nitrogen fixing ability [10], thus improving soil nitrogen (N) content [11]. Promiscuous soybean genotypes nodulate and fix nitrogen effectively with diverse indigenous rhizobia available in the soil while non-promiscuous genotypes form symbioses with specific rhizobial strains thus limiting their N-fixing ability [12]. Recent studies on promiscuous soybeans cultivars in the study area have reported increased nodulation upon inoculation and fertilizer application [13-14], which could increase BNF benefits in smallholder systems. Therefore, although soybean is relatively a new crop to many smallholders in Kenya, its cultivation is expected to gain popularity in the near future because of the increasing demand for food, fodder and search for alternative soil fertility management strategies which rely more on agroecological cycles.

Nodulation and nitrogen fixation in legumes occurs effectively if other mineral elements such as Phosphorus (P), Potassium (K) and Sulphur (S) are present in the soil [15]. This leads to increased yield components in these legumes. Therefore, this necessitates constant addition of PKS fertilizers to boost the soil mineral nutrient level especially in low carbon sites. Much research on the effect of soybean inoculation and P application has been conducted [16]. However, there is limited information on the effects of soil amendments with PKS fertilizers on production of promiscuous soybean cultivars in smallholder systems. The main objective of this study was to investigate the effects of soil amendments with PKS fertilizers on growth patterns and yield components of two promiscuous soybeans cultivars in low and high carbon level sites.

2. Materials and Methods

2.1. Study Area

Field experiments were conducted in two sites located in Tharaka Nithi County (Meru South) in the south-eastern slopes of Mt. Kenya, approximately 1500 m above sea level. The area is in upper midlands 2 and 3 [17], with soils that are mainly humic nitisols [18] derived from basic volcanic rocks. The soils are deep, well weathered with moderate to high inherent fertility. The average maximum temperature is 27°C; the minimum is 14°C while the average temperature is 20.5°C. The area receives annual rainfall varying from 500 to 2200 mm, bimodally. Long rains occur between March and June while short rains fall from October to December.

Eight farms were identified in each area and the cropping history noted. In each farm, two sites were selected based on total organic carbon (C) (one site with the lowest C and one site with the highest C). A mixture of concentrated sulphuric acid and aqueous potassium dichromate was used to determine the soil organic carbon [19].

2.2. Field Preparation and Experimental Layout

The experiment was laid out as a randomized complete block design (RCBD) with each farm serving as a replicate. The promiscuous soybean cultivars SB 19 (TGx 1740-2F), an early maturing cultivar and SB 20 (TGx 1448-2E), a late maturing cultivar were the main treatments while fertilizer inputs were the sub-treatments. Plot sizes measured 4 m by 2.7 m. A total of two treatments and five sub-treatments were used (Table 1). The experimental fields were cleared of grasses and other prevalent weeds using mechanical methods, after which they were demarcated. The fields were ridged at 45 cm intervals to a depth of 30 cm. Soybean seeds of high viability and quality were carefully selected to increase chances of uniform germination. All the fertilizer inputs were applied in the planting line on the trough and incorporated before planting. After the application of fertilizers, soybeans seeds were planted in rows, at a spacing of 45 between rows and 5 cm within rows. Weed control was done manually by periodically scouting the plots and uprooting the weeds wherever necessary.

Table 1. Treatment structure (implemented on a high carbon and a low carbon sites)

Treatment	Cultivar	Sub-treatments	Fertilizer	Amount of fertilizer (kg ha ⁻¹)			Seed (kg ha ⁻¹)
1	SB19	1	None	0P	0K	0S	140
	SB19	2	PKS	60P	60K	24S	140
	SB19	3	PK	60P	60K	0S	140
	SB19	4	PS	60P	0K	24S	140
	SB19	5	KS	0P	60K	24S	140
2	SB20	1	None	0P	0K	0S	140
	SB20	2	PKS	60P	60K	24S	140
	SB20	3	PK	60P	60K	0S	140
	SB20	4	PS	60P	0K	24S	140
	SB20	5	KS	0P	60K	24S	140

SB 19 - Soybean cultivar SB, 19 (TGx 1740-2F), SB 20 - Soybean cultivar SB 20 (TGx 1448-2E). P - Phosphorus, K - Potassium and S - Sulphur

2.3. Phenological Measurements and Shoot Biomass

The phenological changes of the soybean crops were regularly determined. These changes included percentage emergence at 3 weeks after planting (WAP), plant height at 10 WAP, flowering, peak biomass (podding), and physiological maturity. At 50% podding, one 50 cm long row of plants (10 plants with a space of 5 cm between each plant) was selected leaving 50 cm from the plot borders. The plants were cut using a sharp knife at about 5 cm above the soil level. Immediately after cutting the above ground biomass was put in labeled polythene bags and then allowed to air dry. Shoot biomass of the plants was determined after oven drying at 65°C to constant weight.

2.4. Yield Components

Physiological maturity was considered to have taken place when 95% of the plants had turned golden yellow[20] and 75% of the plants had their pods filled with seeds and hardened[21]. At harvest, pods were separated from haulms, weighed and then sun dried until they were ready for threshing. After the grain was threshed, the pod walls were combined with the haulms to comprise the crop residue. The threshed seeds were oven-dried to a moisture content of about 8% and the weight determined.

2.5. Data Analysis

Data collected on crop emergence, plant height, plant biomass production, pod fresh weight per plant, a thousand grain weight and haulm weight were analyzed using ANOVA procedure in SAS (Statistical Analysis System) software[22]. Data on crop emergence and yield components were arcsine or $\log(x+1)$ transformed to fulfill the assumptions of ANOVA. The reported data in tables were back-transformed. When ANOVA indicated statistical

significance of a treatment effect ($P < 0.05$), the means were separated using Tukey's HSD test.

3. Results and Discussion

In this study, the response of two soybean cultivars to different fertilizer combinations under high and low carbon level sites was studied. The experiment was conducted in smallholder farms and in collaboration with farmers in the study area allowing their contribution at each experimental phase. Our results demonstrate significant effects on some important soybean parameters based on soybean cultivar, field carbon level and fertilizer treatment.

Crop emergence was significantly ($F=2.8$, $P=0.029$) lower after the application of PKS fertilizer compared to the other fertilizer treatments (Table 2). However, the emergence was not significantly affected by the soybean cultivar, soil carbon level and their interactions. Some of the seedlings that germinated dried up due to lack of rainfall for about two weeks after planting. After germination the early maturing cultivar SB 19 took 60 days to 50% attain flowering, 81 days to form 50% of the pods and 128 days to mature. Cultivar SB 20 took 70 days to attain 50% flowering and 90 days to form 50% of pods and 148 days to mature (Table 3).

Application of PKS, PK, and PS fertilizers significantly ($F= 6.6$, $P < 0.001$) influenced the plant height compared to KS and the Control treatments. Plant height was also significantly ($F= 109.0$, $P < 0.001$) affected by soybean cultivar whereby, cultivar SB 20 had a higher mean height (59.2 ± 1.5 cm) compared to SB 19 (40.8 ± 1.0 cm). The greatest plant mean height (68.7 ± 6.5 cm) was observed in cultivar SB 20 grown after application of PS fertilizer on high carbon fields (Table 2). There were no significant interactions between the treatments.

Table 2. Effects of field carbon level, soybean cultivar and fertilizer application on % crop emergence and plant height (Means \pm SE)

Carbon level	Cultivar	Fertilizer	Emergence (%)	Plant height (cm)
High	SB 19	Control	96.9 \pm 2.49	36.9 \pm 2.89
		PKS	91.3 \pm 4.09	43.7 \pm 2.62
		PK	93.8 \pm 3.63	44.3 \pm 3.22
		KS	97.2 \pm 2.50	40.1 \pm 5.42
		PS	95.6 \pm 3.71	42.1 \pm 3.35
	SB 20	Control	97.5 \pm 2.50	56.2 \pm 6.73
		PKS	95.6 \pm 2.58	62.1 \pm 5.24
		PK	95.6 \pm 2.40	62.7 \pm 4.07
		KS	98.8 \pm 1.25	54.3 \pm 3.11
		PS	98.8 \pm 1.25	68.7 \pm 6.49
Low	SB 19	Control	98.1 \pm 1.32	32.6 \pm 2.20
		PKS	91.3 \pm 3.63	44.1 \pm 2.40
		PK	95.6 \pm 2.40	43.0 \pm 2.01
		KS	96.9 \pm 1.90	38.4 \pm 3.60
		PS	97.5 \pm 1.33	42.6 \pm 2.90
	SB 20	Control	97.5 \pm 1.33	49.9 \pm 3.00
		PKS	95.6 \pm 2.20	62.8 \pm 3.86
		PK	96.9 \pm 1.61	65.2 \pm 3.56
		KS	98.1 \pm 1.88	50.7 \pm 4.49
		PS	98.8 \pm 1.25	59.6 \pm 3.44
<i>P</i> values				
Cultivar			0.104	<0.001
Fertilizer			0.029	<0.001
Carbon level			0.878	0.146

Table 3. Days to onset of flowering, pod-set and maturity of promiscuous soybean cultivars SB 19 and SB 20

Cultivar	Onset of flowering	50% flowering	Onset of pod formation	50% podding	Maturity
SB 19	55	60	60	81	128
SB 20	64	70	69	90	148

Plant biomass production was significantly ($F=13.1$, $P=0.001$) influenced by the fertilizer treatment, the level of organic carbon in the field ($F= 5.9$, $P=0.022$) and marginally higher in SB 20 compared to SB 19. Cultivar SB 20 grown on high carbon fields amended with PKS fertilizer had the best growth vigor (Figure 1) and the highest plant biomass production ($9.7 \pm 2.31 \text{ g plant}^{-1}$) while cultivar SB 20 grown on low carbon fields with no fertilizer application had the poorest growth vigor (Figure 2) and the least plant biomass production ($2.3 \pm .095 \text{ g plant}^{-1}$).

**Figure 1.** Cultivar SB 20 grown on a high carbon field amended with 60 kg P ha^{-1} , 60 kg K ha^{-1} and 24 kg S ha^{-1} fertilizers**Figure 2.** Cultivar SB 20 grown on a low carbon level field with no fertilizer inputs (Control)

Soil amendments with PKS, PK, and PS fertilizers significantly influenced the yield components (Table 4). Interestingly, application of KS fertilizer without P fertilizer resulted to the lowest overall means of different yield components. The late maturing cultivar SB 20 had higher yield components in both low carbon and high carbon fields compared to the early maturing cultivar SB 19.

Pod fresh weight plant^{-1} was significantly influenced by fertilizer application ($F=4.9$, $P<0.001$) and field carbon level ($F= 7.0$, $P=0.009$). Application of PS fertilizer resulted to the highest mean pod fresh weight ($58.5 \pm 7.2 \text{ g plant}^{-1}$) which was statistically significant compared to KS treatment or Control but not PK and PKS. Moreover, the highest pod fresh weight per plant ($73.3 \pm 21.6 \text{ g}$) was obtained from cultivar SB 20 grown on high carbon level fields amended

with PS fertilizers. Cultivars SB 19 and SB 20 and the interactions between the treatments did not significantly affect the pod fresh weight (Table 4).

Soybean cultivars significantly ($F=77.7$, $P<0.001$) influenced 1000 seed weight whereby cultivar SB 20 produced seeds with a heavier weight ($128.0 \pm 0.5 \text{ g}$) compared to cultivar SB 19 ($119.9 \pm 0.9 \text{ g}$). Soil amendments with fertilizers only marginally ($F=2.3$, $P= 0.058$) affected 1000 seed weight while the field carbon level and the interaction between the treatments were not significant (Table 4). Soybean cultivar SB 20 grown on high carbon fields amended with PKS fertilizer had the highest 1000 seed weight of ($129.9 \pm 1.6 \text{ g}$) while cultivar SB 19 on low carbon fields with no fertilizer inputs produced seeds with the lowest 1000 seed weight mean of ($114.9 \pm 3.5 \text{ g}$). Haulm weight plant^{-1} was significantly influenced by the soybean cultivar ($F=27.2$, $P<0.001$), fertilizer application ($F=4.4$, $P=0.002$) and marginally affected by the field carbon level ($F=3.8$ $P=0.055$). Application of PS fertilizer resulted to the highest haulm weight plant which was different from the KS and Control treatments but not PK and PKS (Table 4).

The application of all fertilizer combinations except KS affected plant height, biomass production and pod and haulm weights of both cultivars SB 19 and SB 20 across low carbon and high carbon level fields. This was attributed to the availability of phosphorus, potassium, and sulphur nutrients, which are important in plants growth and metabolism. The positive effect on yield components obtained with all the fertilizer combinations that included P may be attributed to an increase in the amount of Nitrogen derived from the atmosphere (Ndfa). Soybeans require P for N_2 fixation processes and growth [23-24]. Application of KS fertilizer did not result to any significant increase in plant height probably due to phosphorus deficiency, which decreases photosynthetic rate per unit leaf, leaf area ratio, and nodule mass to whole plant ratio [25]. Moreover, P plays important roles in establishment, growth, and function of nodules [26-28], growth of rhizobial strains, and growth of host plant.

A significant increase in pod fresh weight was observed following PS application compared to the Control or the KS treatments but not the PKS, and PK fertilizer combinations. Similar results with PS fertilizer have been reported previously [29]. Although increased legume nodulation and production with only P and K has been observed elsewhere, [30-31] in our case, the inclusion of sulphur fertilizer schedule was advisable since the soil in the study area is S-deficient. Actually, fertilizer combination PS produced the highest pod fresh weight plant^{-1} and haulm fresh weight plant^{-1} indicating that inclusion of sulphur fertilizer in the study area could even be more important than K.

Table 4. Effect, Field carbon level, soybean cultivar and fertilizer treatments on soybean yield components (Means \pm SE)

Carbon level	Cultivar	Fertilizer	Pod fresh weight (g plant ⁻¹)	1000 seed weight (g)	Haulm weight (g plant ⁻¹)		
High	SB 19	Control	36.0 \pm 10.86	118.1 \pm 2.56	10.1 \pm 2.83		
		PKS	51.3 \pm 11.43	123.0 \pm 1.73	12.4 \pm 2.34		
		PK	58.9 \pm 12.43	122.1 \pm 2.13	15.2 \pm 2.90		
		KS	55.0 \pm 15.34	119.4 \pm 2.22	13.6 \pm 3.74		
		PS	59.4 \pm 11.68	119.9 \pm 2.51	18.3 \pm 3.40		
	SB 20	Control	52.3 \pm 19.79	125.9 \pm 1.84	21.9 \pm 5.94		
		PKS	45.8 \pm 13.24	129.9 \pm 1.56	21.7 \pm 5.02		
		PK	53.4 \pm 13.46	129.8 \pm 0.77	27.9 \pm 6.09		
		KS	41.8 \pm 12.21	129.6 \pm 0.56	20.4 \pm 4.75		
		PS	73.3 \pm 21.58	129.1 \pm 0.67	34.5 \pm 8.26		
Low	SB 19	Control	25.5 \pm 7.10	114.9 \pm 3.47	9.2 \pm 2.03		
		PKS	35.6 \pm 9.27	123.4 \pm 1.70	11.1 \pm 2.55		
		PK	37.8 \pm 8.56	119.1 \pm 3.80	12.6 \pm 2.75		
		KS	33.6 \pm 6.78	119.4 \pm 3.52	10.9 \pm 2.56		
		PS	56.0 \pm 12.93	120.0 \pm 2.89	18.0 \pm 3.67		
	SB 20	Control	22.0 \pm 3.99	127.0 \pm 2.04	14.4 \pm 3.13		
		PKS	43.1 \pm 10.77	126.6 \pm 2.39	23.1 \pm 5.94		
		PK	32.1 \pm 4.06	127.5 \pm 1.75	21.8 \pm 3.96		
		KS	23.2 \pm 8.30	126.8 \pm 1.22	14.8 \pm 4.07		
		PS	45.2 \pm 9.30	128.0 \pm 1.32	23.8 \pm 5.69		
		<i>P</i> values					
		Cultivar			0.476	<0.001	<0.001
		Fertilizer			<0.001	0.058	0.002
		Site			0.009	0.126	0.055

Collectively, results from this study depict the significance of P in the production of promiscuous soybeans in the study area. Other studies with soybean and with other leguminous plants are also consistent with this interpretation [32]. Moreover, P could be a limiting factor of soybean bean N-fixation and production in the study area as soils are generally acidic and prone to P fixation. Notably, in this study, nitrogenous fertilizer was not applied nor did we inoculate the soybean seeds prior to sowing. Our assumption was that, promiscuous soybeans are able to nodulate with a wide variety of native bradyrhizobia and thus fix enough nitrogen for their use and that of the following crop. Additionally, inoculation with elite bradyrhizobial strains may not be beneficial due to competition with the indigenous strains[33].

Interestingly, the late maturing SB 20 had a higher biomass and yield component production compared to the early maturing SB 19. This was probably due to longer duration of stay in the field of SB 20, which resulted to a higher Ndfa[34] and also the agro-climatic patterns of the study area. This finding confirms previous reports by others [35-37] who have shown that increasing growth duration increases Ndfa in promiscuous soybean cultivars. This is because the increased period allows the late maturing cultivar to fix more N₂ than the early maturing cultivar[38]. These results suggest further screening of the available soybean cultivars in the study area as plant genotype may play an essential role in determining the final production and the returns obtained by the farmer.

Soil organic matter is important since it binds soil particles

together into stable aggregates, which are necessary for soil structural stability. It is also involved in adsorption of cations, which are important in plant nutrition, and can significantly influence soil water holding capacity[39]. The exceptionally low yield components in low carbon level fields may be attributed to a lower rhizobial population or inability to form effective nodules[40], lower population of arbuscular mycorrhizal fungi and other beneficial microorganisms and reduced host plant growth. Since low carbon soils are characterized by low organic matter content and reduced plant nutrients it is essential that interventions and approaches to improve and manage soil fertility be developed if the widespread and recurring food deficits in the country are to be averted. In this study, we suggest that the crop residues must be returned to the soil[41-42] to realize a positive N balance. If the legume stover is not returned to the soil at harvest, then there will be a significant removal of soil N from the system by the legume crop[43]. Furthermore, soil fertility heterogeneity at farm level especially the soil organic carbon differences observed in this study ought to be an important factor of consideration in future research.

4. Conclusions

The results from this study clearly demonstrate:- (i) The importance of P in the fertilizer combinations used for maximized soybean production by smallholders in the study area (ii) Better production of the late maturing cultivar SB 20 in the study area (iii) The strong influence of soil carbon

level on soybean production within the same farm, although farmers in the study area own relatively small pieces of land and thus the distance between the high carbon and low carbon field was quite small. With the majority of the population in the study area being dependent on the limited agricultural land (requiring no irrigation), improved soybean production by modest application of PKS fertilizers will boost food security and soil fertility in the study area. This will increase crop yields in Kenya and therefore, improve the livelihood of rural populations by offering good and reliable economic returns. Among the most immediate viable strategies as proposed by this study is the amendment of these soils with the currently underutilized organic and inorganic fertilizers and the use of biological nitrogen fixation by legumes. Besides this, new strategies must be defined to connect more closely applied research with the needs of smallholder farmers.

ACKNOWLEDGEMENTS

The authors are grateful to Kenyatta University-Department of Plant and Microbial Sciences for providing the necessary laboratory facilities and acknowledge the cooperation and contributions by Meru South farmers.

REFERENCES

- [1] Appunu, C.; N'Zoue A.; Laguerre, G. Genetic diversity of native Bradyrhizobia isolated from soybeans (*Glycine max* L.) in different Agricultural-Ecological-Climatic regions in India. *Applied and Environmental Microbiology* 2008, 74(19): 5991-5996.
- [2] Mpeperek, S.; Javaheri, F.; Davis, P.; Giller, K. E. Soybeans and sustainable agriculture; promiscuous soybeans in southern Africa. *Field crop research* 2000, 65: 137-149.
- [3] Chianu, J. N.; Ohiokpehai, O.; Vanlauwe, B.; Adesina, A.; De Groote, H.; Sanginga, N. Promoting a Versatile but yet Minor Crop: Soybean in the Farming Systems of Kenya. *Journal of Sustainable Development in Africa* 2009, 10(4): 324-344.
- [4] Food and Agricultural Organization Statistical Database (FAOSTAT), 2013; <http://faostat.fao.org>
- [5] World Bank, *Sustainable land management source book*. Washington DC: World Bank, 2008.
- [6] Wasike, V. W.; Lesueur, D.; Wachira, F. N.; Mungai, N. W.; Mumera, L. M.; Sanginga, H. N.; Mugadi, D.; Wango P.; Vanlauwe, B. Genetic diversity of indigenous *Bradyrhizobium* nodulating promiscuous soybean [*Glycine max* (L) Merr.] cultivars in Kenya: Impact of phosphorus and lime fertilization in two contrasting sites. *Plant and Soil* 2009, 322(1-2): 153-163.
- [7] Kapkiyai, J. J.; Karanja, N. K.; Woome, P.; Qureshi, J. N. Soil organic carbon fractions in the long-term experiment and the potential for their use as diagnostic assays in highland farming systems central Kenya, *Africa African Crop Science Journal* 1998, 6(1): 19-28.
- [8] Mutege, E.; Kung'u, J.; Muna, M.; Pieter, P.; Mugendi, D. Complementary effects of organic and mineral fertilizers on maize production in the smallholder farms of Meru South District, Kenya. *Agricultural Sciences* 2012, 3: 221-229.
- [9] Muriuki, A. W.; Qureshi, J. N. *Fertilizer use manual: A comprehensive guide on fertilizer use in Kenya*. Kenya Agricultural Research Institute (KARI), Nairobi, Kenya, 2001.
- [10] Kasasa, P.; Mpeperek, S.; Giller, K. E. Qualification of nitrogen fixed by promiscuous soybean cultivars under Zimbabwean field condition. In: *Forum for working document programme and extended abstracts*. Fourth regional meeting of the forum for agricultural resource husbandry, 11-14 July 2000, Lolongwe, Malawi. pp.64-66.
- [11] Tran, T. Y. Response to and benefits of rhizobial inoculation of soybean in the South Vietnam, Vietnam, 2004.
- [12] Tefera, H. Breeding for Promiscuous Soybeans at IITA, Soybean - Molecular Aspects of Breeding, Dr. Aleksandra Sudaric (Ed.), ISBN: 978-953-307-240-1, InTech, 2011, pp 147-162.
- [13] Gitonga, M. N.; Gatheri, G. W.; Cheruiyot, R.; Maingi J. M. Nodulation and nitrogen fixation in promiscuous and non promiscuous soybean (*Glycine max* (L.) Merrill) varieties in Eastern Kenya. *Journal of Tropical Microbiology and Biotechnology* 2010, 6(1).
- [14] Mugendi, E.; Gitonga, N.; Cheruiyot, R.; Maingi, J. Biological Nitrogen Fixation by Promiscuous Soybean (*Glycine max* L. Merril) in the Central Highlands of Kenya: Response to Inorganic Fertilizer Soil Amendments, *World Journal of Agricultural Sciences* 2010, 6(4): 381-387.
- [15] Marschner, H. *Mineral nutrition of higher plants*. London, Academic Press Ltd, 1993.
- [16] Kessel, V. C.; Hartley, C. Agricultural management of grain legumes: has it led to an increase in nitrogen fixation? *Field Crops Research* 2000, 65: 165-181.
- [17] Jaetzold, R.; Schmidt, H.; Hornetz, B.; Shisanya, C. *Farm handbook of Kenya: Natural conditions and farm management information Natural Conditions and Farm Information*. 2nd Edition. Vol.11/ C. Eastern Province. Ministry of Agriculture/ GTZ, Nairobi, Kenya, 2007.
- [18] Food and Agriculture Organization. Forestry and Food Security. FAO Forestry Paper, Rome, FAO (UN) 1989, 90: 1-2.
- [19] Okalebo, R. J.; Gathua, K. W.; Woome, P. W. *Laboratory methods of soil and plant analysis: A Working Manual* (2nd edition). Department of Soil Science, Moi University, Eldoret, Kenya, 2002.
- [20] Tukamuhabawa, P.; Dashiell, K. E.; Rubaihawo, P.; Nabasiye, M. Determination of field yield loss and effects of environment on pod shattering in soybean. *African Crop Science Journal* 2002, 10(3): 203-209.
- [21] Masumba, B.A.N. Physiological measurement for ranking bean cultivars with respect to relative drought and heat resistance. *East African Agricultural and Forestry Journal* 1984, 44: 291-296.

- [22] SAS/STAT User's Guide, Version 6, vol. 2, 4th ed. Cary, NC, USA. SAS Institute, 1996.
- [23] Drevon, J. J.; Hartwig, U. A. Phosphorus deficiency increases the argon-induced decline of nodule nitrogenase activity in soybean and alfalfa. *Planta* 1997, 201(4): 463-469.
- [24] Almeida, J. P.; Hartwig, U. A.; Frehner, M.; Nosberger, J.; Luscher, A. Evidence that P deficiency induces N feedback regulation of symbiotic N₂ fixation in white clover (*Trifolium repens* L.). *Journal of Experimental Botany* 2000, 51:1289-1297.
- [25] Sa, T. M.; Israel, D. W. Nitrogen assimilation in nitrogen fixing soybean plants during phosphorus deficiency. *Crop Science* 1995, 35: 814-820.
- [26] Miao, S. J.; Qiao, Y. F.; Han, X. Z.; An, M. Nodule Formation and Development in Soybeans (*Glycine max* L.) in Response to Phosphorus Supply in Solution Culture. *Pedosphere* 2007, 17:36-43.
- [27] Israel, D. W. Investigation of the role of phosphorus in symbiotic dinitrogen fixation. *Plant Physiology* 1987, 84(3): 835-840.
- [28] Israel, D. W. Symbiotic dinitrogen fixation and host plant growth during development of and recovery from phosphorus deficiency. *Physiologia Plantarum* 1993, 88(2): 294-300.
- [29] Dwivedi, A. K.; Bapat, P. N. Sulphur-phosphorus interaction on the synthesis of nitrogenous fractions and oil in soybean. *Journal of Indian Society of Soil Science* 1998, 46(2): 254-257.
- [30] Huda, S. M. S.; Sujauddin, M.; Shafinat, S.; Uddin, M. S. Effects of phosphorus and potassium addition on growth and nodulation of *Dalbergia sissoo* in the nursery. *Journal of Forestry Research* 2007, 18(4): 279-282.
- [31] Xiang, D. B.; Yong, T. W.; Yang, W. Y.; Wan, Y.; Gong, W. Z.; Cui, L.; Lei, T. Effect of phosphorus and potassium nutrition on growth and yield of soybean in relay strip intercropping system. *Scientific Research and Essays* 2012, 7(3): 342-351.
- [32] Abdul Jabbar, B. K.; Saud, H. M. Effects of phosphorus on biological nitrogen fixation in soybean under irrigation using saline water. *Global Journal of Science Frontier Research Agriculture & Biology* 2012, 12(1): 64-72.
- [33] Shiro, S.; Yamamoto, A.; Umehara, Y.; Hayashi, M.; Yoshida, N.; Nishiwaki, A.; Yamakawa, T.; Saeki, Y. Effect of *Rj* Genotype and Cultivation Temperature on the Community Structure of Soybean-Nodulating Bradyrhizobia. *Applied and Environmental Microbiology* 2012, 78(4): 1243-1250.
- [34] Eaglesham, A. R. J.; Ayanaba, A.; Ranga Rao, V.; Eskew, D. L. Mineral N effects on cowpea and soybean crops in a Nigerian soil. II. Amounts of N₂ fixed and accrual to the soil. *Plant and Soil* 1982, 68: 183-192.
- [35] Patterson, T., G.; LaRue, T. A. Nitrogen fixation by soybeans: Seasonal and cultivar effects, and comparison of estimates. *Crop Science* 1983, 23: 488-492.
- [36] Giller, K. E.; Wilson, K. J. *Nitrogen fixation in tropical cropping systems*, Wallingford, UK. CAB International, 1991.
- [37] Sanginga, N.; Dashiell, K.; Okogun, J. A.; Thottappilly, G. Nitrogen fixation and N contribution in promiscuous soybeans in southern Guinea savanna of Nigeria. *Plant and Soil* 1997, 195: 257-266.
- [38] Ogoke, I. J.; Carsky, R. J.; Togun, A. O.; Dashiell, K. Effect of P fertilizer on N balance of soybean crop in guinea savanna of Nigeria. *Agriculture, Ecosystems and Environment* 2003, 100: 153-159.
- [39] Australian Collaborative Land Evaluation Program (ACLEP). *Soil Information Transfer and Evaluation System: database design and exchange protocols*, ACLEP, Technical Report No. 3. Canberra, CSIRO Division of Soils, 1995.
- [40] Sanginga, N.; Thottappilly, G.; Dashiel K. Effectiveness of rhizobia nodulating recent promiscuous soybean selections in the moist savanna of Nigeria. *Soil Biology and Biochemistry* 2000, 32: 127-133.
- [41] Kihara, J.; Martius, C.; Bationo, A.; Vlek, P. L. G. Effects of tillage and crop residue application on soybean nitrogen fixation in a tropical ferralsol. *Agriculture* 2011, 1: 22-37.
- [42] Singh, A.; Carsky, R. J.; Lucas, E. O.; Dashiell, K. Soil N balance as affected by maturity class in the Guinea savanna of Nigeria. *Agriculture, Ecosystems and Environment* 2003, 100(2-3): 231-240.
- [43] Wani, S. P.; Rupela, O. P.; Lee, K. K. Sustainable agriculture in the semi-arid tropics through biological nitrogen fixation in grain legumes. *Plant and Soil* 1995, 174: 29-49.