Journal of Plant Nutrition

ISSN: 0190-4167 (Print) 1532-4087 (Online) Journal homepage: https://www.tandfonline.com/loi/lpla20

Effect of nitrogen sources on the yield of common bean (*Phaseolus vulgaris*) in western Kenya

Fanuel Kawaka, Mathews Dida, Peter Opala, Omwoyo Ombori, John Maingi, Alice Amoding & John Muoma

To cite this article: Fanuel Kawaka, Mathews Dida, Peter Opala, Omwoyo Ombori, John Maingi, Alice Amoding & John Muoma (2018) Effect of nitrogen sources on the yield of common bean (*Phaseolus vulgaris*) in western Kenya, Journal of Plant Nutrition, 41:13, 1652-1661, DOI: 10.1080/01904167.2018.1458870

To link to this article: https://doi.org/10.1080/01904167.2018.1458870

Published online: 15 May 2018.

JOURNAL OF PLANT NUTRITION
2018, VOL. 41, NO. 13, 1652–1661
https://doi.org/10.1080/01904167.2018.1458870

Taylor & Francis
Taylor & Francis Group

Effect of nitrogen sources on the yield of common bean (*Phaseolus vulgaris*) in western Kenya

Fanuel Kawaka[a,b], Mathews Dida[a], Peter Opala[c], Omwoyo Ombori[d], John Maingi[e], Alice Amoding[f], and John Muoma[g]

[a]Department of Applied Plant Sciences, Maseno University, Maseno, Kenya; [b]Department of Pure and Applied Sciences, Technical University of Mombasa, Mombasa, Kenya; [c]Department of Soil Science, Maseno University, Maseno, Kenya; [d]Department of Plant Sciences, Kenyatta University, Nairobi, Kenya; [e]Department of Microbiology, Kenyatta University, Nairobi, Kenya; [f]Department of Soil Science, Makerere University, Kampala, Uganda; [g]Department of Biological Sciences, Masinde Muliro University of Science and Technology, Kakamega, Kenya

ABSTRACT

Depletion of soil nutrients due to continuous cultivation without adequate external fertilization is one of the challenges facing many smallholder farmers in western Kenya. This study was conducted to assess the effects of organic (water hyacinth compost), inorganic (urea) nitrogen (N) sources, and commercial Rhizobia inoculant on the yield of common bean (*Phaseolus vulgaris*) for two consecutive seasons in the short rains (2013) and long rains (2014). The experiments were laid out in a randomized complete block design and replicated four times. Triple superphosphate was applied to all treatments except those with compost to ensure that the soil had adequate phosphorus (P). Yellow and Rose coco bean varieties grown with urea and inoculated with commercial Rhizobia inoculant gave significantly higher yield of 382 kg ha^{-1} and 341 kg ha^{-1}, respectively in the short rains (SR) season. In the long rains (LR) season bean yield was high in water hyacinth compost (1526 kg ha^{-1}) and control with non-limiting P (1300 kg ha^{-1}) treatments. Commercial Rhizobia inoculant did not significantly increase in yield in the SR and LR seasons. There was no significant influence on soil properties after two seasons of continuous cultivation of common bean and application of organic and inorganic fertilizers. These results demonstrate that water hyacinth compost improved bean yield in the LR season. However, longer field testing and economic analysis are required for it to be recommended as a substitute for inorganic N source among smallholder farmers.

ARTICLE HISTORY
Received 31 January 2017
Accepted 15 February 2018

KEYWORDS
inorganic; organic; rhizobia; smallholder; water hyacinth

1. Introduction

The decline in soil fertility due to continuous cultivation without adequate addition of external inputs is a major challenge facing many smallholder farmers in sub-Saharan Africa (Seck et al. 2013; Mucheru-Muna et al. 2007). In addition, continued conventional farming practices have resulted in economic and environmental concerns such as low soil productivity, pollution, and high cost of inorganic fertilizers. These challenges require the adoption of sustainable alternative food production practices that do not compromise on environmental stability. Common bean (*Phaseolus vulgaris* L.) is recognized as a legume crop that could ensure food security in sub-Saharan Africa if challenges associated with its production are addressed (Namugwanya et al. 2014). The crop improves soil fertility through addition of biologically fixed nitrogen (N), enhancement of soil organic matter, and prevention of nutrient leaching (Mothapo

CONTACT Fanuel Kawaka fkawaka@tum.ac.ke Department of Applied Plant Sciences, Maseno University, Maseno, Kenya.
Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/lpla.

et al. 2013). In Kenya, dry bean production is predominantly done by small-scale farmers and has been on the decline in recent years. The low bean yields have been attributed to many constraints such as soil infertility, which is one of the most limiting factors (Namugwanya et al. 2014). N, the nutrient taken up by beans in the largest amounts among the essential plant nutrients is a major constraint to bean production in many smallholder farms (CIAT 1989; Vance 2001). However, small-holder farmers who are the major dry bean producers in Kenya rarely apply N fertilizers and rely mainly on the ability of the bean to fix N. However, beans are known to be poor N fixers (Hardarson 1993; Kabahuma 2013).

There are several options that are available to manage N deficiency in smallholder farms. Chemical fertilizers are often considered to offer immediate solution to nutrient deficiencies in soil (Chaia, Wall, and Huss-Danell 2010; Gentili, Wall, and Huss-Danell 2006), but these fertilizers are expensive and most small-holder farmers cannot afford them. The other options that are used to replenish N include the use of organic materials such as crop residues, animal manures, and agroforestry tree prunings (Mathu et al. 2012). Application of these organic materials to soils has multiple benefits such as increasing the soil organic carbon (C) content, soil microbial activity, improves the soil structure and the nutrient status (Sanni and Adesina 2012). However, most of the commonly available organic materials in smallholder farms are usually inadequate in quantity with poor quality to meet the crop nutrient demand (Opala 2011). The use of non-traditional, largely unexploited, organic resources to augment common organic inputs in crop production has therefore received considerable research attention in the recent past (Opala, Okalebo, and Othieno 2012). One such organic material is the water hyacinth (*Eichhornia crassipes*), a water weed that is abundant in Lake Victoria. The effect of the water hyacinth infestation has negatively impacted the economic status of the local fishing community as the weed kills fish due to oxygen depletion. Despite these problems, studies have shown that water hyacinth is rich in N and macronutrients that are essential for plant nutrition (Gunnarsson and Petersen 2007). However, the potential of water hyacinth compost as an alternative source of N compared to the inorganic N fertilizers on smallholder farms in western Kenya has not been evaluated. The current study evaluated the effect of water hyacinth compost and inorganic N fertilizer on the yield of common bean.

2. Materials and methods

2.1. Study site

Field studies were conducted in Kisumu (0° 05′35″ S, 0° 34° 41.32″ E) and Kakamega (0° 17′25.57″ N, 34°45′50.02″) counties, Kenya. The two sites were selected based on agro-climatic conditions and prevalence of common bean cultivation. Kakamega county is located at an altitude of 1585 meters above sea level, within a high potential agro-ecological zone with an annual rainfall of 1200–2100 mm. Kisumu county is located at an altitude of 1300 meters above sea level with an annual relief rainfall of 1200–1300 mm. Soils at Kakamega and Kisumu are classified as Nitisols and Arenosols, respectively (Jaetzold et al. 2009). Initial soil characteristics of the two sites are shown in (Table 1).

2.2. Compost preparation

Fresh water hyacinth plants were harvested manually from Lake Victoria and chopped into small pieces of about 5–10 cm. The chopped pieces were then spread and sun dried before being filled into boxes. The boxes were placed at a distance of 1–2 m between columns and rows, respectively and a well-fitting sack in the shape of the composting box was first fitted in the box before filling each of the boxes with water hyacinth. Above ground closed aerobic heap design was used to prepare the compost to maturity (Tumuhairwe et al. 2009).

2.3. Experimental layout

The experiment was set up during the short rains (SR) of 2013 and long rains (LR) of 2014 in a randomized complete block design (RCBD) with four replications. Commercial (Rose coco) and farmer

Table 1. Initial surface (1–20 cm) soil properties Kakamega and Kisumu.

	Value	
Soil property	Kakamega	Kisumu
pH	4.98	6.10
% Nitrogen (N)	0.24	0.11
% Organic Carbon (OC)	2.66	1.32
Potassium (cmol/kg)	0.93	1.39
Magnesium (cmol/kg)	1.39	1.17
Calcium (cmol/kg)	3.08	3.02
Aluminum (cmol/kg)	2.56	0.62
Manganese (ppm)	75.2	38.3
Phosphorus (ppm)	28	35
% Sand	15.68	71.84
% Clay	66.88	18.16
Texture	Clay	Sandy loam

preferred (Yellow bean) bean varieties were planted at inter-plot spacing of 40 cm × 15 cm on a 2.4 m × 3 m plots and managed using recommended agronomic practices (Adama, Tahir, and Mamadou 2008). External soil fertility amendment inputs either inoculated or non inoculated (1) Triple superphosphate (TSP), (2) urea, and (3) water hyacinth compost were applied every season for two seasons. An absolute control with no external input was also included. Urea and water hyacinth compost were applied to provide 100 kg N ha^{-1}. Uniform TSP was applied at a rate of 60 kg ha^{-1} to all treatments with no compost input to ensure non-limiting soil P. The commercial Rhizobium inoculant was applied at the rate of 100 g for 15 kg of seeds in the appropriate treatments. All the nutrient inputs were applied at the time of planting. The average chemical analysis of water hyacinth compost is shown in (Table 2). Soil was sampled and analyzed in the SR and LR using established procedures (Okalebo, Gathua, and Woomer 2002). Four plants were randomly selected from each plot and dug out at 7 weeks after emergence and separated into shoots and roots. The plant shoots were oven-dried at 70°C for 48 hr for dry weight determination. At maturity, pods were harvested from each experimental plot, excluding the outer rows and the outer guard plants in each row, shelled, and tagged for yield assessment. The grains were sun-dried until a constant weight was established. Yield parameters determined included the number of pods per plant and total grain yield. Seed yield per hectare was extrapolated from the seed yield per plot.

2.4. Data analysis

All data on shoot dry weight (SDW), nodules, pods, and yield were subjected to analysis of variance (ANOVA) using General Linear Models Procedure of SAS software version 9.1 (SAS 2003) and means separated using the least significance differences of means (LSD) at $p < 0.05$.

Table 2. Mean chemical composition of water hyacinth compost used in this study.

Chemical property	Value
pH	8.37
% Nitrogen (N)	1.33
% Organic Carbon (OC)	12.23
Potassium (cmol/kg)	25
Sodium (cmol/kg)	2.1
Phosphorus (ppm)	280
Calcium (cmol/kg)	20.65
Magnesium (cmol/kg)	9.33
Zinc (ppm)	2.96
Iron (ppm)	1.29

3. Results

3.1. Soil properties

After two seasons of continuous cultivation and application of organic and inorganic N, no significant difference in soil properties was observed in most treatments in the SR and LR (Tables 3, 4, 5, and 6). The average soil pH increased during the LR in response to organic and inorganic inputs compared to the SR. Soil N and organic C were lower while calcium (Ca), potassium (K), and phosphorus (P) were higher compared to the critical values. Initial soil pH ranged from 4.98 (Kakamega) and 6.10 (Kisumu) with clay and sandy loamy texture, respectively. The soil texture was sandy loam in Kisumu with high sand content (71.84%) compared to the high clay content (66.88%) in Kakamega. The water hyacinth compost contained high P, organic C, Ca, and K with a basic pH.

3.2. Bean growth and yield

The growth and yield of beans varied between treatments in the SR and LR across the two sites (Tables 7 and 8). The Dry weight (DW) was significantly higher ($p < 0.05$) in inoculated Rose coco control with P at Kisumu and inoculated Yellow bean with urea at Kakamega in SR.The average DW of bean plants in Kakamega was high compared to Kisumu in all treatments in the LR. Bean plants grown with urea treatments produced lower number of nodules in all the seasons. Water hyacinth compost and control with P treatments had high number of nodules compared to other treatments. The number of pods was high in inoculated Rose coco beans grown with water hyacinth and yellow bean in absolute control in Kisumu in SR. Kakamega had fewer pods in the non-inoculated Yellow beans treated with water hyacinth and urea. More pods were found in inoculated Yellow beans treated with water hyacinth compost, non-inoculated urea, and absolute control in LR. Yields were high in inoculated yellow and Rose coco beans treated with urea (382 kg ha^{-1} and 341 kg ha^{-1}) in Kisumu and Kakamega, respectively in the SR. Non-inoculated Rose coco grown with water hyacinth compost had higher yield (1583.4 kg ha^{-1}) than the other treatments in Kakamega. At the end of the LR, yield increment of 1525.8 kg ha^{-1} and 1299.9 kg ha^{-1} was recorded in inoculated Rose coco grown with water hyacinth compost and control, respectively (Figure 1). However, inoculated Yellow bean grown with urea and Rose coco in absolute control produced lower yield increment of 446.4 kg ha^{-1} in the LR. Rhizobium inoculation had no significant influence on yield in all the treatments during the SR and LR seasons.

Table 3. Mean soil characteristics in the SR season at Kisumu.

	Treatment	pH	N	OC	Ca	Mg	K	Al	Mn	P
1	Rose coco-I	5.63b	0.09abc	0.92ab	8.87bc	1.26bc	1.23ab	2.05bcde	39.73bcd	14.17abcd
2	Rose coco NI	5.58ab	0.10a	1.22ab	6.31bc	1.20bc	0.81ab	1.58cde	46.59bcd	14.60abcd
3	Rose coco TSP-I	5.59b	0.12c	1.31ab	5.38a	1.30bc	1.00ab	1.13a	53.65cd	19.47cd
4	Rose coco TSP-NI	5.75b	0.14bc	1.32b	4.58ab	1.24bc	1.07ab	1.00ab	47.78bcd	22.85bcd
5	Rose coco TSP UREA-I	6.03a	0.15ab	1.45a	2.66bc	1.23bc	1.40a	0.64e	42.57bcd	36.36a
6	Rose coco TSP UREA-NI	5.58a	0.11c	1.29ab	6.24ab	1.45a	0.96ab	0.74a	60.33a	15.37d
7	Rose coco WH-I	6.10ab	0.13a	1.37ab	5.14c	1.25bc	1.60ab	0.74e	47.90bcd	44.61abc
8	Rose coco WH-NI	6.13b	0.09bc	1.03ab	7.30ab	1.56ab	0.93ab	1.97e	86.80bc	7.78bcd
9	Yellow bean-I	5.61ab	0.13ab	1.42ab	6.58bc	1.12bc	0.54ab	1.20bcde	37.56bc	30.60abcd
10	Yellow bean-NI	5.55ab	0.11ab	1.34ab	5.18ab	1.21c	0.71ab	1.31cde	50.62b	15.98abc
11	Yellow bean TSP-I	5.68b	0.12ab	1.33a	5.39ab	1.21c	0.86b	1.12bcd	60.60d	32.98abcd
12	Yellow bean TSP-NI	5.72b	0.12bc	1.31ab	6.51bc	1.14bc	0.80ab	1.04bc	64.25bcd	39.59bcd
13	Yellow bean TSP UREA-I	5.70ab	0.13ab	1.34ab	6.61ab	1.23c	0.94ab	1.12bcd	63.39b	40.53abc
14	Yellow bean TSP UREA-NI	5.64ab	0.12ab	1.32ab	6.12ab	1.23bc	0.84ab	1.20bcde	58.99bcd	30.95abcd
15	Yellow bean WH-I	6.12ab	0.13ab	1.32ab	6.13ab	1.18c	0.90ab	1.17bcde	62.25b	38.35ab
16	Yellow bean WH-NI	6.17ab	0.12ab	1.32ab	6.00ab	1.23bc	0.90ab	1.14bcd	57.86bcd	31.43abcd
LSD (5%)		0.50	0.03	0.42	3.09	0.24	0.91	0.50	21.85	26.08

Means within a column followed by the same letter(s) are not significantly different at $p < 0.05$.
LSD-Least Significant Difference of means; I-Rhizobia Inoculation; NI-Non-Rhizobia Inoculation; TSP-Triple Superphosphate; WH-Water Hyacinth Compost.

Table 4. Mean soil characteristics in the LR at Kisumu.

	Treatments	pH	N	OC	Ca	Mg	K	Al	Mn	P
1	Rose coco-I	5.70a	0.24d	1.77b	4.47a	1.26abc	1.24abc	2.00c	78.90abcde	44.00abcd
2	Rose coco NI	5.63ab	0.16d	1.44b	5.65a	1.08a	0.70ab	1.76c	54.15abcde	31.00abcd
3	Rose coco TSP-I	6.26ab	0.12ab	1.30ab	7.31a	1.29abcd	1.10a	0.99a	64.10abc	65.00bcd
4	Rose coco TSP-NI	5.93ab	0.13cd	1.34b	7.60a	1.41bcd	1.19cd	0.96ab	60.30bcde	64.50d
5	Rose coco TSP UREA-I	6.04ab	0.14a	1.49a	5.88a	1.07abcd	1.02abc	0.99ab	53.65a	98.50bcd
6	Rose coco TSP UREA-NI	5.65ab	0.19cd	1.31b	6.81a	1.29bcd	0.99bcd	0.93bc	87.00cde	42.50cd
7	Rose coco WH-I	6.18ab	0.25cd	2.15b	5.55a	1.24bcd	0.98abc	1.76c	86.05e	52.00a
8	Rose coco WH-NI	6.12ab	0.16bc	1.48b	4.60a	1.06abc	0.79abc	1.29c	55.55a	34.31bcd
9	Yellow bean-I	5.68ab	0.13cd	1.44b	4.44a	1.03d	0.55cd	1.09bc	66.55abc	38.60bcd
10	Yellow bean-NI	5.63ab	0.13cd	1.37b	4.30a	1.11d	0.89abcd	1.20c	69.00abc	41.85ab
11	Yellow bean TSP-I	5.98ab	0.16d	1.44b	6.58a	1.02cd	0.77d	1.25c	78.08abcde	61.22bcd
12	Yellow bean TSP-NI	5.88b	0.13d	1.33b	7.56a	1.02bcd	0.86abcd	1.06bc	78.44abcde	72.34bcd
13	Yellow bean TSP UREA-I	6.00ab	0.13cd	1.36b	7.75a	1.29bcd	1.05bcd	0.98bc	69.20abcd	67.17bcd
14	Yellow bean TSP UREA-NI	5.84ab	0.13d	1.34b	6.12a	1.03bcd	0.69bcd	0.99c	77.19ab	55.60ab
15	Yellow bean WH-I	6.14ab	0.16cd	1.43b	5.61a	1.08ab	0.81abc	1.22c	77.65abcde	58.20abc
16	Yellow bean WH-NI	6.12ab	0.13d	1.27b	7.05a	1.07cd	0.78cd	0.95c	83.42abcde	72.07bcd
LSD (5%)		0.63	0.06	0.56	4.12	0.26	0.41	0.58	23.72	35.22

Means within a column followed by the same letter(s) are not significantly different at $p < 0.05$.
LSD-Least Significant Difference of means; I-Rhizobia Inoculation; NI-Non-Rhizobia Inoculation, TSP-Triple Superphosphate; WH-Water Hyacinth Compost.

4. Discussion

After two seasons of applying water hyacinth compost and planting common bean at the two sites, there was no significant influence on soil properties. Lack of change in the soil properties could be attributed to the long term effect of compost application in soil. These results are consistent with similar previous studies that demonstrated slow N mineralization from organic compost in the short term (Wadhwa and Bakshi 2013; Diacono and Montemurro 2010). Diacono and Montemurro (2010) further reported that significant cumulative and residual effect of organic compost application is usually visible after 4–5 years of continuous application. This study was conducted for two consecutive seasons that may be considered too short to realize significant effect of compost on soil properties. In addition, only a fraction of the N and P in compost is readily made available in soil as a larger part remains to be mineralized (Eghball, Ginting, and Gilley 2004; Turuko and Mohammed 2014). Beans grown with

Table 5. Mean soil characteristics in the SR at Kakamega.

	Treatment	pH	N	OC	Ca	Mg	K	Al	Mn	P
1	Rose coco-I	5.39bcde	0.26abcd	2.21a	2.87de	1.27ef	1.12a	1.68d	86.90abc	20.00ab
2	Rose coco NI	5.15bcde	0.21abcd	1.94b	3.16abc	1.19f	1.21a	2.13abcd	55.10bcd	15.96b
3	Rose coco TSP-I	5.22abcd	0.21a	2.43ab	2.63cde	1.14def	1.26a	1.34bcd	75.30a	23.54ab
4	Rose coco TSP-NI	5.29bcde	0.20abcd	1.64ab	4.10bcde	1.09ef	1.19a	2.30abcd	56.70bcd	14.67b
5	Rose coco TSP UREA-I	5.88bcde	0.23abcde	1.97ab	4.36cde	1.36def	1.33a	2.07cd	80.90abc	18.67ab
6	Rose coco TSP UREAN-I	5.54bcde	0.17abcde	1.91ab	2.86bcde	1.28ef	1.25a	2.16abcd	49.10cd	29.92ab
7	Rose coco WH-I	5.19a	0.18ab	1.91ab	2.89ab	1.23bcdef	1.24a	1.62abcd	69.30ab	22.58ab
8	Rose coco WH-NI	5.21ab	0.17abcde	2.27ab	3.16cde	1.18cdef	1.28a	2.29abcd	50.70cd	26.67ab
9	Yellow bean-I	4.88abc	0.21e	2.11ab	4.63bcde	1.80ab	1.20a	2.15abcd	62.11abcd	19.73ab
10	Yellow bean-NI	4.81bcde	0.15cde	1.70ab	3.89e	1.71abcd	1.25a	1.84bcd	60.02d	19.11ab
11	Yellow bean TSP-I	5.42de	0.08abcd	1.89ab	3.07a	1.67a	1.25a	2.05abcd	66.40abcd	22.11ab
12	Yellow bean TSP-NI	5.18e	0.12bcde	2.14ab	2.53abcde	1.61ab	1.34a	1.75abcd	39.33abcd	32.00ab
13	Yellow bean TSP UREA-I	5.25bcde	0.11abc	1.74ab	4.01abcd	1.70ef	1.39a	2.48a	66.30bcd	27.96ab
14	Yellow bean TSP UREA-NI	4.98de	0.21abcde	2.09b	3.73abcde	1.65abcde	1.32a	2.68abcd	51.77bdc	35.54ab
15	Yellow bean WH-I	5.16bcde	0.22de	2.31ab	4.01abcd	1.15ab	1.34a	2.78ab	54.54abcd	26.67ab
16	Yellow bean WH-NI	4.98cde	0.18abcd	1.57ab	3.92abcde	1.47abc	1.30a	2.10abc	58.15cd	28.63a
LSD (5%)		0.52	0.10	0.76	1.42	0.38	0.52	1.01	28.52	19.11

Means within a column followed by the same letter(s) are not significantly different at $p < 0.05$.
LSD-Least Significant Difference of means; I-Rhizobia Inoculation; NI-Non-Rhizobia Inoculation; TSP-Triple Superphosphate; WH-Water Hyacinth Compost.

Table 6. Mean soil characteristics in the LR at Kakamega.

Treatment		pH	N	OC	Ca	Mg	K	Al	Mn	P
1	Rose coco-I	4.94fg	0.18abc	2.49h	6.88e	1.52b	1.33abc	1.78abcd	75.98def	21.98a
2	Rose coco NI	5.31h	0.29abc	2.15fg	7.05g	1.85gh	1.42ab	1.80ab	89.00cd	30.00d
3	Rose coco TSP-I	4.93fg	0.25bc	1.59abc	7.97g	1.62bcd	1.47a	1.49bcde	75.97def	58.97k
4	Rose coco TSP-NI	4.56ab	0.20abc	2.11ef	7.05g	1.16a	0.93cd	1.45bcde	81.00b	44.00h
5	Rose coco TSP UREA-I	4.75abc	0.23abc	2.27abc	7.83b	1.29cde	1.21abc	1.04efg	78.00a	41.67b
6	Rose coco TSP UREAN-I	5.20fg	0.27c	2.53g	8.80g	1.58gh	1.02bcd	1.42bcde	79.66cde	38.00h
7	Rose coco WH-I	5.29gh	0.22abc	2.47def	9.84ef	1.44efg	1.25abc	0.63gh	98.24cde	48.04e
8	Rose coco WH-NI	4.90bcde	0.15abc	1.95ab	6.72cd	1.12bc	1.22abc	0.39h	76.87cde	29.97f
9	Yellow bean-I	5.08bcd	0.35abc	2.26h	5.61bc	1.26bcd	1.00cd	1.87ab	79.71g	31.11g
10	Yellow bean-NI	5.25cdef	0.21abc	2.40bcde	10.70de	1.20def	1.09abcd	2.15a	79.00fg	46.00i
11	Yellow bean TSP-I	5.23def	0.23a	1.72def	9.15h	1.52fg	0.76d	1.08efg	69.07cde	33.07h
12	Yellow bean TSP-NI	5.10bcd	0.24abc	2.34abcd	8.30a	1.36fgh	1.12abcd	1.26cdef	70.80cde	27.00c
13	Yellow bean TSP UREA-I	5.01a	0.31abc	2.51cdef	7.21g	1.21h	1.04bcd	1.55bcde	82.02efg	39.91g
14	Yellow bean TSP UREA-NI	4.56def	0.23ab	2.55ef	7.95h	1.13gh	0.96cd	1.80abc	77.95g	23.95bc
15	Yellow bean WH-I	5.47ef	0.23ab	2.30ab	7.01fg	1.06fgh	1.29abc	1.24def	74.36c	34.01e
16	Yellow bean WH-NI	5.06h	0.30abc	2.18a	5.60e	1.06gh	0.92cd	0.73fgh	70.00cde	47.00j
LSD (5%)		0.21	0.15	0.19	0.73	0.18	0.41	0.54	5.93	1.83

Means within a column followed by the same letter(s) are not significantly different at $p < 0.05$.
LSD-Least Significant Difference of means; I-Rhizobia Inoculation; NI-Non-Rhizobia Inoculation; TSP-Triple Superphosphate; WH-Water Hyacinth Compost.

urea in the SR had high DW due to enhanced vegetative growth that could have been supported by the immediate release of N from inorganic fertilizer. Total shoot and plant biomass always increase in response to added soil N (Zatylny and St-Pierre 2006; Balemi and Negisho 2012). Similarly, Balemi and Negisho (2012) and Turuko and Mohammed (2014) reported an increase in DW of common beans in soils with adequate amount of P. Soil P plays a vital role in enhancing cell division during the growth of plants. Beans in the water hyacinth compost and control treatments produced more nodules confirming that the compost could have reduced aluminum (Al) toxicity and promoted nodulation as previously reported (Lawson, Muramatsu, and Nioh 1995). Slow mineralization of the water hyacinth compost could have further led to reduced release of N that favored the proliferation of nodules. Since

Table 7. Yield of common bean in the short rains (SR).

Treatments		Kisumu				Kakamega			
		DW (g plant^{-1})	Nodules per plant	Pods per plant	Yield (kg ha^{-1})	DW (g plant^{-1})	Nodules per plant	Pods per plant	Yield (kg ha^{-1})
1	Rose coco-I	12.4bc	60ed	13efgh	129.1fg	5.5c	87a	14abc	323.5abc
2	Rose coco NI	7.9efg	14f	15cdefg	266.2b	4.7c	73ab	12bcde	182.5fg
3	Rose coco TSP-I	17.0a	78ab	13fgh	120.7g	6.0bc	61b	16ab	250.4def
4	Rose coco TSP-NI	11.4bcd	77abc	11h	181.1defg	4.9c	59b	13abcd	269.3bcd
5	Rose coco UREA-I	6.9fg	9f	18bc	256.7bc	5.8bc	3c	14abc	341.0a
6	Rose coco UREA-NI	14.0ab	19f	14defgh	265.0b	4.5c	7c	11cde	326.8ab
7	Rose coco WH-I	5.7g	63cde	23a	193.0de	5.5c	60b	17a	244.0def
8	Rose coco WH-NI	10.1cdef	72bcd	16cdef	202.3cd	5.6c	92a	9def	238.9def
9	Yellow bean-I	8.3defg	91a	21ab	133.8efg	5.0c	74ab	11bcde	221.4defg
10	Yellow bean-NI	7.5efg	16f	14defgh	195.9cd	7.0bc	11c	9def	235.4def
11	Yellow bean TSP-I	7.1efg	59e	18bc	143.3defg	8.7b	86a	13abcd	152.8g
12	Yellow bean TSP-NI	12.0bc	84ab	15cdefg	198.3cd	4.9c	81a	10cdef	254.2cde
13	Yellow bean UREA-I	5.6g	6f	16cde	382.0a	14.0a	7c	11cde	290.0abcd
14	Yellow bean UREA-NI	10.3cde	10f	15cdefg	312.1b	4.9c	4c	8ef	287.1abcd
15	Yellow bean WH-I	6.8fg	90a	17cd	184.2def	5.7bc	74ab	14abc	245.8def
16	Yellow bean WH-NI	8.0efg	55e	12gh	202.3cd	4.8c	60b	6f	191.3efg
LSD (5%)		3.4	14.4	3.6	61.7	3.1	19.4	4.7	71.4
CV (%)		22	17	14	18	30	22	25	17

Means within a column followed by the same letter (s) are not significantly different at $p < 0.05$.
LSD-Least Significant Difference of means; CV-Coefficient of Variation; I-Rhizobia Inoculation; NI-Non-Rhizobia Inoculation; TSP-Triple Superphosphate; WH-Water Hyacinth Compost.

Table 8. Yield of common bean in the long rains (LR).

Treatment	Kisumu				Kakamega			
	DW (g plant^{-1})	Nodules per plant	Pods per plant	Yield (kg ha^{-1})	DW (g plant^{-1})	Nodules per plant	Pods per plant	Yield (kg ha^{-1})
1 Rose coco-I	6.3defg	13cd	7g	95.7h	13.3bcd	19c	11a	1069.6g
2 Rose coco NI	6.0fg	4e	9efg	223.4fg	14.8bc	18cd	13a	691.7g
3 Rose coco TSP-I	7.8cdef	13cd	13cdefg	251.9efg	16.5ab	37a	13a	1419.1cd
4 Rose coco TSP-NI	6.2efg	10d	13cdefg	423.4bc	13.9bcd	12de	16a	1006.0b
5 Rose coco UREA-I	9.3bcdef	3e	16cdef	258.4ef	12.0cd	4f	14a	1196.9bc
6 Rose coco UREA-NI	9.5bcdef	13cd	11defg	486.1ab	13.3bcd	4f	12a	1063.9bc
7 Rose coco WH-I	9.8bcd	17ab	6g	530.9a	15.0abc	16cde	12a	957.6cde
8 Rose coco WH-NI	10.9abc	14bc	8fg	383.6cd	15.9ab	28b	13a	1583.4a
9 Yellow bean-I	3.8g	3e	18cd	177.7g	18.4a	16cde	15a	656.8g
10 Yellow bean-NI	14.2a	13cd	29a	92.2h	10.9d	10ef	14a	807.2efg
11 Yellow bean TSP-I	12.0ab	12cd	19bcd	188.6fg	14.2bcd	10ef	15a	698.2fg
12 Yellow bean TSP-NI	9.1bcdef	12cd	16cdef	319.1de	14.0bcd	18cd	13a	893.4cde
13 Yellow bean UREA-I	12.4ab	3e	17cde	423.4bc	13.2bcd	5f	15a	695.0g
14 Yellow bean UREA-NI	9.9bc	3e	27ab	426.2bc	14.9abc	5f	13a	796.2efg
15 Yellow bean WH-I	8.9bcdef	18a	21abc	470.2ab	16.6ab	30b	14a	879.4def
16 Yellow bean WH-NI	9.6bcde	4e	19bcd	453.2abc	13.3bcd	21c	15a	1191.0b
LSD (5%)	3.6	3.8	9	80.4	3.7	6.4	4.2	182.1
CV (%)	24	24	35	15	15	24	18	11

Means within a column followed by the same letter(s) are not significantly different at $p < 0.05$.
LSD-Least Significant Difference of means; CV-Coefficient of Variation; I-Rhizobia Inoculation; NI-Non-Rhizobia Inoculation; TSP-Triple Superphosphate; WH-Water Hyacinth Compost.

adequate soil P improves total and active nodules (Ganeshamurthy and Sammi Reddy 2000), water hyacinth compost could have supplied sufficient P that supported the formation of nodules in the control treatments. Legume nodulation is an energy driven process and requires P to provide nutrition required for N fixation. The lower number of nodules in the plants grown with urea resulted from the inhibitory effects of N. Soil N inhibits nodulation and biological N fixation in many legume crops including common bean (Salvagiotti et al. 2008; Gentili, Wall, and Huss-Danell 2006). High soil N levels inhibit early cell divisions in the cortex thus inhibiting nodulation. The high number of pods in the water hyacinth compost treated plants has been reported by many authors. These authors reported that addition of organic compost increases the number of pods in different crop legumes (Azimzadeh, Shirvani, and Shariatmadari 2014; Azimzadeh, Shirvani, and Shariatmadari 2016).

High bean yield in the urea treatments in the SR across the sites could have resulted from the readily available N in it. The yield was significantly higher in water hyacinth compost plants at Kakamega in the LR. The high yield could further be attributed to the provision of additional soil benefits besides N

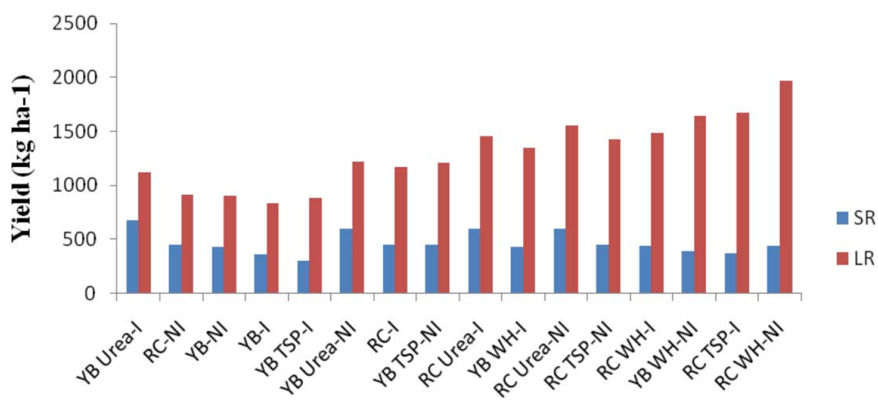

Figure 1. Yield increment at the end LR. Key: YB-Yellow bean, RC-Rose coco.

by the organic compost that promotes plant growth and yield (Naluyange et al. 2016; Mutegi et al. 2012). A similar study demonstrated that organic compost supplies essential plant nutrients by alleviating Al toxicity and producing organic acids which form a complex with Al, thus increasing nutrient availability and crop yield (Mucheru-Muna et al. 2007).The readily decomposed form of the water hyacinth compost used in this study could have further improved bean yield. Application of readily decomposed organic material has been reported to improve crop tolerance to root rots and increasing crop yield (Otieno, Muthomi, and Nderitu 2007). The yield increment in compost treatments at the end of the LR season resulted from gradual release of nutrients by the compost over prolonged periods of time (Okalebo et al. 2007). The high amount of organic C and a basic pH of the water hyacinth compost further supported the high yield. Organic matter increases soil moisture retention and nutrient dissolution, particularly P and N over time (Otieno, Muthomi, and Nderitu 2007; Bationo 2004). Addition of organic residues with alkaline pH such as water hyacinth compost used in this study could be a low input strategy of reducing lime requirements in acidic soils (Naluyange et al. 2014; Mokolobate and Haynes 2002). Low yields of plants in the absolute control could be due to lack of external nutrient replenishment. The heavy rains in the LR season could have resulted in rapid solubility of urea that led to N loss through leaching and run off. Bationo (2004) pointed out that regular use of inorganic fertilizer does not increase crop yield but just sustains them. Inoculation of beans with commercial Rhizobium inoculant did not improve yield across the two seasons. Similarly, Kawaka et al. (2014) reported the occurrence of resident Rhizobia in soils of western Kenya with superior N fixation than commercial inoculants. High population of ineffective Rhizobia in soil limits the effectiveness of the introduced inoculum strains (Shamseldin 2007; Kawaka et al. 2014; Amos and Joshua 2001). Since no significant differences on soil properties were observed across the two seasons, long term experiments are therefore needed to ascertain the effect of water hyacinth compost on soil. The improved yield in water hyacinth compost treatments during the LR demonstrates benefits that can be derived from utilization of water hyacinth compost. However, more field testing and economic analysis are required before it can be recommended for adoption as a substitute for inorganic N source among smallholder farmers.

Acknowledgments

The authors wish to thank the field assistants in Kisumu and Kakamega for their support during this study. Smallholder farmers along the Lake Victoria Basin, Kenya are further acknowledged for providing free access into their farms.

Funding

The study was supported by the Swedish International Development Cooperation Agency (Sida) and the Inter-University Council for East Africa (IUCEA) through the Lake Victoria Research Initiative (VicRes), National Commission for Science, Technology and Innovation (NACOSTI), the Ørskov Foundation (Scotland, UK), and Association of African Universities (AAU) Small Grants for Theses and Dissertations Programme.

References

Adama, D., A. D. Tahir, and G. Mamadou. 2008. Nodulation in situ of common bean (Phaseolus vulgaris L.) and field outcome of an elite symbiotic association in Senegal. *Research Journal of Agriculture and Biological Sciences* 4 (6):810–18.

Amos, M., and O. O. Joshua. 2001. Response of common bean to Rhizobium inoculation and fertilizers. *Journal of Food Technology in Africa* 6 (4):121–25.

Azimzadeh, Y., M. Shirvani, and H. Shariatmadari. 2014. Green manure and overlapped rhizosphere effects on Pb chemical forms in soil and plant uptake in maize/canola intercrop systems: a rhizobox study. *Soil and Sediment Contamination: An International Journal* 23 (6):677–90. doi: 10.1080/15320383.2014.861795.

Azimzadeh, Y., M. Shirvani, and H. Shariatmadari. 2016. Rhizosphere and green manure effects on soil chemical attributes and metal bioavailability as a function of the distance from plant roots in mono and mixed corn and canola cultures. *Archives of Agronomy and Soil Science* 62 (8):1066–81.

Balemi, T., and K. Negisho. 2012. Management of soil phosphorus and plant adaptation mechanisms to phosphorus stress for sustainable crop production: a review. *Journal of Soil Science and Plant Nutrition* 12 (3):547–62.

Bationo, A. 2004. *Managing nutrient cycles to sustain soil fertility in sub-Saharan Africa*. Nairobi, Kenya: Academy Science Publishers. A Division of African Academy Sciences.

Chaia, E. E., L. G. Wall, and K. Huss-Danell. 2010. Life in soil by the actinorhizal root nodule endophyte Frankia. A review. *Symbiosis* 51 (3):201–26. doi: 10.1007/s13199-010-0086-y.

CIAT (Centro Internacional de Agricultura Tropical). 1989. *Bean production problems in the tropics*, eds. H. F. Schwartz and M. A. Pastor-Corrales, 2nd ed., p. 726. Cali, Colombia: CIAT.

Diacono, M., and F. Montemurro. 2010. Long-term effects of organic amendments on soil fertility. A review. *Agronomy for Sustainable Development* 30 (2):401–22. https://doi.org/10.1051/agro/2009040.

Eghball, B., D. Ginting, and J. E. Gilley. 2004. Residual effects of manure and compost applications on corn production and soil properties. *Agronomy Journal* 96 (2):442–47. https://doi.org/10.2134/agronj2004.4420.

Ganeshamurthy, A. N., and K. Sammi Reddy. 2000. Effect of integrated use of farmyard manure and sulphur in a soybean and wheat cropping system on nodulation, dry matter production and chlorophyll content of soybean on swell-shrink soils in Central India. *Journal of Agronomy and Crop Science* 185 (2):91–97. doi: 10.1046/j.1439-037x.2000.00403.x.

Gentili, F., L. G. Wall, and K. Huss-Danell. 2006. Effects of phosphorus and nitrogen on nodulation are seen already at the stage of early cortical cell divisions in Alnus incana. *Annals of Botany* 98 (2):309–15. doi: 10.1093/aob/mcl109.

Gunnarsson, C. C., and C. M. Petersen. 2007. Water hyacinths as a resource in agriculture and energy production: a literature review. *Waste Management* 27 (1):117–29. doi: 10.1016/j.wasman.2005.12.011.

Hardarson, G. 1993. Methods for enhancing symbiotic nitrogen fixation. *Plant and Soil* 152 (1):1–17. doi: 10.1007/BF00016329.

Jaetzold, R., H. Schmidt, R. Hornetz, and C. Shisanya. 2009. *Farm management handbook of Kenya*. Nairobi, Kenya II: Ministry of Agriculture.

Kabahuma, M. K. 2013. Enhancing biological nitrogen fixation in common bean (*Phaseolus vulgaris* L.). MSc. Thesis, IOWA State University, p. 4.

Kawaka, F., M. M. Dida, P. A. Opala, O. Ombori, J. Maingi, N. Osoro, M. Muthini, A. Amoding, D. Mukaminega, and J. Muoma. 2014. Symbiotic efficiency of native rhizobia nodulating common bean (*Phaseolus vulgaris* L.) in soils of western Kenya. *International Scholarly Research Notices* 2014:1–8. doi: 10.1155/2014/258497.

Lawson, I. Y. D., K. Muramatsu, and I. Nioh. 1995. Effect of organic matter on the growth, nodulation, and nitrogen fixation of soybean grown under acid and saline conditions. *Soil Science and Plant Nutrition* 41 (4):721–28. doi: 10.1080/00380768.1995.10417022.

Mathu, S., L. Herrmann, P. Pypers, V. Matiru, R. Mwirichia, and D. Lesueur. 2012. Potential of indigenous bradyrhizobia versus commercial inoculants to improve cowpea (Vigna unguiculata L. walp.) and green gram (Vigna radiata L. wilczek.) yields in Kenya. *Soil Science and Plant Nutrition* 58 (6):750–63. doi: 10.1080/00380768.2012.741041.

Mokolobate, M., and R. Haynes. 2002. Comparative liming effect of four organic residues applied to an acid soil. *Biology and Fertility of Soils* 35 (2):79–85. doi: 10.1007/s00374-001-0439-z.

Mothapo, N. V., J. M. Grossman, J. E. Maul, W. Shi, and T. Isleib. 2013. Genetic diversity of resident soil rhizobia isolated from nodules of distinct hairy vetch (Vicia villosa Roth) genotypes. *Applied Soil Ecology* 64:201–13. doi: 10.1016/j.apsoil.2012.12.010.

Mucheru-Muna, M., D. Mugendi, J. Kung'u, J. Mugwe, and A. Bationo. 2007. Effects of organic and mineral fertilizer inputs on maize yield and soil chemical properties in a maize cropping system in Meru South District, Kenya. *Agroforestry Systems* 69 (3):189–97. doi: 10.1007/s10457-006-9027-4.

Mutegi, E. M., J. B. Kung, P. Pieter, and D. N. Mugendi. 2012. Complementary effects of organic and mineral fertilizers on maize production in the smallholder farms of Meru South District, Kenya. *Agricultural Sciences* 3 (2):221–29. doi: 10.4236/as.2012.32026.

Naluyange, V., D. M. W. Ochieno, P. Wandahwa, M. Odendo, J. M. Maingi, A. Amoding, O. Ombori, D. Mukaminega, and J. Muoma. 2016. Belowground influence of rhizobium inoculant and water hyacinth composts on yellow bean infested by aphis fabae and colletotrichum lindemuthianum under field conditions. *Journal of Plant Studies* 5 (2):32–46. doi: 10.5539/jps.v5n2p32.

Naluyange, V., D. M. W. Ochieno, J. M. Maingi, O. Ombori, D. Mukaminega, A. Amoding, M. Odendo, S. A. Okoth, W. A. Shivoga, and J. V. O. Muoma. 2014. Compatibility of Rhizobium inoculant and water hyacinth compost formulations in Rosecoco bean and consequences on Aphis fabae and Colletotrichum lindemuthianum infestations. *Applied Soil Ecology* 76:68–77. doi: 10.1016/j.apsoil.2013.12.011.

Namugwanya, M., J. S. Tenywa, E. Otabbong, D. N. Mubiru, and T. A. Masamba. 2014. Development of common bean (Phaseolus Vulgaris L.) production under low soil phosphorus and drought in sub-Saharan Africa: a review. *Journal of Sustainable Development* 7 (5):128. doi: 10.5539/jsd.v7n5p128.

Okalebo, J. R., K. W. Gathua, and P. L. Woomer. 2002. *Laboratory methods of soil analysis: A working manual*, 2nd ed. Nairobi, Kenya: TSBR-CIAT and SACRED Africa.

Okalebo, J. R., C. O. Othieno, P. L. Woomer, N. K. Karanja, J. R. M. Semoka, M. A. Bekunda, D. N. Mugendi, R. M. Muasya, A. Bationo, and E. J. Mukhwana. 2007. Available technologies to replenish soil fertility in East Africa. In *Advances in integrated soil fertility management in sub-Saharan Africa: Challenges and opportunities*, A. Bationo, B. Waswa, J. Kihara and J. Kimetu (eds.), 45–62. Dordrecht, Netherlands: Springer.

Opala, P. A., J. R. Okalebo, and C. O. Othieno. 2012. Effects of organic and inorganic materials on soil acidity and phosphorus availability in a soil incubation study. *ISRN Agronomy* 2012:1–10. doi: 10.5402/2012/597216.

Opala, P. A. 2011. Management of organic inputs in East Africa: a review of current knowledge and future challenges. *Archives of Applied Science Research* 3 (1):65–76.

Otieno, P. E., J. W. Muthomi, and J. H. Nderitu. 2007. Effect of rhizobia inoculation, farmyard manure and nitrogen fertilizer on growth, nodulation and yield of selected food grain legumes. *African Crop Science Conference Proceedings*, 8:305–12. El-Minia, Egypt, 27–31 October 2007.

Salvagiotti, F., K. G. Cassman, J. E. Specht, D. T. Walters, A. Weiss, and A. Dobermann. 2008. Nitrogen uptake, fixation and response to fertilizer N in soybeans: a review. *Field Crops Research* 108 (1):1–13. doi: 10.1016/j.fcr.2008.03.001.

Sanni, K. O., and J. M. Adesina. 2012. Response of water hyacinth manure on growth attributes and yield of Celosia argentea L (Lagos Spinach). *Journal of Agricultural Technology* 8 (3):1109–18.

SAS. 2003. *SAS/Stat user's guide: Version 9.1.3*. Cary, NC: SAS Institute.

Seck, P. A., A. A. Touré, J. Y. Coulibaly, A. Diagne, and M. C. S. Wopereis. 2013. Africa's rice economy before and after the 2008 rice crisis. *Realizing Africa's rice promise*. Oxfordshire and Boston: CAB International. 2:24–34.

Shamseldin, A. 2007. Use of DNA marker to select well-adapted Phaseolus-symbionts strains under acid conditions and high temperature. *Biotechnology Letters* 29 (1):37–44. https://doi.org/10.1007/s10529-006-9200-x.

Tumuhairwe, J. B., J. S. Tenywa, E. Otabbong, and S. Ledin. 2009. Comparison of four low-technology composting methods for market crop wastes. *Waste Management* 29 (8):2274–81. https://doi.org/10.1016/j.wasman.2009.03.015.

Turuko, M., and A. Mohammed. 2014. Effect of different phosphorus fertilizer rates on growth, dry matter yield and yield components of common bean (Phaseolus vulgaris L.). *World Journal of Agricultural Research* 2 (3):88–92. https://doi.org/10.12691/wjar-2-3-1.

Vance, C. P. 2001. Symbiotic nitrogen fixation and phosphorus acquisition. Plant nutrition in a world of declining renewable resources. *Plant physiology* 127 (2):390–97. https://doi.org/10.1104/pp.010331.

Wadhwa, M., and M. P. S. Bakshi. 2013. *Utilization of fruit and vegetable wastes as livestock feed and as substrates for generation of other value-added products*, 4 (30). Cotonou, Benin: RAP Publication.

Zatylny, A. M., and R. G. St-Pierre. 2006. Nitrogen uptake, leaf nitrogen concentration, and growth of saskatoons in response to soil nitrogen fertility. *Journal of plant nutrition* 29 (2):209–18. https://doi.org/10.1080/01904160500468738.