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Effect of Sheep Manure and Phosphorus Fertiliser on Productivity of Snap Bean (*Phaseolus vulgaris* L.) in Northern Rwanda

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Authors' contributions

This work was carried out in collaboration between all authors. Author CB designed the study, wrote the protocol and performed the statistical analysis. Authors BU and DU collected the data and wrote the first draft of the manuscript. Authors FN and AK contributed in statistical and profitability analyses and managed the literature search. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Snap bean (*Phaseolus vulgaris* L.) productivity is low in Rwanda. Investigations were carried out to assess the productivity of Snap bean using pot experiments.
Methodology: The experiment was laid out in a completely randomized design with seven (7) treatments: Compost (T0), Cow manure (T1), Sheep manure (T2), Compost with diammonium phosphate (DAP), DAP alone (T3), Cow manure with DAP (T4), Sheep manure with DAP (T5) and control (T6) on Andisol and Oxisol replicated three (3) times.
Results: The results showed that the pod yield was the highest in Andisol (2.39 tha^{-1}) and the application of sheep manure significantly (P<.001) increased the leaf area, the number of leaves (P = .01) and the plant height (P= .01). The number of pods, the pod weight and the total pod

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yield were also significantly (P<.001) different between the fertilizer treatments and the soil types. Treatments with DAP (T3, T4 and T5) showed better development of the leaf area (231.50 cm^2, 221.30 cm^2 and 231.80 cm^2 respectively), increased the number of leaves (9.67, 9.83 and 10.17 per plant respectively), the plant height (270.80 cm, 266.70 cm and 271.70 cm respectively), the number of pods (11.17, 11.33 and 13.33 per plant), the pod weight (10.68, 10.98 and 12.11 g $plant^{-1}$) and the total pod yield (2.44 tha^{-1}, 2.51 tha^{-1} and 3.31 tha^{-1} respectively). Agronomic efficiency (AE) was the highest in Andisol (5.17 kg of snap bean pod yield per kg nitrogen applied) and in pots that received sheep manure combined with DAP (6.52 kg of snap bean pod yield per kg nitrogen applied).

Conclusion: Use of sheep manure and DAP could be a potential option for fertilisation of snap bean in Northern Rwanda.

Keywords: Snap bean; organic fertiliser; soil fertility management; andisol; oxisol.

1. INTRODUCTION

The Rwandan agriculture continues to be characterised by very low levels of input use compared to the required standards, especially mineral fertilisers. The national rate of fertiliser use per cultivated hectare stands in the neighbourhood of 4 kg/ha, far below the average of 9 to 11 kg/ha for sub-Saharan Africa. The type and quantity of fertiliser applied depend on recommendations formulated based on the quality of the soil and crop requirements. Some soils may be more responsive than others and crops require some specific quantities of micro and macronutrients.

The snap bean is grown as cash crop beside other crops such as Irish potato, bush beans and maize. Growers hold small pieces of land of about 0.3 to 0.5 ha and mostly apply compost made of kitchen and agricultural waste and a small number of them use cow or goat manure. The crop is largely cultivated in Northern Province [1], but the production is still at a low scale [2]. Snap bean yields are below potential due to limited soil fertility [3] and inadequate use of fertiliser [4]. Snap beans are grown in a range of soil types, including Andisol in Northern Province and Oxisol in south and western province of Rwanda [3]. Andisols are rich in soil nutrients; however, they form strong complexes with phosphorus and when poorly managed, phosphorus can be limited [5]. Oxisols are poor in soil nutrients in general and heavily deficient in lime, magnesia, phosphates, nitrogen, and potash [5].

Beans are grown by smallholder farmers using organic fertilisers. The required quantity of organic fertilisers is still huge and it is challenging to rely on one source of this resource. Use of farmyard/compost alone on snap bean production will not lead to sustainable snap bean production for smallholder farmers in Rwanda due to its limited availability [6]. The alternative is to use/combine several sources of fertiliser resources. Numerous studies have been conducted under tropical context, advocating for combining mineral and organic fertilisers to improve soil fertility. Smallholder farmers use farmyard manures mainly on maize, common beans and sweet potato [7]. The application of organic manures not only produces the highest and sustainable crop yield, but also improves the soil fertility and productivity [8,9]. It has been shown that long-term use of farmyard manure along with chemical fertilisers results in yield improvement and maintenance of soil fertility [10].

The assessment of fertiliser uptake by plants may be via quantifying crop yield but also via estimating the nutrient use efficiency. Nutrient Use Efficiency (NUE)' indices serve to evaluate crop production systems. Strong response to fertilisers is directly linked to the ability of crops to utilise applied nutrients and producing a larger biomass or economic agricultural products per unit of fertilisers applied. Therefore, the amount of nutrients taken up by plants is an important indicator of the level of efficiency at which nutrients are utilised [11].

This study was designed to test the effects of different organic fertilisers combined with the mineral fertiliser diammonium phosphate (DAP) on productivity of snap beans in two different soil types. Specifically, the study aims at (i) evaluating the application of different organic fertilisers (compost, cow manure and sheep manure) combined or not with DAP on growth and yield of snap beans in Andisol and Oxisol and (ii) determining fertiliser use efficiency by snap beans in Andisol and Oxisol in the Northern Province of Rwanda.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted during the 2016A cropping season in Musanze district, Northern Province of Rwanda. This region (1.50°S, 29.63°E) is located at 2,200 m above sea level and is characterised by annual average temperature of 12.2 to 21.5°C and annual average precipitation of 1,800 mm [12].

2.2 Methodology

2.2.1 Experimental setting

A pot experiment was conducted using BB 2209 variety of snap beans, the most used in the region. Pots used had 16 cm of diameter and 14.5 cm depth with 0.003 m^3 of volume. Different organic fertilisers alone or combined with DAP were compared including compost (made of agricultural and kitchen waste) (T0), cow manure (T1), sheep manure (T2), Compost with DAP (T3), Cow manure with DAP (T4), Sheep manure with DAP (T5) and the control with no fertiliser applied (T6). DAP was included to provide P to beans, since the sheep manure mainly provides N. The experiment was laid out in a randomised complete block design (RCBD) with 7 treatments replicated three (3) times. Fertilisers were applied at planting. Farmers' rates were used to replicate farmers' practices and therefore the same amount was systematically applied for different organic fertilisers (compost/manure). Each pot contained 3 kg of soil, combined with 100 g of compost, 100 g of cow manure, 100 g of sheep manure, and 0.5 g of DAP with respect to the specified treatment (Table 1).

Before the experiments were conducted, soil samples and fertilisers were analysed for their nutrient contents. These were air-dried in the laboratory, crushed and ground, sieved using a 2 mm sieve and analysed for pH, N, P, K and organic carbon following standard methods. The pH was determined on a 1:2.5 soil/fertiliser: H_2O suspension with a glass electrode pH meter. Organic carbon was determined calorimetrically after oxidation with sulphuric acid and potassium dichromate mixture at 150°C for 30 min following the wet oxidation method. Total nitrogen was determined using Kjeldahl digestion method. Available phosphorus was determined using $Bray^{-1}$method. K was analysed with Atomic Absorption Spectrophotometer, AAS [14].

Three snap bean seeds were sown in each pot. All treatments were consistently and similarly watered. The crop was kept free of weeds by hand picking every week after emergence. The thinning was done two weeks after sowing to remain with 2 seedlings per pot. The amount of fertiliser was calculated and measured accurately using an analytical balance. Harvesting started 2 months after planting and pods were picked as they reached maturity (8 to 10 cm long, ½ inches thick).

2.2.2 Data collection

The vegetative growth was evaluated on plant height, number of leaves and leaf area at 50% flowering. The green pod yield was assessed on the number of pods per plant, pod weight and yield per hectare at harvesting. Plant height measurement was assessed using a tape meter, from the bottom to the top of the plant. The number of leaves was counted from the bottom to the top of the plant. The yield was obtained by weighing pods per pot and expressed in $kgha^{-1}$.

2.2.3 Data analysis

Data collected was analysed using Genstats [15] to test the differences between means. Mean separation was done using Least Significant Differences (LSD) at $p<0.05$.

Table 1. Description of different fertiliser treatments tested in greenhouse experiment

Treatment	Fertiliser	Quantity per ha
T0	Compost	**10 t ha^{-1}
T1	Cow manure	10 t ha^{-1}
T2	Sheep manure	10 t ha^{-1}
T3	Compost + DAP	10 t ha^{-1}+*30 kg ha^{-1}
T4	Cow manure +DAP	10 t ha-^{1}+30 kg ha^{-1}
T5	Sheep manure +DAP	10 t ha^{-1}+30 kg ha^{-1}
T6	Control (With no fertiliser)	0kg ha^{-1}

***Source: Rates set based on the recommendations by Kelly et al. [13]*

Nutrient use efficiency was estimated using agronomic use efficiency (AE) expressed in kg of pods produced per kg of nutrient applied using the following formula:

$$AE = Y_F – Y_0 / F_{app},$$

Where

Y_F and Y_0 refer to bean pod yield in the treatment where nutrients were applied and in the control pots respectively

F_{app} is the amount of fertiliser and/or nutrients applied [16].

3. RESULTS

3.1 Chemical Properties of Soils and Fertilisers

The results for the soil and fertiliser analysis are reported in Table 2. The pH was not significant (*P*=0.099) between soil types. Soil organic C (*P*=0.021) and organic matter (*P*=0.013) were significant and greater in Andisol than in Oxisol. Total N content was the highest in Andisol. The same trend was observed for the Available P (*P*<0.001). Potassium was also significantly higher in Andisol than in Oxisol (*P*<0.001). Soil organic C, organic matter, total N and total P were significantly different (*P*<0.001*)* among fertiliser types. Soil organic C, organic matter and total nitrogen content were greater in sheep manure and were the lowest in the compost. Total phosphorous content was higher in sheep manure followed by compost and was the lowest in cow manure. Total potassium content was significantly different (*P*=0.009) among fertiliser types and the highest level was recorded in cow manure.

3.2 Snap Bean Growth Influenced by Soil and Fertiliser Types

Plants were significantly taller (*P*<0.001) in the Andisol than in the Oxisol, averaging 282.4 cm and 224.5 cm respectively. Fertiliser application increased significantly (*P*=0.011) the plant height by 15% compared to the non-fertilised treatment (control). The number of leaves per plant was similar among soil types. Significant differences (*P*=0.009) were observed among fertiliser treatments where treatments T5, T4, T3 and T2 recorded a greater number of leaves followed by treatments T1 and T0 (with 8 and 7 leaves per plant respectively). The control treatment recorded significantly lower plant leaves with the mean of 6 leaves per plant (Table 3).

Leaf area differed significantly (*P*=0.003) between soil types. Means were 208.8 cm^2 for Andisol and 161.8 cm^2 for Oxisol. Similarly, significant differences (*P*<0.001) were observed among fertiliser treatments: treatments T5 and T3 recorded a significantly greater number of leaves with means of 231.8 and 231.5 cm^2 respectively followed by treatments T4, T2, T0 and T1 with 21.3 cm^2, 204.4 cm^2, 163.1 cm^2 and 157.1 cm^2 respectively. The control treatment (T6) recorded the lowest leaf area (87.8 cm^2).

3.3 Snap Bean Pod Yield Influenced by Soil and Fertiliser Types

The results on crop yields are reported in Table 4. The average number of pods per plant, pod weight and pod yield were significantly (*P*<0.001) influenced by soil type and fertiliser. Treatments T5 (sheep manure with DAP) and T4 (cow manure with DAP) had higher pod number and pod weight, followed by treatments T3 (compost with DAP), T2 (sheep manure), T1 (cow manure), T0 (compost) and finally treatment T6 (control) which gave the lowest number of pods and pod weight. Total pod yield showed significant differences between fertiliser treatments and soil types. Andisol gave greater pod yield with averages of 2.39 t ha^{-1} and 1.42 t ha^{-1} respectively. Treatments T5 (sheep manure with DAP), T4 (cow manure with DAP) and T3 (compost with DAP) recorded significantly higher pod yield of 3.30, 2.50 and 2.42 t ha^{-1} followed by treatments T2 (sheep manure), T1 (cow manure) and T0 (compost) with averages of 1.77 t ha^{-1}, 1.34 t ha^{-1} and 1.19 t ha^{-1} respectively. Treatment T6 gave the lowest pod yield with an average of 0.82 t ha^{-1}. Interaction between soil type and fertiliser type was significant for the number of pods per plant and the total pod yield but not for the pod weight. Significant interaction effects were due to the magnitude of differences between treatments under different soil types. The expression of different treatments was more pronounced under Andisol than under Oxisol. For instance, treatments T3, T4 and T5 had greater effects on the number of pods per plant than treatment T0 (Compost) in Andisol but this was not the case in Oxisols. Similarly, treatment T3 had a significant effect on the total pod yield compared with the compost (T0) in Andisol but this was not materialised in Oxisols.

Table 2. Chemical properties of soils and fertilizers used in the study

Factor	pH (H_2O)	Total N (g kg^{-1})	Extractable P (mgkg^{-1})	K (cmol(+)/kg)	Org. C (%)	Org Matter (%)
Soil type						
Andisol	6.02	4.9	32.61	0.79	2.55	4.60
Oxisol	5.15	1.7	8.47	0.25	1.16	2.01
Fertiliser type						
Compost	9.95	2.59	0.03	0.03	15.75	27.26
Cow manure	9.19	3.21	0.01	0.04	18.21	31.39
Sheep manure	9.15	3.79	0.06	0.03	26.86	46.35
P soil type	NS	0.018	<0.001	<0.001	0.021	0.013
P fertiliser type	<0.001	<0.001	<0.001	0.009	<0.001	<0.001
LSD soil type	0.27	0.018	0.006	0.002	0.090	0.11
LSD fertiliser type	0.014	0.016	0.002	0.002	0.090	0.082

LSD: Least Significant difference, P: Probability level and NS: Not significant at P= 0.05

Table 3. Plant height, number of leaves per plant and leaf area in greenhouse experiment with Andisol, Oxisol and with different fertiliser treatments

Factors and treatments	Plant height (cm)	Number of leaves/plant	Leaf area (cm^2)
Soil types			
Andisol (S1)	282.40	9.05	208.80
Oxisol (S2)	224.50	8.81	161.80
Fertiliser types			
Compost (T0)	250.80	8.50	163.10
Cow manure (T1)	260.80	8.50	157.10
Sheep manure (T2)	258.30	9.00	204.40
Compost + DAP (T3)	270.80	9.67	231.50
Cow manure + DAP (T4)	266.70	9.83	221.30
Sheep manure + DAP (T5)	271.70	10.17	231.80
No fertiliser or control (T6)	195.00	6.83	87.80
P soil type	<.001	NS	0.003
P fertiliser type	0.011	0.009	<.001
LSD soil type	21.66	0.9	28.92
LSD fertiliser type	40.52	1.68	54.10

*LSD: Least Significant difference, P: Probability level and NS: Not significant at P=0.05.*Interaction between factors were not significant at P=0.05*

3.4 Snap Bean Agronomic Use Efficiency

Agronomic nitrogen (N) use efficiency (AE) indices are highlighted in Table 5. AE was significantly different ($P<0.001$) across soil and fertiliser types. Agronomic nitrogen use efficiency was the highest in Andisol (5.17 kg snap bean pod yield per kg of fertiliser) than in Oxisol (2.61 kg snap bean pod yield per kg fertiliser applied). Treatments T5 (sheep manure with DAP), T4 (cow manure with DAP) and T3 (compost with DAP) recorded significantly higher AE of 6.52, 6.07 and 5.18 kg snap bean pod yield per kg fertiliser applied respectively. These were followed by treatments T2 (sheep manure), T1 (cow manure) and T0 (compost) with the averages of 2.48, 1.66 and 1.44 kg snap bean pod yield per kg fertiliser applied respectively.

4. DISCUSSION

The results of the study indicated that snap yield is significantly influenced by the conditions in which the crop is cultivated. The type of soil is a determinant factor of the crop productivity. Snap bean performed better in Andisols than in Oxisols due to the greater availability of nutrients and better use of nutrient resources (Tables 2 and 5); resulting in better growth and development. Greater crop productivity in Andisols is reflected by the results on soil analysis (Table 2). Horneck et al. [17] reported that Andisols are slightly acid with high nitrogen, moderate phosphorous, high potassium and organic carbon as compared with Oxisols which are naturally fairly acid with moderate nitrogen, low phosphorous, low potassium and moderate organic carbon.

Table 4. Average number of pods per plant, pod weight and snap bean pod yield kg.ha^{-1} with fertiliser treatments under different soil types in greenhouse experiment

Factors and treatments	Number of pods plant^{-1}	Pod weight (g plant^{-1})	Total pod yield (kgha^{-1})
Soil types			
Andisol (S1)	10.81	10.56	2394.2
Oxisol (S2)	7.19	9.71	1427.3
Fertiliser types			
Compost (T0)	6.50	9.13	1191.8
Cow manure (T1)	7.00	9.65	1346
Sheep manure (T2)	8.83	9.99	1777.9
Compost + DAP (T3)	11.17	10.68	2424.2
Cow manure + DAP (T4)	11.33	10.98	2506.7
Sheep manure + DAP (T5)	13.33	12.11	3308.9
No fertiliser or control (T6)	4.83	8.42	820
Soil types * Fertiliser type			
S1*T0	7.00	9.56	1338.9
S1*T1	7.33	9.60	1394.7
S1*T2	10.33	10.61	2180.4
S1*T3	14.00	11.36	3191.7
S1*T4	14.33	11.13	3208
S1*T5	17.33	12.98	4512.5
S1*T6	5.33	8.67	933.3
S2*T0	6.00	8.70	1044.7
S2*T1	6.67	9.70	1297.3
S2*T2	7.33	9.37	1375.3
S2*T3	8.33	10.00	1656.7
S2*T4	8.33	10.83	1805.3
S2*T5	9.33	11.23	2105.3
S2*T6	4.33	8.17	706.7
P soil type	<0.001	<0.001	<0.001
P fertiliser type	<0.001	<0.001	<0.001
P soil type * fertiliser type	<0.001	NS	<0.001
LSD soil type	0.90	0.42	255.62
LSD fertiliser type	1,68	0.80	478.22
LSD soil type * fertiliser type	2.36	1.12	676.3

LSD: Least Significant difference, S1: Andisol, S2: Oxisol, T0: compost, T1: cow manure, T2: sheep manure, T3: compost with DAP, T4: cow manure with DAP, T5: sheep manure with DAP, T6: control without any fertiliser application, P: probability level and NS: Not significant at P=0.05

The increase of snap bean growth and pod yield in treatments T5 (sheep manure with DAP), T4 (cow manure with DAP) and T3 (compost with DAP) (Tables 3 and 4) could certainly be attributed to DAP applied which stimulates mobilisation of phosphorous and increased accumulation of photosynthates in the plant economic part [18]. The improved bean productivity could also due to the contribution of N from the biological nitrogen fixation process that characterises majority of legume species.

Differences in soil type are reflected in crop yield across farms, with an average bean yield of 2.3 tons ha^{-1} obtained on Andisols, significantly higher than 1.4 tons ha^{-1} on Oxisols. Such on-farm variability has been widely studied and appears to be a generalised feature in sub-Saharan Africa [16,19-21]. The differences are partly caused by the initial soil type.

The positive effects of integrating P with organic manure are reported by many authors. Datt et al. [9] found an increase in bean pod yields by 16% over the control (with no fertilisers) as a result of high P content in pods. Arjumand et al. [6] indicated that the application of phosphorous fertiliser on snap bean enhanced the mobilisation of phosphorous and increased the photosynthetic activity which leads to an increase in plant height, number of branches, number of leaves and number of pods per plant as well as pod yield. The low snap bean growth and yield observed in the control treatment was due to nutrient shortage. Similar results were reported by Mostafa and Zohair [22] who observed low number of leaves and branches, leaf area index and pods number per plant, and pods yield in control treatment due to shortage of nutrients [18].

Table 5. Agronomic N use efficiency for different soil types and treatments tested in greenhouse experiment

Factors and treatments	Agronomic N use efficiency (kg bean pods kg N applied^{-1})
Soil type	
Andisol (S1)	5.17
Oxisol (S2)	2.61
Fertiliser type	
Compost (T0)	1.44
Cow manure (T1)	1.66
Sheep manure (T2)	2.48
Compost + DAP (T3)	6.07
Cow manure + DAP (T4)	5.18
Sheep manure + DAP (T5)	6.52
P soil type	<0.001
P fertiliser type	<0.001
P soil type * fertiliser type	*NS*
LSD soil type	0.80
LSD fertiliser type	1.40

LSD: Least Significant difference, S1: Andisol, S2: Oxisol, T0: compost, T1: cow manure, T2: sheep manure, T3: compost with DAP, T4: cow manure with DAP, T5: sheep manure with DAP, T6: control without any fertiliser application, P: Probability level. Interactions between factors were not significant

Agronomic use efficiency by snap bean crop was much better in Andisol than in Oxisol, indicating that nutrients were used in a more efficient way in a more fertile soil than in poor soil (Table 5). The same trend was noticed in a recent study in Rwanda [4]. The authors reported that beans grown on a fairly fertile soil with substantial amount of nutrients were showing greater N use efficiency indices, implying the importance of soil fertility level in improving the efficiency with which beans are utilizing available nutrient resources. Fertiliser application is essential for growth, development and productivity of snap bean plants as this crop requires high amounts of nutrients like nitrogen and phosphorus [22,23]. With application of adequate amount of fertilisers, farmers can produce more snap beans of better quality, especially in areas with poor soil fertility [3]. The calculation of nutrient use indices may assist in determining the correct amount of nutrients needed. Such approach may be of importance in determining fertiliser recommendations for the specific area. In Rwanda, fertiliser application is based on blanket recommendations for crops such as beans and farmers still apply the same fertiliser rate all over the country, despite the differences in soils and farmer land management strategies. Knowledge of site-specific fertiliser recommendations for snap bean can potentially help in determining the exact amount of fertilisers required by the crop and avoid applying unnecessary extra fertilisers and possibly realize savings on fertiliser use.

The current results were obtained from a greenhouse experiment with the intention of keeping other variables stable and to allow accurate assessment of the effects of different applied fertilisers. Though much variation may be expected under farmer fields, the trend of the results indicates the potential of sheep manure in raising snap bean productivity in the area. In this smallholder context, farmers rely more on local resources and take the advantages of crop-livestock integration. The presence of a large number of sheep in the area and the relatively higher level of nutrients of sheep manure make it an interesting soil fertility management option for farmers with limited resources.

5. CONCLUSION

Soil and fertiliser types had significant influence on the growth and yield of snap beans. Snap pod yield was greater in Andisol than in Oxisol and sheep manure combined with DAP resulted in better performance compared to other fertiliser treatments. Agronomic nitrogen use efficiency was the highest in Andisol with 5.17 kg bean pods per kg N applied and with the sheep manure combined with DAP (6.52 kg bean pods per kg N applied), indicating that both soil and fertiliser types may influence nutrient uptake. As snap beans are grown on different types of soils, the NUE approach may be of importance in determining the potential of snap bean to respond to different types of soils.

The combination of sheep manure and DAP showed the potential to increase the productivity of snap bean. Farmers with limited resources could take advantage of beneficial effects of sheep manure combined with limited amount of P fertiliser to improve the soil fertility level of their fields. Sheep is an important livestock in the

Northern Province of Rwanda and its manure is available in relatively large quantities. The availability of such a soil nutrient supplying source may constitute an advantage for bean growers in highland areas of the region where beans are an important staple food crop.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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