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Exploring on-farm additive common bean yield potential to organic and mineral fertilizers on contrasting soils of Buganda Catena, Central Uganda

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Mineral and organic fertilizers have great potential to enhance crop yields in low fertility soils of the Buganda catena. However, the need for site-specific knowledge on use and yield of the two fertilizer types in a complex soil scape is acute among smallholder farmers exploiting any soil differences. This study evaluated on-farm grain yield response of common bean (*Phaseolus vulgaris* L.) to organic and mineral N and P fertilizers on three soils. Treatments included poultry manure at 0, 2.5 and 5.0 t ha^{-1}, and N and P each at 0, 7.5, and 15 kg ha^{-1} in a complete factorial for two rainy seasons on each of the local farmers' soils classified as Phaeozem, Cambisol, and Umbrisol. Fertilizer application resulted in 20, 25 and 36% maxima grain yield increase relative to soils (Phaeozem, Cambisol and Umbrisol soil, respectively) potentials when no nutrient inputs is applied. Mineral fertilizers applied separately reduced yield on the Cambisol while on Umbrisol soil, there was no particular increase; hence these were risky applications on highly degraded soils. Yield increases were greater with manure, with or without mineral fertilizers, but yield increase was not particularly fundamental on Phaeozem sites but was on Cambisol and marginal on the Umbrisol, resulting into positive and negative interaction effects, respectively. Thus, soil specific rates of manure nutrient ratios or with N and P mineral fertilizers are an effective strategy for targeting improved common bean yield under indigenous soil taxonomy of Buganda catena soils.

Key words: *Phaseolus vulgaris* L, integrated soil fertility management, smallholder farming, soil type.

INTRODUCTION

Common beans (*Phaseolus vulgaris* L.) are vital for nutrition security and considered a cost-effective option

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for improving the diets of low-income consumers in developing countries. Annual per capita bean consumption in Uganda is second worldwide after Rwanda and is about 9.8 kg, contributing 12 and 4% of the total protein and calorie requirements, respectively, per person (Larochelle et al., 2016). Besides food security, nutrition and health sustainable development goals (Larochelle et al., 2016), common beans contribute to biological nitrogen fixation (BNF) (Kabahuma, 2013; Gunnabo et al., 2019) and poverty reduction among small landholders who grow them for market. However, production of common beans is below the average potential of 2000 kg ha^{-1} (Goettsch et al., 2016). Low bean productivity emanates among others from inherently low soil fertility coupled with low and poor use of land productivity enhancing inputs (Larochelle et al., 2016).

Soil use and management is a major determinant of the food self-sufficiency and income of smallholder farmers in sub-Saharan Africa (SSA). Improving productivity of poorly fertile soils in farming system remains a major concern. With increasing land pressure, complex farming systems and accelerated climate change impacts, Integrated Soil Fertility Management (ISFM) which includes use of both mineral and organic fertilizers, improved seeds and locally adapted practices, is at the forefront for increasing yields. Both organic and mineral fertilizers are comparatively expensive and often inadequate for application in farmers' degraded plots (Mugwe et al., 2009). Degraded soils are often deficient in nitrogen (N), phosphorus (P), and potassium (K) (Stoorvogel and Smaling, 1990; Morris et al., 2007; MAAIF, 2016), and other nutrients resulting in poor crop yields. Yield losses are particularly severe for annual crops (Semalulu et al., 2012; Apanovich and Lenssen, 2018), including common bean (Place et al., 2003; Goettsch et al., 2016, 2017) where N and P defficiencies limit production (Wortmann et al., 1998; Kyomuhendo et al., 2018).

Improving productivity through soil fertility management is largely by use of inorganic fertilizers. Mueller et al. (2012) closed the yield gap by 73% using considerable amounts of N, P_2O_5 and K_2O fertilizers. However, the rate of nutrient application in SSA is about 10 kg total nutrients ha^{-1} (Fairhurst et al., 2012), an inadequate amount for degraded soils. In Uganda, fertilizer use is estimated to supply about 1.0 kg of nutrients ha^{-1} (Morris et al., 2007; MAAIF, 2016). This is because few fertilizers are imported and the majority of smallholder farmers lack the financial resources to purchase them. Using more available organic fertilizers was found to be economically attractive to farmers (Sanchez, 1997) but is challenged by unbalanced nutrient supply to crops (Sileshi et al., 2016). This may deplete other nutrients and reduce fertilizer efficiency over time. Therefore, providing fertilizers in a balanced nutrient management program may improve crop productivity and smallholder farmer buy-in.

Combined application of organic with mineral nutrient sources has been a good option to increase fertilizer use, efficiency and productivity. Combined applications can improve synchronization of nutrient availability and subsequent uptake by the crop (Ayuke et al., 2004), especially when the levels applied are low (Kapkiyai et al., 1999). Some studies reported greater yield increase than when either fertilizer type was applied alone at a nutrient rate equivalent to the combination (Chivenge et al., 2009; Bekunda et al., 2010; Pincus et al., 2016). Muyayabantu et al. (2012) reported greater maize (*Zea mays* L) yield with increasing rates of farmyard manure application. However, grain yields above 3.5 t ha^{-1} were only obtained when both farmyard manure and inorganic N and P fertilizers were applied. In contrast, some studies indicate higher yield with sole organic than inorganic and combinations of inorganic and manure (Mucheru-Muna et al., 2013). These differences in response to fertilizer combinations may result from many factors including genotype and large heterogeneity in local soil fertility. Thus, farmer buy-in of fertilizer packages may also require understanding relative grain yield based on genotypic potential under diverse environments and soil management levels.

Although many studies continue reporting different productivity from combined fertilizer use, adaptations to highly variable biophysical and agro ecological conditions receive limited attention. Soils vary in their responsiveness to fertilizers with farmers expecting positive returns from try-outs for continued use. For example, Bagula et al. (2014) reported yield differences from 52 and 190% observed among soils and fertilizer treatments. Reducing this variability require understanding the added yield benefits from fertilizer combination relative to a crop potential on a given soil. This enables farmers to make adoptive fertilizer use decisions based on yield targets, resource availability and risk aversion (Lambrecht et al., 2014). Understanding specific fertilizer options for each soil would therefore reduce the observed yield variability while increasing beneficial returns from organic and mineral fertilizer use. This in turn saves on fertilizer use and affects efficiency and technology uptake. Improved yield with reduced variability further leads to stable food supply and farmer income (Ray et al., 2015). Therefore, the objective of this study was to determine the on-farm additive effect of organic and mineral fertilizers for common bean grain (*P. vulgaris* L.) yield on contrasting soils.

MATERIALS AND METHODS

Study area

On-farm demonstration trials were conducted in Masaka district, south central Uganda, in the tropical wet and dry or savanna

Table 1. Means for selected properties of the three farmer defined soil types.

Property	Phaeozem	Cambisol	Umbrisol	F-test	Critical values
pH	6.4±0.2	5.2±0.08	5.5±0.3	0.003	5.5#
SOC (%)	2.7±0.4	2.5±0.1	2.4±0.2	0.598	3.0#
N (%)	0.203±0.004	0.175±0.001	0.196±0.002	0.001	0.250*
P (mg/kg)	14.3±2.6	4.2±0.6	12.6±3.4	0.016	15.0*
K (cmol(+)/kg	0.49±0.15	0.14±0.02	0.45±0.01	0.051	0.15*
Ca (cmol(+)/kg	2.41±0.37	0.86±0.13	1.01±0.27	0.002	4.50#
Mg (cmol(+)/kg	1.74±0.03	0.8±0.20	1.06±0.23	0.009	2.00#
Sand (%)	56.0±2.4	53±1.9	56.5±3.2	0.497	-
Clay (%)	31.8±2.5	39±1.9	35.5±3.2	0.121	-
Silt (%)	12.3±0.63	8.0±0.0	8.0±0.0	0.001	-

Significant effect ($P < 0.05$).
Source: *Schwartz and Pastor-Corrales (1989) and #Okalebo et al. (2002).

Table 2. Chemical characteristics of applied chicken manure on dry matter basis.

Parameter	pH	OM (%)	N (%)	P (%)	Ca (%)	Mg (%)	K (%)
Chicken manure	7.2	22.4	1.43	0.10	0.26	0.07	0.02

climate. In this region, agriculture is rain-fed with average annual precipitation of about 1350 mm in a bi-modal distribution. The main rainy seasons are the months of March-May (Season A) and August-November (season B). Annual mean temperature varies between 16 and 27°C with an average of about 21°C. Temperature, humidity and wind patterns display relatively small variations throughout the year in Lake Victoria crescent zone where Masaka is located. Farmers in this area distinguish three local soil types commonly cropped to beans by color and stoniness: *Liddugavu* (black) soil ‘more fertile’, *Luyinjayinaja* (gravelly) soils ‘moderately fertile’ and *Limyufumyufu* (red) soils ‘least fertile’ (Goettsch et al., 2016, 2017; Apanovich and Lenssen, 2018; Kyebogola et al., 2020). These black, gravelly and red soils are classified as Phaeozem, Umbrisol and Cambisol, respectively, along the landscape (Kyebogola et al., 2020) from which the sites for experimentation were selected. Agriculture in this area is characterized by smallholder mixed farming activities with cash crops, food crops, forestry and livestock. The dominant crops are coffee (*Coffea arabica* L.), banana (*Musa* species), maize and beans. Poultry, cattle, goats and pigs are the main livestock from which farmers obtain manure to fertilize their crops. However, a few farmers benefit from compost heaps from plant and animal waste as fertilizers. Depending on the season, farmers plant common beans once or twice per annum either as a mono crop or intercrop depending on the purpose. However, beans are mainly cultivated for food consumption during ‘A’ season with a few farmers cultivating for commercial purposes in ‘B’ season. In both seasons, either mineral or organic fertilizer, mainly chicken manure, may be applied, but rarely is this done by smallholders. Mineral fertilizers, also referred to as inorganic fertilizers, are rarely applied to beans, but a few farmers spray urea solution to young growing bean plants. Other mineral fertilizers like diammonium phosphate (DAP) and organic fertilizers are targeted to companion maize plants at planting from which intercropped beans may benefit.

Soil sampling and analysis

Immediately after site identification, but before land preparation, soil samples were collected from 0 to 15-cm depth using an auger to evaluate soil chemical and physical characteristics. The collected soil samples were taken in a zigzag pattern from five different places in each field and composited into one sample. Soils were analyzed at the National Agricultural Research Laboratories, Kawanda, Uganda for pH, organic carbon (OC), N, P, K, calcium (Ca) and magnesium (Mg) using standard methods described in Okalebo et al. (2002) and results presented (Table 1). The wet oxidation method of Walkley and Black (Nelson and Sommers, 1982) was used for soil organic carbon determination. Total soil N was measured following Kjeldahl digestion (Okalebo et al., 2002). Available P was determined using Mehlich 3 solution (Mehlich, 1984). For each season, a composite manure sample was analyzed at Kawanda for moisture concentration, pH, OC, N, and Mehlich 3 extractable P, K, Ca and Mg. The obtained manure nutrient concentrations are presented in Table 2.

On-farm trials

On-farm trials were carried out during the first and second rain of 2015 (seasons 2015A and B), on each of the three soils. In each season, experimental locations were changed, but all were previously cultivated to maize a season before set up. All three soils were deficient in N and P (Table 1). Soil pH was low for Cambisol and Umbrisol soils but only slightly acidic for Phaeozem soil. These soils exhibited low OC concentration that was below preferred levels (Table 1). The Phaeozem and Umbrisol site had comparatively high available K, but Ca and Mg were low on all soils (Table 1). Prior to initiating any treatments, each site was ploughed twice using a heavy hand hoe. At the onset of rains, experiments

Table 3. Effect of manure application on bean yield (kg ha^{-1}) on three soil types.

Manure (t ha^{-1})	Phaeozem	Cambisol	Umbrisol
0.0	1836	1370	1824
2.5	2063	1609	1975
5.0	2099	1719	2040
P≤F	0.006	<0.001	0.018
LSD (0.05)	169	170	151

were laid out in a randomized complete block design (RCBD) in a factorial arrangement of mineral N and P fertilizer and manure application on each of the three soils. There were three replications of each treatment at each site in each season. The N and P fertilizer rates were 0.0, 7.5, and 15.0 kg N and P ha^{-1} each. The N was applied as urea and P as triple super phosphate (TSP). Composted poultry manure (layer chickens) (Table 2) was obtained from a local farmer in A and B seasons and applied at 0.0, 2.5, and 5.0 t ha^{-1}. Both mineral and organic fertilizers were basal broadcasted in appropriate plots then incorporated into soil using a hand hoe. At a spacing of 50 cm between rows and 15 cm within rows, two seeds of K131 common bean (Nkonya, 2001) were planted per hole on 7th April and 15th September for the 2015 A and B seasons, respectively.

Plots were hand-weeded during the second, fourth and sixth week after planting (WAP). Where weeds occurred after the sixth week, they were hand-pulled to preclude confounding weed competition with fertility treatments. Due to high pest prevalence, farmers sprayed the bean plants against aphids, flower thrips and caterpillars using formulated dimethoate on a weekly basis from second WAP up to flowering and twice from pod formation to maturity.

Data collection

Bean plants were hand-harvested at maturity, when all pods were dry. Harvesting started on 27th July 2015 for Phaeozem and 1st August for Cambisol and Umbrisol in Season A. In 2015B season, harvesting was on 19th, 20th, and 21st December for the Phaeozem, Umbrisol and Cambisol sites, respectively. In each plot, the number of plants harvested from the three middle rows for 1.2-m was counted and threshed. The threshed samples were winnowed, sorted for further removal of foreign materials, and grains weighed using ±0.001 kg weighing balance. A sub-sample of 80 g bean grains was oven-dried at 72°C to determine dry matter yield at 12.5% moisture basis.

Statistical analysis

The mean effect of inorganic N, P and chicken manure on bean grain yield was analyzed using a generalized linear model analysis of variance with Genstat 12.1. Yields were averaged across the two seasons. Fertilizer treatments and soils were included in the model as variables and tested for their interactions. Due to differences, soils were analyzed separately for fertilizer application effects on yield. Prior to any statistical analysis, data were tested for normality and homogeneity of variance using Cook's statistics (Payne et al., 2009). Fisher's protected Least Significant Difference (LSD) at 0.05 probability level was used to separate means when significant differences were evident. Using mean yield from fertilizer combinations, relative yield increase (added yield due to fertilizer application) resulting from fertilizer application of planted variety was calculated according to Equation 1:

$$\text{Relative yield } (\%), R = \frac{(\text{Yield in fertilized plot} - \text{Yield in control})\ \text{kg x } 100}{\text{Attainable yield } (2500\ \text{kg})} \quad (1)$$

To test for the result of combining mineral and organic fertilizers, the interaction effects (added yields from combining fertilizer types) on grain yield was determined according to Vanlauwe et al. (2002):

$$\text{Interactive effect} = Y_{comb}\text{-}(Y_{fert} - Y_{con})\text{-}(Y_{OM} - Y_{con}) - Y_{con} \quad (2)$$

where Y_{con}, Y_{fert}, Y_{OM}, and Y_{comb} signify mean grain yields in the control, treatments with sole application of inorganic fertilizer, organic fertilizer, and in the treatment receiving both inorganic and inorganic fertilizers, respectively. In Equation 2, yields are adjusted for similar amounts of organic resources and mineral N and P applied in the combined as in the sole treatments. Sample test was used to determine statistical significance of interactive effects from combining fertilizers. Positive interactive effect signifies the additional yield obtained through the combined application of mineral and organic fertilizers compared with what is obtained when either input is applied on its own at the same total rate in the combined application.

RESULTS

Mineral N, P and organic fertilizers on common bean grain yield and their relative responses

On all the three soils, there were significant ($P<0.05$) yield differences observed with manure application (Table 3). Bean yield was improved over the non-manured controls on all soil types. However, increasing manure application from 2.5 to 5.0 t ha^{-1} did not improve yield. It is noteworthy that common bean had greater yields on Phaeozem and Umbrisol soils compared with Cambisol regardless of manure application.

The greatest relative yield increases on Phaeozem soil occurred when nutrient applications included both mineral N and P fertilizers and manure, particularly when 5 t ha^{-1} manure applications were used with mineral fertilizers (Table 4). On Cambisol soil, application of mineral N and P fertilizers without manure largely did not improve yield (Table 5). The application of manure with mineral N and P resulted in similar relative yield increases as on Phaeozem. The greatest relative (added yield) yield for mineral fertilizers without manure was a 3.4% increase, considerably less than 17.4 and 24.8% found when 2.5 and 5.0 t ha^{-1} manure were included with mineral N and/or P (Table 5). Manure at 5.0 t ha^{-1} increased common bean yield by 11.9% in the absence of mineral fertilizers. On Umbrisol soils, fertilizer application significantly ($p < 0.05$) increased common bean yield (Table 6). Yield response to mineral fertilization N and P addition on Umbrisol was always positive, but not

Table 4. Relative yield change (R) due to fertilizer application on Phaeozem.

N (kg ha^{-1})	P (kg ha^{-1})	Manure (t/ha)					
		0.0		2.5		5.0	
		Grain (kg ha^{-1})	R (kg ha^{-1})	Grain (kg ha^{-1})	R (kg ha^{-1})	Grain (kg ha^{-1})	R (kg ha^{-1})
0	0	1519	-	1800	281 (12.8)	1631	111 (5.1)
	7.5	1584	65 (3.0)*	1589	69 (3.2)	1746	226 (10.3)
	15	1792	273 (12.5)	1849	330 (15.1)	1826	306 (14.0)
7.5	0	1594	74 (3.4)	1859	339 (15.5)	1958	438 (20.0)
	7.5	1621	101 (4.6)	1912	393 (18.0)	1928	408 (18.7)
	15	1593	73 (3.4)	1901	382 (17.5)	1959	439 (20.1)
15	0	1611	92 (4.2)	1738	219 (10.0)	1897	377 (17.3)
	7.5	1603	84 (3.8)	1712	193 (8.8)	1940	421 (19.2)
	15	1540	21 (1.0)	1886	366 (16.7)	1646	126 (5.8)
LSD (0.05)	-	-	-	443	-	-	-

*Figures in parenthesis are relative yield change (%) resulting from fertilizers application.

Table 5. Relative yield change (R) due to fertilizer application on Cambisol soil.

N (kg ha^{-1})	P (kg ha^{-1})	Manure (t ha^{-1})					
		0.0		2.5		5.0	
		Grain (kg ha^{-1})	R (kg ha^{-1})	Grain (kg ha^{-1})	R (kg ha^{-1})	Grain (kg ha^{-1})	R (kg ha^{-1})
0	0	**1228**	-	1319	91 (4.2)	1487	260 (11.9)
	7.5	1101	-126 (-5.8)*	1609	381 (17.4)	1489	261 (12.0)
	15	1080	-148 (-6.8)	1441	213 (9.7)	1581	353 (16.1)
7.5	0	1299	71 (3.3)	1450	223 (10.2)	1605	377 (17.2)
	7.5	1171	-57 (-2.6)	1256	28 (1.3)	1485	258 (11.8)
	15	1303	75 (3.4)	1348	121 (5.5)	1408	180 (8.2)
15	0	1133	-95 (-4.3)	1160	-67 (-3.1)	1770	542 (24.8)
	7.5	1185	-43 (-2.0)	1491	263 (12.0)	1404	176 (8.0)
	15	1284	56 (2.6)	1595	367 (16.8)	1306	79 (3.6)
LSD (0.05)	-	-	-	445	-	-	-

*Figures in parenthesis are relative yield change (%) resulting from fertilizers applications.

particularly consistent. Typically, the larger yield increases occurred only with the inclusion of manure. However, application of 7.5 kg P ha^{-1} or 15 kg N ha^{-1} had large increases in yield despite the absence of manure. Although the generally greater yield increases with combined N and P fertilizer application, the greatest yield increase on Umbrisol soil, 36%, occurred with 5.0 t manure ha^{-1} and no mineral N or P. This added relative yield was 10% greater in comparison to manure applied with N and or P best combinations of (7.5N + 15P) 2.5 and (15N+15P) 5.0 t ha^{-1}.

Interactive effect between mineral N and P and organic fertilizer

Generally, combining chicken manure with mineral N and/or P fertilizers did not necessarily result in larger yield benefits (synergistic effect) than either of mineral and organic fertilizers separately applied at the same

Table 6. Relative yield change (R) due to fertilizer application on Umbrisol soil.

N (kg ha^{-1})	P (kg ha^{-1})	Manure (t ha^{-1})					
		0.0		2.5		5.0	
		Grain (kg ha^{-1})	R (kg ha^{-1})	Grain (kg ha^{-1})	R (kg ha^{-1})	Grain (kg ha^{-1})	R (kg ha^{-1})
0	0	1397	-	1731	334 (15.3)	2183	787 (36.0)
	7.5	1857	461 (21.1)*	1703	306 (14.0)	1758	362 (16.5)
	15	1469	73 (3.3)	1648	251 (11.5)	1760	364 (16.6)
7.5	0	1628	231 (10.6)	1607	210 (9.6)	1669	272 (12.4)
	7.5	1434	37 (1.7)	1715	318 (14.5)	1758	362 (16.5)
	15	1492	95 (4.3)	1950	554 (25.3)	1613	216 (9.9)
15	0	1851	454 (20.8)	1908	511 (23.4)	1570	174 (7.9)
	7.5	1734	337 (15.4)	1720	324 (14.8)	1760	363 (16.6)
	15	1504	107 (4.9)	1574	177 (8.1)	1991	595 (27.2)
LSD (0.05)	-	-	-	396	-	-	-

*Figures in parenthesis are relative yield change (%) resulting from fertilizers applications.

Table 7. Additive (extra) yield benefits from combining organic with mineral N and P fertilizers on three diverse soils.

N (kg ha^{-1})	P (kg ha^{-1})	Phaeozem		Cambisol		Umbrisol	
		2.5 t	5.0 t	2.5 t	5.0 t	2.5 t	5.0 t
0	7.5	-276	51	417	128	-488	-886
	15	-224	-78	270	242	-156	-495
7.5	0	-16	253	60	46	-355	-746
	7.5	11	196	-7	54	-53	-462
	15	28	255	-46	-155	124	-665
15	0	-154	175	-64	378	-277	-1067
	7.5	-172	226	214	-41	-347	-760
	15	65	-5	220	-237	-264	-299
LSD (0.05)		777		715		960	

rate. The interaction effect was mainly positive on Pheozem and Cambisol. On Phaeozem interactive effect was greater with mineral fertilizer combination at 5.0 t than at 2.5 t manure ha^{-1}(Table 7). Adding N increased interactive effect from negative to positive at increasing P rate at the 7.5N. On Cambisol, the interaction effect was mainly positive and higher at 2.5 than 5.0 t manure with mineral fertilizers. On Umbrisol, the interaction effect was only positive (142 kg) for 7.5N +15P at 2.t manure ha^{-1}.

DISCUSSION

Mineral N, P and organic fertilizers on grain yield and relative responses of common beans

Common bean grain yield response to improved mineral and organic fertilizer use is specific to soil types, nutrient limitations and inputs. Manure application significantly increased yield over the control despite of no yield difference between 2.5 and 5.0 t manure ha^{-1}. These yields are less than the yield potential of K131 variety. This could be due to the Leibig’s law of the minimum caused by major nutrients in the applied fertilizer (Table 2). Large amounts of N and P from manure are often in organic forms and poorly available for uptake by young, growing plants when they are most sensitive to deficiencies (Rodriguez and Fraga, 1999; Fageria, 2014), thus, increasing risk when manure is the only applied source of nutrients. In conformity, the rate of yield increase with manure rates was greater on less fertile Cambisol than Phaeozem and Umbrisol soils (Table 3). This is confirmed by Sileshi et al. (2016) who observed low plant available nutrients and use efficiencies due to poor nutrient ratios at high manure rates applied on more fertile soils. Manure recommendations should therefore be based on limiting nutrients, manure nutrient ratios and soil type fertility than rates.

Applying mineral N and P fertilizers improved common bean yields only a nominal amount on Phaeozem and Umbrisol soils, but generally decreased yields on Cambisol soil. Thus a coining by farmers 'mineral fertilizers damage the soil (Vanlauwe and Giller, 2006)' provided individual plot soil measurements' variations are small and apparent with entire site composited sample (Rocha et al., 2017). Mineral fertilizer nutrient uptake in the tropics is highly influenced by SOC. The SOC concentration of these soils (Table 1) is below critical levels even for bean grain yield response to mineral fertilizers (Schwartz and Pastor-Corrales, 1989; Wortmann et al., 1998; Okalebo et al., 2002; Musinguzi et al., 2016) making it risky for application on Cambisols. Goettsch et al. (2016) reported that utilization of mineral fertilizers was economically advantageous on Phaeozem soil. Conversely, Goettsch et al. (2017) reported an economic loss from fertilization of common bean on degraded Cambisol. Thus, the low yield of mineral N and P fertilizers suggests that their use should be specific to soils OC levels.

Furthermore, when mineral N and P applications were combined with manure, common bean yield was always enhanced. Surprisingly, yields at 5.0 t ha^{-1} manure were greater than for mineral or combined fertilizers on Umbrisol as similarly reported by Mucheru-Muna et al. (2013). Combining fertilizers increases manure mineralization, improving nutrient remobilization and release. Manure also contains a large number of elements required for plant growth that are infrequently examined for yield enhancement in sub-Saharan Africa, particularly in common bean production systems. Some of the manure containing nutrients like Ca and Mg are in limestone, a major soil pH resulted in improvement recommendation (Kyomuhendo et al., 2020). However, liming is uneconomical on Cambisol due to the high cost of limestone (Goettsch et al., 2017) even when costs are accounted for over two rainy seasons, despite substantial yield increases. In the present study, bean yields were studied only in the season when fertilizers and manure were added. In acidic soils with substantial concentrations of extractable Fe^{+2} and Al^{+3}, Mehlich-3 extractable P can be rapidly complexed and become unavailable for subsequent crops (Jones, 1998). Thus, residual effects can be substantial for high rates of P and manure application.

The bases in the manure like limestone enhance plant nutrition and productivity by improving many soils properties to release essential nutrients (Oustani et al., 2015). Nutrients in manure have not received adequate research attention in many developing countries to understand well their temporal variability due to the influences of animal type and class, diet and storage conditions (Sileshi et al., 2016). However, chicken production has increased in recent years in several countries including Uganda (UBOS, 2015) and manure is more readily available for purchase than limestone. Still, long-term studies are necessary on degraded Cambisol and Umbrisol soils to better understand the residual and economic impacts of manure and limestone application even on subsequent crop production.

Additional yields due to fertilizers (Tables 4 to 6) require applying organic with N and P inorganic fertilizers with higher beneficial returns. Satyanarayan et al. (2002) observed unenhanced beneficial effects at higher rates of organic with mineral fertilizers. Also higher manure application rates are less accessible or affordable and may discourage usage. Primarily, if benefits are longer term, farmers are likely only to use these inputs on land that they own (Amede and Kirkby, 2004) and forego their use on rented or borrowed lands. Applications of comparatively small amounts of N and P (7.5 to 15 kg ha^{-1}) generally enhanced common bean yield in this study and is a promising method even for smallholder farmers (Goettsch et al., 2016, 2017). From the current study, it appears that combining mineral N and P fertilizers with manure at 7.5 kg N + 15 kg P + 2.5 t manure ha^{-1} on Umbrisol, 7.5 kg N and P ha^{-1} + 2.5 t manure ha^{-1} on Phaeozem and 15 kg N and P ha^{-1} + 2.5 t manure ha^{-1} on Cambisol soil could improve technology buy-in for higher yields. Depending on farmer resources and yield targets, relative yields increases would benefit farmers' decisions based on soil type. Additionally, more studies are necessary on residual effect and to determine economically beneficial fertilizer rates for the shorter-and longer-term.

Interactive yield effect of combined application of organic and mineral N and P fertilizers

Although combining fertilizers resulted in larger yield benefits, positive yield interactions varied among soils (Table 7). Positive interaction is partly attributed to temporary immobilization of nutrients early in the season, so that they are protected from losses for later crop uptake. Affecting immobilization depends upon manure quality and soil characteristics like clay amount (Pincus et al., 2016). Materials like maize stover with moderate organic carbon have always produced positive interactive effect unlike high quality materials most especially for longer duration crops (Chivenge et al., 2009). The high quality manure used for this study would have led to excessive nutrient losses under some fertilizer combinations especially on Umbrisol and Phaeozem containing low clay concentrations. Nutrient fixation on clay surface may reduce further losses hence utilization and positive interactions on Phaeozem at 5.0 t ha^{-1}

manure. Meanwhile, higher clay concentration of Cambisol (Table 1) may have released more of the clay-fixed nutrients, during critical growth stages when BNF is low. Common beans are among the poorest symbiotic N_2 fixing legume (Kabahuma, 2013; Gunnabo et al., 2019) and often cease N_2 fixation during reproductive phases hence utilizing nutrients on the clay surface. Lack of beneficial returns to specific organic and mineral fertilizer combinations may make and encourage sole applications mainly those with positive relative increases (Tables 4 to 6) better options for farmers use. Separate fertilizer application may encourage fertilizer use on a larger area (extensive) as opposed to intensifications of the combination on a plot. Applying combinations with higher yields and some positive additive benefits would reduce risks like those associated with farmers' habitual use of untested fertilizer combinations. Similarly, higher rates, mostly for manure applied with mineral fertilizers may discourage their usage even with positive yield interactions since farmers desire strong benefits of fertilizer integration. Moderate positive interactions may improve farmers' perception on fertilizer integration, and hence adoption. In this respect, Jinwei and Lianren (2011) recommended application of small amount of inorganic fertilizers with organic materials but Tarfa et al. (2017) observed higher profit potential only if a minor amount of manure was added to mineral fertilizer. Therefore, application of above suggested low manure rates with N and P mineral fertilizers with positive interactions can be further field validated to avoid risky options.

Conclusions

Mineral and organic fertilizer use for improved soil fertility management in common bean farming systems should be specific to soil type, nutrient limitations and inputs. Greater bean grain yields were obtained on Phaeozem and Umbrisol soils compared to Cambisol soils. Larger relative yield increases occurred when nutrient applications included both mineral N and P fertilizers and manure particularly when 5 t ha^{-1} manure applications were used with mineral fertilizers on more fertile soils. Application of mineral N and P fertilizers without manure largely decreased yield on Cambisol while on Umbrisol soil the response was always positive, but not particularly consistent and hence a risky intervention on degraded soils. The highest 36% added relative yield increase occurred on Umbrisol soil with the application of 5.0 t manure ha^{-1} and no mineral N or P. However, higher yields from combining mineral N and P fertilizers with chicken manure did not necessarily result into a positive interaction effect. Also, the high quality manure resulted into negative yield interaction under some fertilizer combinations especially on Umbrisol and Phaeozem soils with characteristically lower clay concentrations.

Primarily, any soil specific applications of chicken manure with N and P mineral fertilizers of this study require further field and economic validation so as to avoid risky options.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Amede T, Kirkby R (2004). Guidelines for Integration of Legumes into the Farming Systems of East African Highlands. In. Bationo A (Eds.), Managing Nutrient Cycles to Sustain Soil Fertility in Sub-Saharan Africa. Academy Science Publishers (ASP) in association with the Tropical Soil Biology and Fertility Institute of CIAT Edited by AfNet Coordinator, TSBF-CIAT. pp. 43-64.

Apanovich N, Lenssen AW (2018). Cropping systems and soil quality and fertility in south-central Uganda. African Journal of Agricultural Research 13(5):792-802.

Ayuke FO, Rao MR, Swift MJ, Opondo-Mbai ML, Bationo A (2004). Effect of Organic and Inorganic Nutrient Sources on Soil Mineral Nitrogen and Maize Yields in Western Kenya. In. Bationo A (Eds.), Managing nutrient cycles to sustain soil fertility in Sub-Saharan Africa. Nairobi: African Academy of Sciences and TSBFI, pp. 647-746.

Bagula ME, Pypers P, Mushagalusa NG, Muhigwa JB (2014). Assessment of Fertilizer Use Efficiency of Maize in the Weathered Soils of Walungu District, DR Congo. In. Vanlauwe B, vanAsten P, Blomme G (Eds.), Challenges and Opportunities for Agricultural Intensification of the Humid Highland Systems of Sub-Saharan Africa. Springer Cham Heidelberg New York Dordrecht London, pp. 187-200.

Bekunda M, Sanginga N, Woomer PL (2010). Restoring soil fertility in sub-Saharan Africa. Advances in Agronomy 108:183-236.

Chivenge P, Vanlauwe B, Gentile R, Wangechi H, Mugendi D, Kessel C, Six J (2009). Organic and mineral input management to enhance Crop productivity in Central Kenya. Agronomy Journal 101(5):1266-1275.

Fageria NK (2014). Growth, Nutrient Uptake, and Use Efficiency in Dry Bean in Tropical Upland Soil. Journal of Plant Nutrition 37(13):2085-2093.

Fairhurst T, Bationo A, Giller K, Kelly V, Lunduka R, Mando A, Mapfumo P, Oduor G, Romney D, Vanlauwe B, Wairegi L, Zingore S (2012). Handbook for Integrated Soil Fertility Management. Africa Soil Health Consortium, Nairobi.

Goettsch LH, Lenssen AW, Yost RS, Luvaga ES, Semalulu O, Tenywa M, Miiro R, Mazur RE (2016). Improved production systems for common bean on Phaeozem soil in south-central Uganda. African Journal of Agricultural Research 11(46):4796-4809.

Goettsch LH, Lenssen AW, Yost RS, Luvaga ES, Semalulu O, Tenywa M, Miiro R, Mazur RE (2017). Improved production systems for common bean on Ferralsol soil in south-central Uganda. African Journal of Agricultural Research 12(23):1959-1969.

Gunnabo AH, Geurts R, Wolde-meskel E, Degefu T, Giller KE, van Heerwaarden J (2019). Genetic interaction studies reveal superior performance of Rhizobium tropici CIAT899 on a range of diverse East African common bean (*Phaseolus vulgaris* L.) genotypes. Applied and Environmental Microbiology 85(24):1-19.

Jinwei Z, Lianren Z (2011). Combined application of organic and inorganic fertilizers on black Soil fertility and maize yield. Journal of Northeast Agricultural University 18(2):24-29.

Jones DL (1998). Organic acids in the rhizosphere - a critical review. Plant Soil 205(1):25-44

Kabahuma MK (2013). Enhancing biological nitrogen fixation in common bean (*Phaseolus vulgaris* L). Iowa State University Digital Repository, Graduate Theses and Dissertations. Paper 13162.

Kapkiyai JJ, Karanja NK, Qureshi JN, Smithson PC, Woomer PL (1999). Soil organic matter and nutrient dynamics in a Kenyan nitisol under long-term fertilizer and organic input management. Soil Biology and Biochemistry 31(13):1773-1782.

Kyebogola S, Burras LC, Miller BA, Semalulu O, Yost RS, Tenywa MM, Lenssen AW, Kyomuhendo P, Smith C, Luswata CK, Gilbert MJ, Goettsch L, Pierce CJ, Mazur RE (2020). Comparing Uganda's indigenous soil classification system with World Reference Base and USDA Soil Taxonomy to predict soil productivity. Geoderma Regional 22:e00296.

Kyomuhendo P, Tenywa MM, Semalulu O, Lenssen AW, Yost RS, Mazur RE, Kyebogola S, Goettsch LH (2018). Limiting Nutrients for Bean Production on Contrasting Soil Types of Lake Victoria Crescent of Uganda. African Crop Science Journal 26(4):543-554.

Kyomuhendo P, Tenywa MM, Semalulu O, Lenssen A, Yost R, Mazur R, Kyebogola S (2020). Lime requirements for bean production on two contrasting soils of Lake Victoria Crescent agro-ecological zone. African Journal of Agricultural Research 15(4):531-537.

Lambrecht I, Vanlauwe B, Merckx R, Maertens M (2014). Understanding the Process of Agricultural Technology Adoption: Mineral Fertilizer in Eastern DR Congo. World Development 59:132-146.

Larochelle C, Katungi E, Cheng Z (2016). Household consumption and demand for bean in Uganda : Determinants and implications for nutrition security. Invited paper presented at the 5th International Conference of the African Association of Agricultural Economists, September 23-26, 2016, Addis Ababa, Ethiopia.

Ministry of Agriculture Animal Industry and Fisheries (MAAIF) (2016). National Fertilizer Policy. http://ageconsearch.umnedu/record/257813

Mehlich A (1984). Mehlich III soil test extractant: a modification of the Mehlich II extractant. Communications in Soil Science and Plant Analysis 15:1409-1416.

Morris M Kelly VA, Kopicki RJ, Byerlee D (2007). Fertilizer use in African Agriculture: lessons learned and good practices guideline. World Bank, Washington DC.

Mucheru-Muna M, Mugendi D, Pypers P, Mugwe J, Kung UJ, Vanlauwe B, Merckx R (2013). Enhancing maize productivity and profitability using organic inputs and mineral fertilizer in central Kenya small-holder farms. Experimental Agriculture 50:250-269.

Mueller ND, Gerber JS, Johnston M, Ray DK, Ramankutty N, Foley JA (2012). Closing yield gaps through nutrient and water management. Nature, 490:254-257.

Mugwe J, Mugendi D, Kungu J, Mucheru-Muna M (2009). Effect of plant biomass, manure and inorganic fertilizer on maize yield in the central highlands of Kenya. African Crop Science Journal 15:111-126.

Musinguzi P, Ebanyat P, Tenywa JS, Basamba TA, Tenywa MM, Mubiru DN (2016). Critical soil organic carbon range for optimal crop response to mineral fertiliser nitrogen on a Ferralsol. Experimental Agriculture 52(4):635-653.

Muyayabantu GM, Kadiata BD, Nkongolo KK (2012). Response of maize to different organic and inorganic fertilization regimes in monocrop and intercrop systems in a Sub-Saharan Africa Region. Journal of Soil Science and Environmental Management 3:42-48.

Nelson DW, Sommers LE (1982). Total carbon, organic carbon, and organic matter. In: Page AL (Ed.), Methods of Soil Analysis. Part 2, second ed., Agronomy. Monograph., Vol. 9. Madison, WI: American Society of Agronomy pp. 539-579.

Nkonya E (2001). Bean Marketing in Uganda: Constraints and Opportunities. A paper Presented at the PABRA Millennium Synthesis, May 28 June 1st, 2001, Arusha Tanzania.

Okalebo JR, Gathua KW, Woomer PL (2002). Laboratory Methods of Soil and Plant Analysis: A Working Manual; 2nd Edition. Sacred African Publishers, Nairobi, Kenya.

Oustani M, Halilat MT, Chenchouni H (2015). Effect of poultry manure on the yield and nutrients uptake of potato under saline conditions of arid regions. Emirates Journal of Food and Agriculture 27:106-120.

Payne RW, Harding SA, Murray DA, Soutar DM, Baird DB, Glaser AI, Channing IC, Welham SJ, Gilmour RA, Thompson R, Webster R (2009). 'The Guide to GenStat release 12. Part 2: statistics.' (VSN International: Hemel Hempstead, UK).

Pincus L, Margenot A, Six J, Scow K (2016). On-farm trial assessing combined organic and mineral fertilizer amendments on vegetable yields in central Uganda. Agriculture Ecosystems and Environment 225:62–71.

Place F, Barrett CB, Freeman HA, Ramisch JJ, Vanlauwe B (2003). Prospects for integrated soil fertility management using organic and inorganic inputs: evidence from smallholder African agricultural systems. Food Policy 28:365-378.

Ray DK, Gerber JS, Macdonald GK, West PC (2015). Yield variability. Nature Communication 6:1-9.

Rocha A, Maria R, Waite US, Cassimo UA, Falinski K, Yost R (2017). Improving grain legume yields using local Evate rock phosphate in Gùrué District, Mozambique, African Journal of Agricultural Research 12(22):1889-1896.

Rodriguez H, Fraga R (1999). Phosphate solubilizing bacteria and their role in plant growth promotion. Biotechnology Advances, 17:319-339.

Sanchez PA (1997). Properties and Management of Soils in the Tropics. John Wiley & Sons, Inc., New York P 76.

Satyanarayan V, Vara Prasad PV, Murthy VRK, Boote KJ (2002). Influence of integrated use of farmyard manure and inorganic fertilizers on yield and yield components of irrigated lowland rice. Journal of Plant Nutrition 25(10):2081-2090.

Schwartz HF, Pastor-Corrales MA (1989). Bean production problems in the tropics, 2nd edn. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia P 726.

Semalulu O, Kimaro D, Kasenge V, Isabirye M, Makhosi P (2012). Soil and nutrient losses in banana-based cropping systems of the Mount Elgon hillsides of Uganda: Eeconomic implications. International Journal of Agricultural Science 2(9):256-262.

Sileshi GW, Nhamo N, Mafongoya PL, Tanimu J (2016). Stoichiometry of animal manure and implications for nutrient cycling and agriculture in sub-Saharan Africa. Nutrient Cycling in Agroecosystems 107:91-105.

Stoorvogel JJ, Smaling, EMA (1990). Assessment of soil nutrient depletion in sub-Saharan Africa: 1983-2000. Report No. 28. Vol. I-4. Winand Staring Ctr., Wageningen, the Netherlands.

Tarfa BD, Maman N, Ouattara K, Serme I, Adeogun TA, Arunah UL, Wortmann CS (2017). Groundnut and Soybean Response to Nutrient Application in West Africa. Agronomy Journal 2332(109):2323-2332.

Uganda Bureau of Statistics (UBOS) (2015). Uganda Bureau of Statistics: Statistical abstract www.ubos.org.

Vanlauwe B, Palm C, Murwira H, Merckx R, Delve R (2002). Organic resource management in Sub-Saharan Africa: Validation of a residue quality drive- decision support system. Agronomie, 22(7-8): 839-846.

Vanlauwe B, Giller KE (2006). Popular myths around soil fertility management in sub-Saharan Africa. Agriculture Ecosystem and Environment 116:34-46.

Wortmann CS, Kirkby RA, Eledu CA, Allen DJ (1998). Atlas on Common Bean (*Phaseolus vulgaris* L.) Production in Africa. Cali, Colombia: Centro Internacional de Agricultura Tropical 297:131.