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Response of Bean Grain Yields on Applied Organic Fertilizers in the Semi-Arid and Humid Environments in Southwestern Uganda

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Abstract

Beans are the main source of protein in most Ugandan households, and they are also a cash crop in most rural households. Despite the importance of beans in Uganda's economy and rural livelihoods, their productivity has been persistently low, mainly due to declining soil fertility in smallholder farming systems. A farm soil fertility trial was established in the semi-arid and humid sub-agroecological zones of southwestern Uganda with five farmer groups. Each farmer group had one learning site on which the experiment was laid with three replicates for the different soil fertility improving innovations. The performance of bean grain yields on the applied soil fertility improving innovations was significant in the dry cattle corridor that had sandy soils and erratic rains. Bean grain yields were unresponsive in the humid agroecological subzone of southwestern Uganda due to fertile volcanic soils and well-distributed rainfall, which masked the effects of the applied soil fertility-improving innovations. From the study, it was revealed that sandy soils that are inherently nutrient-poor should be applied with organic amendments to enhance their fertility and water-holding capacity to support bean production in the dry cattle corridor.

Subject Areas

Agricultural Science

Keywords

Beans, Grain Yields, Humid, Semi-Arid, Soil Fertility

1. Introduction

Soil fertility challenges in Uganda form a significant barrier to improving agricultural productivity as well as household food, nutrition, and income security [1]. Several interlinked factors contribute to the decline in soil fertility in smallholder farming systems, and this reflects broader trends of association between soil fertility decline and household malnutrition and poverty. Soils under smallholder farming systems are under continuous depletion of nutrients due to the lack or limited use of soil fertility replenishing technologies [2]. This phenomenon is often characterized as a "vicious cycle" or "poverty-environment trap" where low-income farmers are unable to invest in soil improvement, leading to lower yields, increased poverty, and higher malnutrition. Further, widespread soil erosion resulting in loss of fertile topsoil has led to low organic matter content, exacerbating the effects of soil degradation on the soil's capacity to retain nutrients and water [3]. Additionally, Soil acidity in Ferralsols, which cover approximately 70% of the land area in Uganda, is a critical constraint to agricultural productivity, as weathered soils frequently have a pH below the critical value of 5.5. This strong acidity, often characterized by pH levels between 4.7 and 5.0, negatively affects nutrient availability and uptake, with phosphorus (P) being particularly constrained due to high fixation by iron (Fe) and aluminum (Al) oxides [4].

Legumes, more especially beans, form a major source of protein in Uganda. Nonetheless, beans have exhibited perpetual low grain yields of only 0.6 - 0.8 MT/ha, far below the potential of 2.5 - 3.5 MT/ha due to reduced soil fertility, even when improved bean varieties are grown [5]. Resource-constrained households have a high tendency to completely leave out the use of soil fertility-improving innovations in the bean-grown fields, which amplifies the negative effects of declining soil fertility on bean grain yields.

To improve bean production amidst challenges related to soil fertility decline coupled with climatic shifts, the National Agricultural Research Organization (NARO), in partnership with the Korea-Africa Food and Agriculture Cooperation Initiative (KAFACI), implemented a project supporting the enhancement of bean production using organic inputs in smallholder farming systems of Uganda. The objective of the research study was to assess the performance of bean production on the applied organic soil fertility amendments in the semi-arid and humid subzones of southwestern Uganda.

2. Methods and Materials

2.1. Study Area

The study was conducted in Rubirizi and Isingiro districts, located in southwestern Uganda, exhibiting contrasting climatic conditions. Rubirizi is generally humid with high annual rainfall (1500 - 2000 mm) and temperatures from 12.5˚C to 30˚C. On the other hand, Isingiro district is characterized as semi-arid with lower rainfall (approx. 1200 mm) and temperatures ranging from 17˚C to 30˚C. Both districts experience two main rainy seasons (March-May, Sept-November) but face increasing drought risks [6]. Effects of droughts are more experienced in Isingiro district, with erratic rains, characteristic of the semi-arid cattle corridor, compared to Rubirizi district, with over 30 scenic crater lakes.

The soils of Isingiro District are characterized by a mix of clay, laterite loam, and sandy soils, influenced by a terrain dominated by steep hillslopes and deep valleys. While fertile in some areas, the soils are highly susceptible to degradation due to intensive agricultural practices and a semi-arid climate [7]. On the other hand, Rubirizi District is characterized by highly productive, fertile soils of diverse composition, largely shaped by its volcanic history and hilly topography within the Western arm of the Great East African Rift Valley [6].

2.2. Research Approach

The experiment was established on a farm in the short rain season of March-May in 2025 with three and two farmer groups in Isingiro and Rubirizi districts, respectively. Membership of each group was 15 - 20, composed of women, men, and the youth. Each farmer group had one site used for learning and demonstration, with all seven treatments replicated three times in three blocks. Each plot of 2mx3m was planted with clean biofortified seed, NAROBEAN 2. This was an early-maturing, high-yielding, and biofortified bush bean variety that typically matures in 60 - 75 days. The soil treatments applied were (i) Farmyard manure (FYM), (ii) Biochar, (iii) Tithonia, (iv) Bioslurry, (v) Mycorrhiza, (vi) Biofoliar, and (vii) No amendment (Control). Biofoliar was made from locally available organic resources that were easily accessible to farmers. Biochar, FYM, Bioslurry, and Tithonia were uniformly mixed with the soil in the randomly selected plots at soil depths of 0 - 20 cm at the rate of 20 ton/ha. Biofoliar was mixed with water at a 1:5 ratio and applied to the leaves every two weeks. Similarly, soil mycorrhiza was mixed with wet and sugar-coated bean seed just before planting. Soil mycorrhiza were trapped using moistened maize bran as a substrate placed in the soil around tree roots in the woodlot. The trapped mycorrhiza was used as an inoculant on bean seed at planting. Biochar was obtained through the pyrolysis of maize cobs left as farm residue after threshing maize.

The experiment was harvested when bean pods were fully dried at 90 days after planting. At this time, plants were mostly brown, the leaves had fallen off, and the pods were dry with a light brown or tan color, brittle, and rattling. The beans from each plot were separately threshed, cleaned, weighed using a sensitive weighing scale, and expressed in kg per acre.

The collected field data were entered in Microsoft Excel, cleaned, managed, and later analyzed using R statistics software. Farmer group sites in each district were treated as an independent replicate in the analysis.

3. Results and Discussion

3.1. Baseline Soil and Chemical Characteristics of Experimental Sites

The experimental fields exhibited soil pH values of 6.5 and 6.7 in the semi-arid and humid subzones of Isingiro and Rubirizi districts, respectively (Table 1). The ideal soil pH range for most plants and crops is 6.0 to 7.5, as this ensures that vital nutrients such as nitrogen, phosphorus, and potassium are readily available for plant uptake [8].

Table 1. Soil chemical characteristics of experimental sites.

District	pH	P	K	Ca	Mg	S	Fe	Mn	Zn	N	OM	Texture
		(--------------------------------mg kg^{-1}-------------------------)								(-----%-----)		
Isingiro	6.7	15.7	150	2136.1	68.2	8.4	28.6	13.5	1.7	0.12	3.0	Sandy Loam
Rubirizi	6.5	28.8	200	2255.2	190.8	17.1	25.9	12.8	1.2	0.20	3.0	Clay Loam

Experimental soils in Isingiro district exhibited low levels of extractable phosphorus, which was below 20 mg kg^{-1}, considered optimum for crop growth [9]. On the other hand, experimental soils in Rubirizi district, existing in the humid zone, had extractable phosphorus well above the critical level below which crops could show phosphorus deficiency.

Exchangeable calcium in both experimental soils in Rubirizi and Isingiro districts was considered very high and did not require any application of calcium-containing fertilizers. On the other hand, exchangeable magnesium was considered to be at moderate and high levels [10]. Levels of sulfur in soils from the experimental sites in Isingiro and Rubirizi were considered moderate and high, respectively. Soils at both sites exhibited extractable iron in the high range, whereas manganese and zinc levels were within the optimum range for crop growth. Total soil nitrogen and organic matter were considered moderate in both experimental soils found in Isingiro and Rubirizi districts.

Experimental fields in Isingiro district were dominated by sandy loam soils characterized by a high percentage of coarse particles, making them well-drained and lightweight. Such soils often warm up quickly but lose nutrients easily due to a low Cation Exchange Capacity (CEC). Although sandy loam soils have large pore spaces that allow water to move downwards rapidly and are filled with air that provides excellent oxygen levels to plant roots, they carry a low electrical charge that leads to the wash of fertilizer and essential minerals right past the root zone during heavy rains or irrigation. This leads to low availability of nutrients for plant uptake. On the other hand, Rubirizi district has clay loam soils containing a high proportion of microscopic clay particles, which creates a dense, heavy soil that excels at holding moisture and nutrients. Nonetheless, such soils are highly prone to waterlogging and compaction [11].

3.2. Rainfall Distribution in the Experimental Period (March-May)

The two districts, Isingiro and Rubirizi, receive the primary rains in the March-May precipitation period. The precipitation period is characterized by a rapid onset in March, peak rainfall in April, and a gradual taper into June (**Figure 1**). Nonetheless, precipitation in Isingiro district found in the dry cattle corridor is much lower than that received in Rubirizi district in the humid subzone. Clear differences in the amounts of rainfall received in the two districts have a great impact on crop performance, including beans, the common legume grown. Optimal bean yields require an even distribution of 300 to 500 mm of rainfall during the 90-to-120-day growing season. Both water shortages and excessive moisture during critical growth stages will devastate harvest quantities [12].

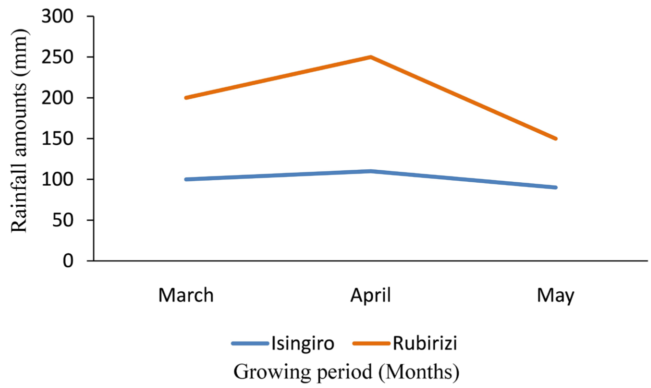

Figure 1. Rainfall distribution during the growth period of beans in two experimental sites.

3.3. Response of Bean Grain Yields with the Location

There was a significant difference in bean grain yields with the sub-agroecological zones in which the experiment was conducted (**Figure 2**). The common beans grown in Isingiro district, in the semi-arid sub-zone, were subject to low soil moisture stress due to limited rainfall and sandy soils that do not retain moisture for long. Isingiro district exhibits characteristics of a typical dry cattle corridor: erratic, poorly distributed rainfall, and high temperatures that negatively impact the growth and yields of common beans [13]. Sandy soils exhibit poor structure with low organic matter and cation exchange capacity. In such soils, beans were prone to low soil moisture and nutrient stress. On the contrary, Rubirizi district is characterized by fertile volcanic soils with high water holding capacity and moderately lower temperature compared to Isingiro district. These soils had high soil organic matter and CEC that conserved nutrients from leaching. Further, the district receives higher rainfall compared to Isingiro, leading to significantly higher grain yields of common beans.

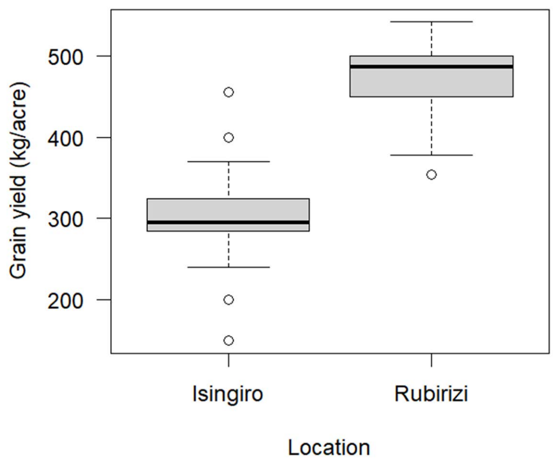

Figure 2. Variation of grain yields of common beans with contrasting locations.

Therefore, this study revealed that grain yields of common beans are significantly influenced by the ecological conditions, such as soil fertility, coupled with soil moisture, rainfall distribution, and temperature, which influence yield components, including grain yield per plant [13].

3.4. Influence of Applied Amendments on Grain Yields of Common Beans

In Rubirizi district, application of biofertilizers could not significantly influence grain yields of common beans due to fertile volcanic soils with good water-holding capacity. Further, higher amounts of rainfall that were well distributed throughout the entire growing period, and cooler temperatures compared to Isingiro, masked the effect of the applied organic amendments.

In Isingiro district, which had poor sandy soils with low water-holding capacity, the application of biofertilizers had a significant influence on grain yields (**Figure 3**). The non-application of organic inputs in such soils exhibited significantly lower grain yields due to inherently low soil nutrient levels coupled with low water-holding capacity. The application of organic inputs in such sandy soils improved soil physical conditions, such as water-holding capacity and soil structure, in addition to providing soil nutrients and enhancing cation exchange capacity. Nonetheless, grain yields of common beans applied with either biochar or *Tithonia diversifolia* were significantly lower than when other organic inputs were used. While biochar improves soil physical characteristics, pH has lower nutrient levels, especially nitrogen and sulfur. Similarly, tithonia decomposes faster in sandy soils, rapidly releasing nutrients in the soil that are easily lost through volatilization, leaching, and surface runoff before being fully utilized by the bean crop. Use of farmyard manure, which was the most available among farmers, had the highest grain yields of common beans. Nonetheless, the effect of farmyard implication on grain yields of common beans was not significantly different from either biofoliar, bio slurry, or mycorrhiza used as soil amendments.

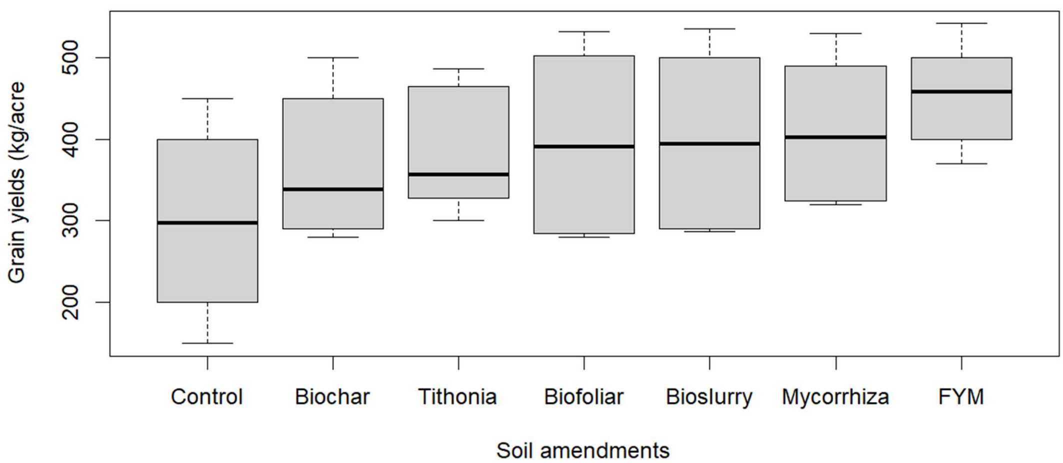

Figure 3. Influence of biofertilizers on grain yields of common beans.

4. Conclusion

Bean grain yields were influenced by the agroecological conditions in which they were grown. In Rubirizi district, which had volcanic soils and well-distributed rainfall, bean grain yields were higher than in Isingiro district, which had typical hot cattle corridor conditions. Further, organic fertilizer application had significant effects on grain yields in Isingiro district with poor sandy soils, with farmyard manure, the locally available organic input, giving the highest grain yields. Hence, there is a need to enhance farmers' ability in the dry cattle corridor to utilize available local organic materials, especially farmyard manure, to improve bean productivity.

Author Contributions

Robert Muzira, Amos Aturinda Wentaro, Peace Kankwatsa, and Dina Nabasumba conceptualized the idea and secured the funding. Robert Muzira, Amos Aturinda Wentaro, and Peace Kankwatsa developed checklists and questionnaires and led investigations with the farmers. Robert Muzira managed data, conducted analysis, and wrote the first manuscript. Amos Aturinda Wentaro provided field supervision during experimentation and baseline data collection. Steven Natuha, Maggiore Mary Kyomugisha, and Hellen Mutenyo were responsible for field data collections, field material assemblage, field labor supervision, and farmer mobilization.

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Conflicts of Interest

The authors declare no conflicts of interest.

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