

Effects of Integrated Use of *Lantana camara*, *Calliandra calothyrsus* and Cow Manure with Diammonium Phosphate and Potassium Chloride on Haricot Bean Yield in the Northern Part of Burundi

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ABSTRACT

Purpose: The use of composts in agriculture has many advantages on soil properties and the productivity of cultivated plants. This study aims to evaluate the response of the bean crop to organic fertilization consisting of composts from *Lantana camara* Linn, *Calliandra Calothyrsus* Meisn, and cow manure in combination or not with chemical fertilizers.

Research Method: The experiment was carried out in a randomized complete block design on a very acidic ferralsol of Matongo commune in the northern part of Burundi. Each experimental plot corresponded to an application of a specific compost or cow manure combined or not with chemical fertilizers (dose N-P₂O₅-K₂O: 18-46-30).

Findings: Adding chemical fertilizers to cow manure and *Lantana* compost significantly increased the number of leaves, flowers, pods, and seeds, the total biomass, and the weight of seeds. These two treatments recorded the highest grain yields (1067 kg.ha⁻¹ and 999 kg.ha⁻¹ respectively). They were followed by the application of cow manure alone (582.90 kg.ha⁻¹). The lowest yields were observed when applying *Calliandra* alone (167 kg.ha⁻¹) or combined with chemical fertilizers (371 kg.ha⁻¹), *Lantana* alone (338.15 kg.ha⁻¹), chemical fertilizers alone (100.79 kg.ha⁻¹), and on unfertilized soil (0.67 kg.ha⁻¹).

Originality/ Value: The *Lantana camara* compost can effectively replace farmyard manure for bean production on an acidic ferrallitic soil, and thus be useful to livestock-less farmers.

Keywords: *Calliandra calothyrsus*, Cow manure, ferralsol, Haricot bean, *Lantana camara*, Soil fertilization

INTRODUCTION

The use of compost has many advantages in agriculture. Martínez-Blanco *et al.* (2013) mention nine environmental benefits of composts: (1) nutrient supply, (2) carbon sequestration, (3) weed, pest and disease suppression, (4) crop yield increase, (5) soil erosion prevention, (6) increase of the capacity of soil to retain green water, (7) improvement of soil workability, (8) improvement of soil biological properties and biodiversity, and (9) crop nutritional quality.

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The use of compost is particularly interesting in tropical soils which have specific properties. The soils of the humid tropical region are generally very withered and degraded by acidification and water erosion. Their clay fraction is dominated by the type 1/1 clays (consisting mainly of kaolinite) as well as iron and aluminum oxy-hydroxides. These mineral colloids are known to have a low Cationic Exchange Capacity (CEC) at typical soil pH (Uehara and Gillman, 1981). Otherwise, in these soils, the basic cations (Ca^{2+} , Mg^{2+} , K^{+} and Na^{+}) are largely leached and displaced to the detriment of the acid cations (Al^{3+} and H^{+}) which accumulate. Tropical soils are further characterized by low nutrient reserves, high P adsorption, and high net zero charge point (PCNZ), which assigns them positive charges (Van Ranst, 1995, Shamshuddin and Anda, 2008; Koy Kasongo *et al.*, 2021). For good management of these soils, increasing organic matter levels is an essential option for increasing agricultural production. This is because organic matter increases CEC and decreases the net zero soil load point (PCNZ), releases nitrogen and phosphorus by mineralization and by blocking sites of anionic absorption (of phosphorus) (Van Wambeke, 1992, Van Ranst, 1995, Xu *et al.*, 2016, Koy Kasongo *et al.*, 2021).

Burundi is a small and densely populated low-income country in East Africa, with more than 420 inhabitants per km^2 in 2017 according to the World Bank (2015). The nutritional situation is particularly alarming (Korachais *et al.*, 2020). The rate of malnutrition is one of the highest in the world. The Burundian population suffers from an extremely high level of famine (Von Grebmer *et al.*, 2014). Chronic malnutrition affects 55% of children under 5 (Odjidja *et al.*, 2020), while acute malnutrition affects 5.1% (MPBGP, MSPLS and ISTEEBU, 2018). In such a situation, there is a need to increase production both in quantity and quality. Yet, agricultural soils in this country are overexploited due to a lack of sufficient agricultural land. This results in a decrease in soil fertility and yields, and an increase in deforestation and soil erosion (Megerle and Niragira, 2020). Continuing to cultivate on such degraded land requires soil conservation practices that include organic fertilization, erosion control and correction of internal degradations such as acidity.

To cope with this soil degradation, Burundian farmers generally resort to limestone amendment to correct acidity and mineral fertilization to increase the soil nutrient content. Organic manure is based on the application of farmyard manure. Chemical fertilizers are expensive for a large proportion of the Burundian population, over 60% of whom live below the poverty line (Ntimarubusa, 2015).

There is, therefore, a need to explore sustainable practices using locally available materials including composts from indigenous plants that produce enough biomass. Their use in soil management could help farmers increase profit by reducing family expenses allocated to chemical fertilizers and sustainably improving soil quality.

The role of some shrubs, such as *Tithonia diversifolia* Hemsl. (Jama *et al.*, 2000), *Sesbania sesban* Linn (Chirwa *et al.*, 2004) and *Calliandra calothyrsus* Meissn. (Mugendi, 1999), in improving soil and agricultural productivity has already been evaluated. However, that of most plants adapted to local conditions in Burundi has not yet been sufficiently explored despite being abundant and useful in sustainable soil management.

This study aimed to identify the types of composts that are as effective as farmyard manure in increasing crop yields. Among the trees/shrubs concerned is *Lantana camara* Linn (*Umuhengerihengeri*: in the native language Kirundi), an invasive species that is abundant in all ecoclimatic regions of Burundi. Its potential effects on soil fertilization and crop yield improvement have been subjected to few investigations. The ultimate goal of the study was to propose a model for improving agricultural productivity through sustainable management of soil fertility by low-cost biological methods. The specific objective of this study was to highlight the effects of applying *Lantana camara* compost on the yield parameters of the common bean (*Phaseolus vulgaris* L.). Its performance on bean yield parameters is every time compared with those of the farmyard manure and *Calliandra* compost whose effects are known.

MATERIALS AND METHODS

Location of the Experimental Site

A field experiment was conducted during the first period of the rainy season, from November 2019 to February 2020, within a family farm located at Bihunge Colline in Matongo commune in the northern part of Burundi. The site is located in a high altitude agro-ecological zone of Burundi (2128 m) on a latitude of $03^{\circ} 06' 31, 9''$ South and a longitude of $29^{\circ} 35' 38, 8''$ East. The climate of the area is (Cw3)S, using Köppen climate classification; i.e., the monthly mean temperature of the coldest month is below 18°C and the mean precipitation of the driest month is below 60 mm whereas the dry season is in the winter (Kottek *et al.*,

2006). In this zone, the mean annual rainfall of 1603.6 mm and the average daily temperature of 18.2°C are noted.

Soil Site Sampling and Analysis

Prior to any activity of the experiment, a composite sample of soil was collected from eight randomly selected points within the experimental site at a depth of 0-30 cm using Riverside auger, bottom part, bay, Ø7 cm. The sample was bulked, air-dried for two weeks, and sieved passing through a 2-mm. The bulked sample was used for physicochemical analysis of the soil carried out at the Soil and Agro-Food Products Analysis Laboratory (LASPA), an asset of the Burundi Institute of Agricultural Sciences (ISABU). They focused on particle size, pH-H₂O, organic carbon, total nitrogen, available phosphorus, CEC, exchangeable bases (Ca²⁺, Mg²⁺, K⁺) and exchangeable acidity (A³⁺, H⁺). The analytical methods used are described in detail in various books such as Van Ranst *et al.* (1999) and Soil Survey Staff (1996, 2004). Briefly, the particle size analysis was carried out after the attack of the organic matter and limestone by H₂O₂ and HCl respectively, and after the dispersion of the clays by the addition of sodium hexamethaphosphate; the CEC and exchangeable cations were measured using the ammonium acetate method; the soil pH was measured in water using an electronic pH meter; the soil organic carbon and phosphorus content were determined by Walkley Black method and by atomic absorption spectrophotometry respectively. The interpretation of these parameters is based on the threshold values set by ISABU (Landon, 1991; Tessens and Gourdin, 1993; Hazelton and Murphy, 2007).

Treatments and Experimental Design

This study concerned the cultivation of beans (*Phaseolus vulgaris* L.) after modifying the properties of the soil by adding organic amendments and/or mineral fertilizers. Common bean was used in this study because it is a staple crop for food security in Burundi (Devos *et al.*, 1983; Birachi *et al.*, 2011). The experimental design was a randomized complete block comprising 3 blocks and three repetitions for each treatment. Treatment consisted of a factorial combination of three soil substrates (control, 2.5 t DM/ha of cow manure, 2.5 t DM/ha of *Calliandra calothyrsus*, 2.5 t DM/ha of *Lantana camara*) with or without NPK fertilizer meeting the dose of N-P₂O₅-K₂O: 18-46-30. The contents of these substrates in essential nutrients (NPK) and in Mg, Ca and organic matter are shown in Table 02.

There were 8 treatments viz. T_1 = Control (0 kg of compost + 0 kg of NPK fertilizer), T_2 = cow manure (2.5 t DM/ha + 0 kg of NPK fertilizer), T_3 = compost of *Calliandra* (2.5 t DM/ha + 0 kg of NPK fertilizer), T_4 = compost of *Lantana* (2.5 t DM/ha + 0 kg of NPK fertilizer), T_5 = Inorganic fertilizer alone (0 kg of compost + NPK fertilizer), T_6 = cow manure (2.5 t DM/ha) and NPK fertilizer, T_7 = compost of *Calliandra* (2.5 t DM/ha) and NPK fertilizer, T_8 = compost of *Lantana* (2.5 t DM/ha) and NPK fertilizer.

Composts Preparation

Biomass sources for compost: The types of organic fertilizers used in this study are from two shrub species, *Lantana camara* Linn and *Calliandra Calothyrsus* Meisn, and cow manure.

Lantana camara Linn is a noxious and invasive weed in Burundi. It is the genus of the Verbenaceae family with 600 varieties existing worldwide. *Lantana camara* Linn is mostly native to subtropical and tropical America, but a few taxa are indigenous to tropical Asia and Africa (Ghisalberti, 2000). *Lantana camara*, also known as wild sage, is a thorny multi-stemmed, deciduous shrub with an average height of 2 m (Neena and Joshi, 2013). The shrub's taxonomic position is defined as belonging to the class of Magnoliopsida, order Lamiales, family Verbenaceae and genus *Lantana* (Sharma *et al.*, 2005).

Although *Lantana* is recognized as a noxious plant, it has several minor uses beneficial to human life. Neena and Joshi (2000) synthesize its uses in medicinal use, as a hedge, in the manufacture of baskets and biofuel, and as a source of nectar for butterflies and moths. Niang *et al.* (1996) mentioned that this shrub can be used as green manure to improve crop productivity.

The species *Calliandra calothyrsus* Meisn was described by Meissner in 1848 (Breteler, 1989). It is a small leguminous tree described as Kingdom: Plantae, Order: Fabales, Family: Fabaceae, Genus: *Calliandra*, Species: *C. calothyrsus* Meisn. Regarding the uses of *C. calothyrsus*, de Luna *et al.* (2020) noted that the benefits derived from planting *C. calothyrsus* include fuelwood, honey and fodder production and environmental services like carbon sequestration.

In soil fertilization, many studies have already shown positive effects of the use of *Calliandra calothyrsus* on the yield of cultivated crops (Kaboneka *et al.*, 2019; Nyambati *et al.*, 2020). This use is a consequence of its high N-fixing potential, abundant biomass production and rapid decomposition (Kaboneka *et al.*, 2019).

Preparation and analysis of organic composts: The composts used in this study were prepared on-site from the green leaves and stems of *Calliandra calothyrsus* and *Lantana camara* collected from the wild. These leaves and stems were then shredded to hasten decomposition. They were then placed in parallelepiped-shaped pits dug at the experimental site. These pits, which measured 2.0 m in length, 1.2 m in width and 0.5 m in depth, were left open to the air to allow the circulation of water and air into the material. These materials were rotated every seven days to prevent overheating. This composting operation was carried out for four weeks. At the same time as this operation of composting the two species of plants, cow manure was collected in a cowshed and placed in a composter following the same process.

At the end of composting, a sample of each compost was taken, packed in a polyethylene bag and transported to the ISABU laboratory (LASPA) for the determination of the chemical composition. All the samples were dried in an oven at 60°C for 4 days and analyzed for % C, % N, % P, % K, % Mg and % Ca. Total Carbon was determined by wet combustion (Nelson and Sommers, 1983), nitrogen was determined by digestion with sulphuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2) followed by steam distillation (Bremner and Mulvaney, 1982); while phosphorus, potassium, calcium and magnesium content were analyzed by atomic absorption spectrophotometry.

Land Preparation

The cropping operations consisted of land preparation, seedlings, weeding and harvesting. The preparation of the land involved ploughing, harrowing, liming, digging seed holes, and depositing composts and chemical fertilizers. After plowing and harrowing the experimental site, lime was applied at the rate of 4.69 t. ha⁻¹, calculated using the formula set up by Yamoah *et al.* (1990) and the soil pH indicated in Table 01.

The land was subdivided into 24 plots, each plot sized 200 cm x 120 cm (2.4 m²) each, i.e. 40 cm between and 20 cm within rows. A distance of 0.8 m and 1.0 m was left between plots and blocks, respectively. In each unit plot, five seed holes per row were dug with a hoe. The quantity of compost deposited in each hole was estimated based on the quantity to be applied over 1 hectare (2.5 DM t. ha⁻¹).

After the deposit of the compost in the planting holes, the next operation was to add chemical fertilizer to the

T5, T6, T7, and T8 treatments. For this reason, the dose applied is that recommended by ISABU (Ruraduma *et al.*, 2012). This is the N-P₂O₅-K₂O formula: 18-46-30; i.e. 18 units of nitrogen, 46 units of P₂O₅ and 30 units of K₂O. We used DAP (Diammonium Phosphate: $(NH_4)_2HPO_4$ and Potassium Chloride (KCl) by mixing 100 kg of DAP and 50 kg of KCl per hectare. In the planting hole, 5 g of the latter mixture was placed in the concerned treatments.

Sowing and Characteristics of the Variety of the Cultivated Plant

The sowing of the bean was conducted on November 13, 2019. It was realized by depositing two seeds into each planting hole. The variety cultivated during this experiment was the variety BCB-11-404 originating from the International Center for Tropical Agriculture (CIAT). Introduced in Burundi by ISABU in 2011, it was distributed to farmers in 2017 where it received the local name of Mabondo in Kirundi. As for its morphological characteristics, it is a semi-climbing bean with pinkish-white flowers and pale yellow seeds of round shape (Ruraduma *et al.*, 2012).

Weeding, Data Collection and Harvesting

Weeding was carried out using a hoe. The first weeding was done 3 weeks after sowing and the second weeding at 6 weeks after sowing. The crop was harvested on February 19, 2020, i.e. on the 98th day after sowing.

Regarding the data collection, the number of germinated plants was counted in each plot on the 14th day after sowing. This number was used to calculate the germination rate. A seed was considered to have germinated if both the plumule and radicle had protruded to a height of at least 0.5 cm.

In each experimental unit, four bean plants were selected to form a sample. For these selected plants, the numbers of leaves and flowers were counted on the 50th day after sowing, while the number of pods was counted on the 70th day after sowing.

Harvesting was conducted by hand pulling. The plants were dug up keeping the roots. They were then piled up treatment by treatment and air dried for a week before collecting data consisting of the number of pods, the number of seed pods, the number of seeds, the weight of seeds, and the total biomass.

Data Analysis

The data obtained from the crop were statistically analyzed using the PROC ANOVA function of JMP

Pro14 software. Means were compared using Tukey's HSD all-pairs comparisons at $p=0.05$ level as a post-hoc test. The graphs were plotted using Microsoft Excel 2013.

RESULTS AND DISCUSSION

Soil Physical and Chemical Properties

The physicochemical properties of the Bihunge experimental soil site are shown in Table 01.

Soil texture: According to the American soil textural classification system as described by Christopher and Mokhtaruddin (1996), the percentages of clay, silt and sand in Table 01, indicate that the soil of the experimental site is silt clay soil classified within clay-textured soils, a texture class that characterizes ferralsols.

Organic carbon content: The organic carbon content determined by the Walkley-Black method (Walkley and Black, 1934) is 5.97%. This value being between 4 and 10% shows that the experimental site has a medium level of organic matter according to the interpretation criteria of Landon (1991).

Soil acidity: The soil of the experimental site is very acidic considering its pH value of 3.94 (Table 01). This strong acidity affects the nutrient availability, especially phosphorus. Moreover, it is accompanied by aluminum and/or manganic toxicity (Rengel, 2005). Indeed, when the pH drops below 5, the aluminum becomes soluble and can compete with the basic cations (Ca^{2+} , Mg^{2+} and K^{+}) on the exchange sites.

Nutrient retention capacity: The nutrient retention capacity is determined by the Cation Exchange Capacity (CEC) and the Effective Cation Exchange Capacity (ECEC). The latter is the sum of the concentrations of all cations adsorbed on the exchange complex. It is expressed in equivalent concentration. In theory, it is equal to the CEC. However, soil characteristics and analytical methods can disturb this equality and show markedly different values. For the soil of interest, the calculated value of the ECEC is 4.67 meq/100g. This value is much lower than that of the CEC (which is 19.4 meq/100g (see Table 01) since it does not even represent a quarter of the CEC. This large difference shows that the soil of the experimental site is dominated by variable charges. These can originate from kaolinite, iron and aluminum oxy-hydroxides and organic matter. This large difference further shows

the inadequacy of the Metson method (ammonium acetate method at pH 7) for acidic tropical soils with predominantly variable charges. Indeed, the CEC was overestimated by the analytical method since the soil pH is 4 and the matrix in which the CEC is analyzed has a high pH of 7.

Base saturation percentage and aluminum saturation percentage: The base saturation percentage calculated for the soil sampled in the experimental site is 28.91%. This value shows that our soil is less base-saturated. The exchange complex is therefore largely dominated by aluminum and the bulk of acidity is represented by aluminum. Indeed, the aluminum saturation rate (m) or Kamprath index is 66.81%.

In short, the soil site is very weathered, very acidic, very desaturated in bases and very rich in aluminum. It deserves to be amended by liming (to increase the pH and to resaturate the system) and by organic manure to increase nutrient retention capacity.

Chemical Properties of the Organic Fertilizers

The chemical composition of the composts and cow manure used for this study is shown in Table 02. The maturity of a compost is analyzed through various parameters including the C/N ratio (Compaore *et al.*, 2010). Composts that have a C/N ratio close to 10-15 are qualified as matured composts (Namkoong *et al.*, 1999). In line with this, only cow manure can be qualified as matured because its value is around 10, while Calliandra and Lantana composts are not matured (Table 02).

Concerning nitrogen (N), all three composts used in this study are good for agriculture. Indeed, compost with a nitrogen content greater than 1% can be used in agriculture (Baker, 1997). The greatest amount of P in organic matter is retained in organic complexes. According to Baker (1997), the C/P ratio of composts is generally between 80 and 100. Ratios greater than this interval indicate immobilization of P. The maximum of this ratio for optimal composting is 120. In composts used in this study, we note from this point of view that only the compost of Lantana fulfills this condition while that of *Calliandra calothyrsus* (with C/P of 127) appears to have a P immobilization property. For cow manure, the C/P ratio is considerably lower than 80. The Ca and Mg concentrations of composts vary on average from 1 to 4% and from 0.2 to 0.4% respectively (Baker, 1997). Following these standards, we find that most of the composts used in this study (except *Lantana camara*) are below the average value

Table 1: Physicochemical properties of the soil sampled at the experimental site

pH-H ₂ O (1/5)	CO (%)	N (%)	P-Olsen (mg/kg)	CEC and exchangeable cations (cmol ⁺ . kg ⁻¹)							Clay (%)	Silt (%)	Sand (%)
				CEC	Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺	Al ³⁺	H ⁺			
3,94	5.97	0.43	4.7	19.4	0.83	0.20	0.28	0.04	3.12	0.20	53.09	42.87	4.04

Table 2: Chemical characteristics of cow manure and composts of *Lantana camara* and *Calliandra calothyrsus*

Organic fertilizer type	OC (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Cow manure	15.05	1.55	0.43	1.06	0.32	0.16
<i>Calliandra calothyrsus</i>	22.9	3.80	0.18	0.99	0.79	0.27
<i>Lantana camara</i>	26.4	3.77	0.32	3.89	1.48	0.54

required for the Ca and Mg contents (Table 02).

Effects of Organic Compost and Inorganic NPK Fertilizer on the Bean Agronomic Characteristics Measured During the Growing Period

The average values of the bean agronomic parameters determined during the period between sowing and harvesting are shown in Table 03. These results indicate the classification of the groups of homogeneous means obtained by the multiple comparisons at the 5% threshold with Tukey's HSD method. Means followed by the same lowercase letter are not significantly different at the 5% level.

Germination rate: The means of germination rate of the bean seeds in this study vary between 82.5 (T₅) and 87% (T₂). We note that the type of compost does not affect the germination of bean seeds as there was no significant difference observed between germination rate means.

Number of leaves per plant: Beans are cultivated for the consumption of the leaves, pods and seeds. The leaves are an excellent source of proteins (Aguida and Capochichi, 2015, Yapo *et al.*, 2021). Besides the nutritional role of human consumption, the abundance of leaves influences the number of pods and the quantity of seeds at harvest (Al-Ballat and Al-Araby, 2019). Generally, the more leaves a bean plant has, the more pods and seeds it will have; hence the need to assess the number of leaves during the vegetative stage.

In this study, statistically significant differences were found between the effects of different types of compost on the number of leaves per plant (Table 03). The highest averages of the number of leaves are observed for two soil organic amendments combined with chemical fertilizers. Those are cow manure (T₆) and *Lantana camara* compost (T₈) which manifested 14

leaves per bean plant. Meanwhile, the lowest average number of leaves (2 leaves) was obtained in the control plots (T₅). This treatment is classified in the same group of homogeneous averages as the treatments of unaltered soil but with the application of chemical fertilizer (T₅), and the treatments with *Calliandra* compost without chemical fertilizer (T₃). Furthermore, the treatments of *Calliandra* compost (with application or not of chemical fertilizers) have average numbers of leaves that are significantly lower than those of *Lantana* compost and cow manure accompanied by chemical fertilizers.

As for the chemical fertilizers, significant differences were observed within plots amended with *Lantana camara* and cow manure. In these two cases, the treatments carried out with the addition of chemical fertilizers show a significantly higher number of leaves than those of the treatments that used only organic manure.

Number of flowers per plant: Significant differences in number of bean flowers were observed between treatments (Table 03). The greatest number of flowers was noted for the treatments amended with *Lantana camara* compost and cow manure combined with chemical fertilizers (T₆ and T₈). In these treatments, the mean numbers of bean flowers (3 flowers) are significantly higher than those obtained in all other plots, which varied between 0.08 (T₁ and T₅) and 1.17 number of flowers (T₇). Regarding the effects of chemical fertilizers on this parameter, significant differences are shown in the case of cow manure and *Lantana* compost use. With these two amendments, the addition of chemical fertilizers significantly increases the number of flowers by 4 to 7 times.

Number of pods: The number of bean pods have been counted on the seventieth day after sowing. The means of the number of pods counted in the treatments with

Table 3: Germination rate, number of leaves, flowers and pods of the haricot bean plants in experimental plots

Treatment	Germination rate (%)	Number of leaves	Number of flowers	Number of pods
T ₁ : Control (0 kg of compost + 0 kg of NPK fertilizer)	85.00±1.44a	2.33±0.74d	0.08±0.08b	0.56±0.29c
T ₂ : Manure (2.5 t DM/ha+ 0 kg of NPK fertilizer)	86.67±2.20a	7.67±0.96b	0.42±0.17b	3.92±0.79b
T ₃ : Calliandra (2.5 t DM/ha + 0 kg of NPK fertilizer)	85.00±1.44a	5.08±0.58bcd	0.5±0.25b	2.64±0.53bc
T ₄ : Lantana (2.5 t DM/ha + 0 kg of NPK fertilizer)	85.00±1.44a	7.33±0.46bc	0.92±0.22b	4.08±0.36b
T ₅ : Inorganic fertilizer alone (0 kg of compost + NPK fertilizer)	82.50±1.44a	3.42±0.44cd	0.08±0.08b	1.03±0.32bc
T ₆ = Manure (2.5 t DM/ha + NPK fertilizer)	83.33±1.67a	13.83±0.30a	2.92±0.17a	10.00±1.30a
T ₇ : Calliandra (2.5 t DM/ha + NPK fertilizer)	83.33±1.67a	7.33±0.55bc	1.17±0.44b	3.42±0.36bc
T ₈ : Lantana (2.5 t DM/ha + NPK fertilizer)	84.17±2.20a	13.50±1.76a	3.33±0.30a	8.92±0.71a

Each data represents the mean of three replicates ± standard error. Treatments with data followed by the same lowercase letter are not significantly different at a 5% probability level. NPK fertilizer: Recommended Dose of Fertilizer - (N-P₂O₅-K₂O: 18-46-30)

chemical fertilizers added to Lantana *camara* compost (9 pods) and cow manure (10 pods) are significantly higher than those obtained in the control plots (0.6 pods), as well as other treatments (Table 03). Moreover; the average numbers of pods counted in the treatments carried out with Calliandra with or without chemical fertilizers (T₃ and T₇) are classified in the same homogeneous groups as the control plots (T₁).

Effects of chemical fertilizers are only observed in the cases of use of Lantana composts and cow manure: treatments carried out with the application of chemical fertilizers show the greatest number of pods (9-10).

Effects of Organic Compost and Inorganic NPK Fertilizer on the Bean Yield Parameters Measured at the End of the Crop Season

Data collected at the end of the vegetative stages are performed in Figures 01-05 and Table 04. In these figures, the treatments followed by the same lowercase letter did not statistically differ.

Survival rate: The site on which this study was conducted is very weathered and its soil is extremely acidic (Table 01). To assess the possible amelioration of the negative effects of the soil acidity on the bean survival by additions of the tested composts,

we counted the number of plants that had not disappeared at the time of harvest and, we calculated the survival rate. The results are shown in Figure 01. The highest survival rate was observed in the case of the Lantana compost and cow manure without any chemical fertilizers (T₂ and T₄). These treatments are statistically different from the treatments conducted without any organic fertilizer (T₁ and T₅) and the treatment of Calliandra compost accompanied with chemical fertilizers (T₇) for this parameter. These three treatments are classified in the last group of homogenous means according to the Tukey HSD's test.

The highest survival rates were observed in plots amended with organic fertilizers without chemical fertilizer. These rates were not different and were significantly higher than those recorded in the control treatments. On the other hand, all treatments combining organic amendments and chemical fertilizers do not significantly differ. Interestingly, chemical fertilizers improved the survival rate of the control treatment but decreased it for amended treatments, particularly for the Calliandra-amended treatment.

Number of productive pods: The average number of productive pods (with seeds) counted in the experimental plots is displayed in Figure 02—the classification of treatments according to the Tukey HSD test results in four groups. The first one is the

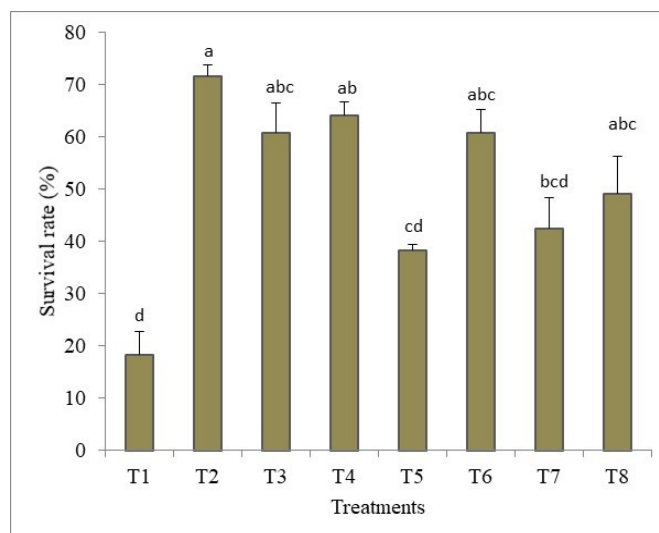


Figure 1: Percentage of survival bean plants in the experimental plots

Each data point represents the mean of three replicates $\pm$ standard error. This means sharing the same lowercase letter is not significantly different at a 5% probability level. T1 is the control treatment; T2, T3 and T4 are the treatments where only organic fertilizers, consisting of cow manure, Calliandra and Lantana composts respectively, are applied without chemical fertilizers. T5 is the treatment where chemical fertilizers are applied to the soil without organic fertilizers; T6, T7 and T8 are the treatments where chemical fertilizers are added to cow manure, Calliandra compost and Lantana compost respectively.

group of treatments with the application of chemical fertilizers combined with cow manure and Lantana *camara* (with 8.0 and 6.7 seed pods, respectively). The last group comprises five treatments viz. the control (T₁), the treatment of chemical fertilizers only (T₅), the treatments of Calliandra with chemical fertilizers or not (T₃ and T₇) and that of Lantana compost with no chemical fertilizers (T₄).

Moreover, it is noted that the use of chemical fertilizers significantly improved this number in plots amended with cow manure and with Lantana *camara* compost, indicating a strong interactive effect between the two organic amendments and the application of chemical fertilizers.

Biomass production: The total bean biomass produced in the experimental plots is shown in Figure 03. Tukey's test classifies treatments into four overlapping groups. The first group includes the treatment with cow manure and chemical fertilizers (T₆: 546 g DM per plot). The second group comprises the treatment of Lantana *camara* with chemical fertilizers (T₈: 362 g DM per plot) and cow manure alone (T₂: 206.23 g DM per plot). The third group contains the treatments with the application of chemical fertilizers added to the soil alone (T₅) and to the composts from Calliandra (T₇), and the treatments with Lantana and Calliandra composts alone (T₄ and T₃, respectively). The last group includes the treatments of the third group (except cow manure) to which is added the control (T₁) that has the lowest total biomass (7.53 g DM per plot).

Regarding the effect of added fertilizers on total biomass production, the finding is that the effect is significant with the uses of cow manure and compost from Lantana *camara*, as was also noted for the number of productive pods.

Seed number: The average numbers of seeds per treatment are shown in Figure 04 which shows four overlapping groups of homogeneous averages. The first group is that of cow manure plus chemical fertilizers (T₆: 604 seeds) and Lantana compost plus chemical fertilizers (T₈: 408 seeds). The last group comprises the treatments without any organic fertilizers: T₁ (0.7 seeds) and T₅ (43.3 seeds).

Concerning the effect of the chemical fertilizers application on the total biomass production, a similar observation is noted as in the cases of the previous parameters (number of productive pods and bean biomass production).

Seed weight per treatment: The average weights of seeds harvested per treatment are shown in Figure 05. Analysis of variance at the 5% threshold shows a significant effect of the treatments on the weight of the seeds harvested. Tukey's test shows 4 overlapping groups of homogeneous means. The first group consists of the treatments of cow manure plus chemical fertilizers (257.19 g). The second one comprises the treatment of Lantana compost plus chemical fertilizers (159.84 g) and cow manure without chemical fertilizers (T₂: 93.3 g). The lowest seed weight is that of the control (T₁: 0.11 g). This treatment is statistically different from the three treatments of the two first

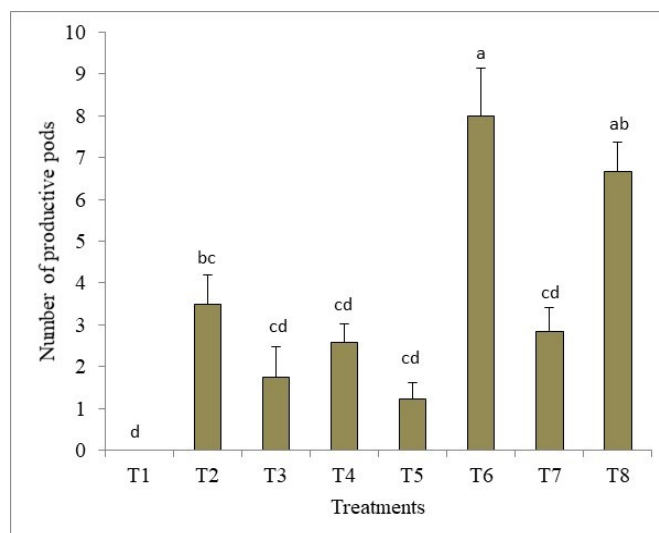


Figure 2: Number of productive pods of beans in the experimental plots

Each data point represents the mean of three replicates $\pm$ standard error. The means sharing the same lowercase letter is not significantly different at a 5% probability level. T1 is the control treatment; T2, T3 and T4 are the treatments where only organic fertilizers, consisting of cow manure, Calliandra and Lantana composts respectively, are applied without chemical fertilizers. T5 is the treatment where chemical fertilizers are applied to the soil without organic fertilizers; T6, T7 and T8 are the treatments where chemical fertilizers are added to cow manure, Calliandra compost and Lantana compost respectively.

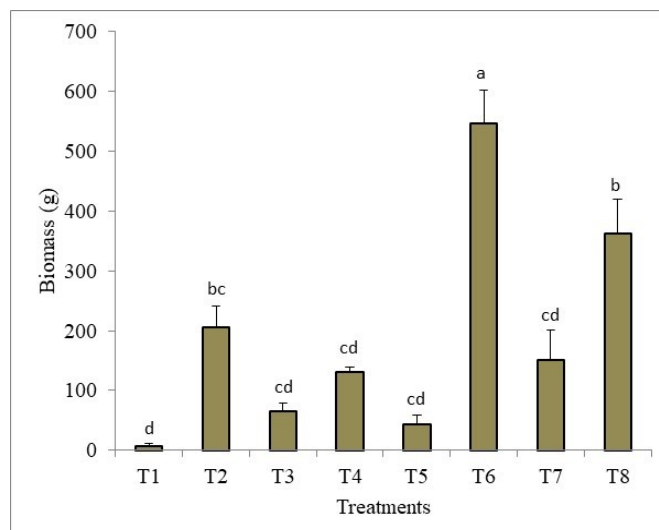


Figure 3: Quantity of bean biomass produced in the experimental plots

Each data point represents the mean of three replicates $\pm$ standard error. The means sharing the same lowercase letter is not significantly different at a 5% probability level. T1 is the control treatment; T2, T3 and T4 are the treatments where only organic fertilizers, consisting of cow manure, Calliandra and Lantana composts respectively, are applied without chemical fertilizers. T5 is the treatment where chemical fertilizers are applied to the soil without organic fertilizers; T6, T7 and T8 are the treatments where chemical fertilizers are added to cow manure, Calliandra compost and Lantana compost respectively.

groups and is not different from other treatments of this experiment.

By examining the effects of chemical fertilizers on the weight of seeds for the same type of compost, we notice that mineral fertilization improves the weight of seeds in the cases of treatments using cow manure and Lantana *camara* compost. The behavior of Calliandra-amended, both with or without chemical fertilizers calls for in-depth analysis. One can speculate that Calliandra compost could be associated with allelopathic/negative

effects, as was advanced elsewhere (Kaboneka *et al.*, 2020).

By extrapolating these seed productions to the area of one hectare whose number of planting holes usually recommended is 125,000 while respecting the same spacing of 20 cm x 40 cm that we used in this study, we obtain the yields shown in Table 04. The grain yield of the variety BCB-11-404 observed by the agronomic research services, in its adaptation zone which includes the regions of altitude between 774

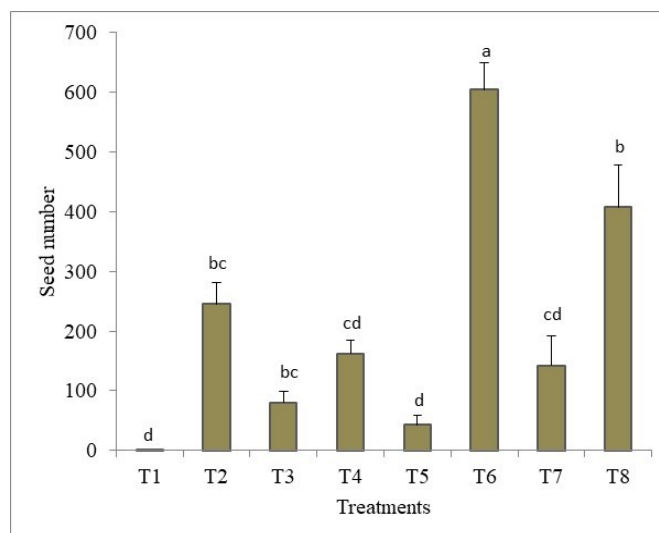


Figure 4: Number of seeds produced in the experimental plots

Each data point represents the mean of three replicates $\pm$ standard error. The means sharing the same lowercase letter are not significantly different at a 5% probability level. T1 is the control treatment; T2, T3 and T4 are the treatments where only organic fertilizers, consisting of cow manure, Calliandra and Lantana composts respectively, are applied without chemical fertilizers. T5 is the treatment where chemical fertilizers are applied to the soil without organic fertilizers; T6, T7 and T8 are the treatments where chemical fertilizers are added to cow manure, Calliandra compost and Lantana compost respectively.

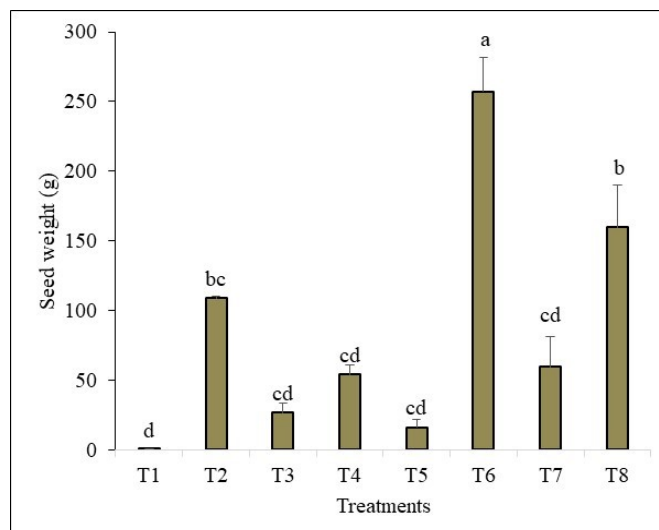


Figure 5: Weight of bean seeds produced in the experimental plots

Each data point represents the mean of three replicates $\pm$ standard error. The means sharing the same lowercase letter are not significantly different at a 5% probability level. T1 is the control treatment; T2, T3 and T4 are the treatments where only organic fertilizers, consisting of cow manure, Calliandra and Lantana composts respectively, are applied without chemical fertilizers. T5 is the treatment where chemical fertilizers are applied to the soil without organic fertilizers; T6, T7 and T8 are the treatments where chemical fertilizers are added to cow manure, Calliandra compost and Lantana compost respectively.

and 1850 m, is 1400 kg. ha⁻¹ under the station and 800 kg/ha farmers' conditions (Nduwarugira *et al.*, 2018). By comparing these observed yields and those that emerge from this study, we find that only the combination of chemical fertilizers with cow manure (T₆: 1067.46 kg. ha⁻¹) and *Lantana camara* compost (T₈: 998.98 kg. ha⁻¹) compared with yields reported under farmers' conditions without reaching research stations yields. We note that all other treatments gave very to extremely low or nil yields (T₁: control) bean seed yields. Bean grain yields were depicted in the

following decreasing order: T₆ > T₈ $\geq$ T₂ $\geq$ T₇ $\geq$ T₄ $\geq$ T₃ $\geq$ T₅ $\geq$ T₁. It can be observed that the addition of chemical fertilizers to the control and Calliandra-amended treatments did not translate in significant bean grain yield increase, contrary to cow manure and Lantana-amended treatments. Application of chemical fertilizers doubled the yields registered with cow manure alone (from 582 to 1067 kg. ha⁻¹) and tripled yields associated with Lantana organic amendment (from 338 to 999 kg. ha⁻¹). Compared to the control/soil alone treatment, the most drastic effect

on bean grain yields was noticed with cow manure application with + 580 kg. ha⁻¹ increase. The addition of Calliandra or Lantana amendments only gave + 166 and 330 kg. ha⁻¹ increase when compared to the soil alone treatment (T1).

During this experiment, the observed germination rate is greater than 83% in all treatments without there being a statistically significant difference. This finding shows, on one hand, that bean seeds do not exhibit dormancy since the germination rate observed is relatively high. On the other hand, none of the composts and chemical fertilizers used in this study interfered with the germination of the bean. Such high germination percentages have also been obtained in other studies. Soltani *et al.* (2018) obtained a bean germination percentage of 85,813 ± 0.692 in normal treatments while Mansouri and Kheloufi (2017) found a germination rate of 100% under controlled conditions in plastic boxes.

Statistically higher numbers of bean leaves and flowers were observed in the cow manure and *Lantana camara* treatments independently of chemical fertilizers application. Moreover, for these two treatments, the numbers of leaves and flowers doubled when chemical fertilizers were added, indicating that chemical fertilizer application therefore significantly improves bean leaves and flower growth under experimental sites and conditions.

It should be remembered that the numbers of leaves counted in the case of the absolute control (without compost and chemical fertilizer) and in the case of the soil alone + chemical fertilizer remain very low and much lower than those obtained when using *Lantana camara* and cow manure alone.

The reason for this low leaves number of control treatments can be found in the physicochemical properties of the experimental soil as shown in Table 01. Indeed, according to Landon (1991) and Tessens and Gourdin (1993), this soil is extremely acidic and poor in nutrients, particularly in basin cations (Ca²⁺, Mg²⁺, and K⁺), and available P.

Contrarily to Lantana-based compost, Calliandra treatment falls into the same group as the control treatment when using chemical fertilizers for the number of pods parameter. The number of pods in *Lantana camara* composts and cow manure treatments is higher than in other treatments. These scenarios are one more indication of the bean production potential associated with the two organic amendments: cow manure and Lantana-based compost.

The survival percentages of bean plants are such that the organically un-amended soil with or without chemical fertilizers application and the Calliandra-amended treatment plus chemical fertilizers record the lowest bean plant survival percentages. The cause of the disappearance of bean plants in the absence of organic and mineral fertilizers is always found in the nutrient poverty of the soil and its high level of acidity. Indeed, it is an extreme acidity doubled by aluminum toxicity and a fixation of the phosphate ions on the positive sites of the exchange complex which inhibit plant growth and (Wang *et al.*, 2006; Marschner, 2011). In this case, any crop grown on such unamended soil, except for the few very acid-resistant plant species, would result in zero or near zero production.

It is known that in tropical soils with variable and acidic loads (pH <5) which contain large amounts of Al and Fe oxides, P is particularly deficient in the soil solution because it is precipitated with or adsorbed on the surface of Al and Fe as insoluble Fe/Al-P compounds, on the surface of Fe/Al oxide minerals (Crawford *et al.*, 2008).

Globally, two treatments consistently perform better than others. These are cow manure and *Lantana camara* compost treatments with chemical fertilizers application. They do have the highest grain numbers and weights as well as high total biomass. *Calliandra calothyrsus* treatment joins the control treatment in the last group of homogeneous means. It is a clear discrimination of treatments that shows the reassuring role of *Lantana camara* composts and farmyard manure in improving the productivity of beans on acid ferral soil from Burundi. These two types of composts exhibit high levels of nutrients as shown in Table 02. The Calliandra compost exhibits little performance of bean productivity than cow manure and Lantana compost in this study. The poor performance of Calliandra compost could be explained by its low rate of decomposition and potential allelopathic effects (Kaboneka *et al.*, 2019, Kaboneka *et al.*, 2020) which block the rapid release of nutrients beneficial to plants.

Finally, the cow manure can be replaced by the compost of *Lantana camara* for bean crops in the context of acidic ferral soil. The positive effects of *Lantana camara* could be due to its high nutrient content as shown by the values in Table 02. These nutrients are made available to the plants. Other studies including that of Niang *et al.* (1996) indicated positive effects of *Lantana camara* on food production. These authors conducted an essay in Kenya and found that the application of *Lantana camara* exhibited significant

Table 4: Dry bean seed yield calculated per hectare

Treatment	Seed yield (kg.ha ⁻¹)
T ₁ : Control 1 (0 kg of compost + 0 kg of NPK fertilizer)	0.67±0.67d
T ₂ : Manure (2.5 t DM/ha)+ 0 kg of NPK fertilizer	582.90±97.22bc
T ₃ : Calliandra (2.5 t DM/ha) + 0 kg of NPK fertilizer	166.69±42.09cd
T ₄ : Lantana (2.5 t DM/ha) + 0 kg of NPK fertilizer	338.15±40.33cd
T ₅ : Inorganic fertilizer alone (0 kg of compost + NPK fertilizer)	100.79±36.71cd
T ₆ : Manure (2.5 t DM/ha) + NPK fertilizer	1067.46±152.37a
T ₇ : Calliandra (2.5 t DM/ha) + NPK fertilizer	371.17±137.96cd
T ₈ : Lantana (2.5 t DM/ha) + NPK fertilizer	998.98±189.01b

Each data represents the mean of three replicates ± standard error. Treatments with data followed by the same lowercase letter are not significantly different at a 5% probability level. NPK fertilizer: Recommended Dose of Fertilizer - (N-P₂O₅-K₂O: 18-46-30)

effects on maize yield.

CONCLUSION

In the context of degraded and acidic soils, characterized by a low capacity to retain nutrients, the enrichment of these soils with organic matter to restore their fertility is a necessity for sustainable agriculture. In Burundi, the main source of organic matter used is farmyard manure. Farmers without livestock, very numerous in Burundi, have difficulty acquiring organic matter to amend their soil. The objective of this study was to assess whether *Lantana camara* compost or *Calliandra calothyrsus* compost can substitute farmyard manure in soil fertilization and be useful for farmers who do not have livestock.

Applied in a mixture with mineral fertilization, the effects of farmyard manure and *Lantana camara* compost did not show a significant difference for the number of leaves, flowers, and pods, the harvest survival rate, the number of seed pods, the total biomass, and the number of seeds per treatment. Without organic fertilizer accompaniment, the amounts of these parameters are always significantly smaller than those of treatments carried out with the same organic amendment to which chemical fertilizers are added. Nevertheless, the effects of *Calliandra calothyrsus* treatments and control treatments, whether or not with mineral fertilizers, are significantly lower than those of cow manure for total biomass, number of seeds, and weight of seeds.

Ultimately, *Lantana camara* compost can replace cow manure for haricot bean production. However, the combination of these two types of organic amendments with chemical fertilizers at the rate of 18-46-30 (N-P₂O₅-K₂O) gives better yields. *Calliandra calothyrsus* composts, although known by previous research to improve soil fertility and crop production, do not show performance compared to soil alone not amended by organic manure.

This study was carried out by measurements of bean yield parameters and demonstrated the positive effects of *Lantana camara* compost on bean yield. However, it did not explore the effects of this plant on the properties of the soil. That's why it would be better for further research to look into this aspect. The management aspects of *Lantana camara*, a species recognized as invasive, is also an interesting research theme for integrated soil fertility management. Finally, an exploration of the potential fertilizer effects of tested organic amendments beyond a one-season experiment (residual effect) would be instructive on the potentialities of *Lantana camara* and *Calliandra calothyrsus* in integrated soil fertility management initiatives in Burundi.

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