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Yield Responses of Maize (*Zea mays* L.) and Successive Potato (*Solanum tuberosum* L.) Crops to Maize Stover co-composted with *Calliandra Calothyrsus* Meisn Green Manure

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ABSTRACT

The present investigation aimed at evaluating the effect of Calliandra calothyrsus Meisn green manure on the quality improvement of maize (Zea mays L.) stover compost. To that end, two field experiments were installed with maize (Zea mays L.) and a successive potato (Solanum tuberosum L.) crop, which was specifically set up to investigate the potential residual effects of tested organo-mineral fertilizers. The potato (Solanum tuberosum L.) crop did not receive any fertilizer, either organic or mineral. The experimental design was a randomized complete block with three replicates. The basic experimental plot was 1.6 m wide and 3 m long (4.8 m²). Treatments under evaluation were: T1=Control, T2=Maize stover co-composted with mineral fertilizer, T3=Maize stover co-compost with Calliandra calothyrsus Meisn green manure; T4=Farm manure+45-60-30; and T5=Maize stover co-composted with Calliandra calothyrsus Meisn green manure+45-60-30. Evaluated parameters were grain yields, root biomass, above-ground biomass, Harvest Index, and Root/Shoot ratio for maize (Zea mays L.). Potato yields were categorized into small size (< 35 mm), medium size (35-65 mm) and big size tubers (> 65 mm). Significant effects ($p < 0.001$) of tested fertilizer treatments were observed for maize grain yields (GY), above-ground biomass (AGB), and root biomass (RB). No effect ($p > 0.05$) of fertilizer treatments could be noticed on the harvest index (HI=0.31-0.38) or R/S ratio (0.079-0.088). For the successive potato crop, a significant effect ($p < 0.001$) of tested treatments was only observed for the seed-oriented medium size tubers (MST) potato yield. Overall, the most relevant observation of the maize experiment is that treatments T4 and T5 gave higher and equivalent grain and biomass yields. From there, we derive that maize stover co-composted with Calliandra calothyrsus Meisn green manure could be a sound substitute to farm manure. Additionally, the potato experiment highlighted the residual effects of the T3 treatment, statistically equivalent to that of T2. Consequently, we advise that the effects of compost-based organo-mineral fertilizers on crop yields should be evaluated beyond a single seasonal crop, in order to fully catch their residual fertilizer potentials.

Keywords: Compost, Calliandra Green Manure, Maize, Potato, Residual Effect, Harvest Index

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1. INTRODUCTION

Composts are defined as mixtures of various decaying organic substances as dead leaves or manure used for fertilizing soil [1-4]. In essence, composting is a biochemical process mediated by microorganisms converting various organic components into relatively stable humus-like substances than can be used as soil amendments or organic fertilizers [5]. It is a controlled aerobic process that degrades organic wastes to stable materials, with the resident microbial

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community mediating the biodegradation and conversion processes [6]. Composts are considered organic and slow-release fertilizers, renewable, biodegradable and environmentally friendly with many physical, chemical, biochemical and microbiological attributes [7-16].

A good compost is a mixture of brown material (rich in C) and green materials (rich in N). Compost is better than inorganic N fertilizer because it decreases NO_3^- leaching [17], and thus is a viable alternative to chemical fertilizers [18]. In industrial countries, the interest of relying to compost in crop production at large is a response to increased environmental concerns related to overuse of inorganic fertilizers in this part of the world [19]. On the other side, in developing countries like Burundi, the use of compost is motivated by the willingness in partial or total substitution of animal manures and inorganic fertilizers to which poor subsistence farmers have no or very little access [19].

Sources of composts are numerous. They include industrial wastes such brewery wastes and coffee factory wastes, organic fractions of municipal solid waste, as well as crop residues [20]. The differences between composts rely on the biochemical composition of original organic sources in terms of C/N ratio, nutrient contents, lignin and polyphenols contents [21-23]. The quality of composts depends on the nutrient content of the original composted material according to the variation theory [24]. Hence, sources of easily decomposable C (like molasses, bagasses, legume and non-legume green manures) are of great importance in the composting process N [5, 25].

It is proven that chemical fertilizers increase soil acidity [23, 26, 27]. They are also causes of health risks and environmental hazards [23]. On the other side, numerous investigators have demonstrated the advantages of combining organic residues, animal manure or inorganic fertilizers as well as vermicomposting and the use of effective microorganims on soil physical, chemical and microbiological conditions [10, 12, 23, 26, 28-39]. Accelerating the composting process protects soil health and environment [23], reduces odors, plant pathogens and phytotoxicity, soil air and water pollution [1, 6, 11, 40-43]. It can then be concluded that composted organic materials are associated with soil quality and productivity added to the preservation or improvement of local and global environmental conditions.

Combining organic residues with inorganic fertilizers improve the fertilizer value of the former [44-46]. Added to this fact, previous studies on composting in Burundi high altitude agro-ecological zone have shown an improvement of the quality of traditionally conducted composting by addition of mineral fertilizers and amendments [47]. The investigator has shown a significant increase in the quality of traditionally conducted composting with the addition of mineral fertilizers (2.5 kg DAP, 0.5 kg K_2SO_4) and 0.5 kg dolomitic lime ($CaCO_3.MgCO_3$) per pit of 2 m^3 volume (Table 1). The effect of mineral addition on the increase in compost quality was remarkable for P_2O_5 (160 %) and MgO (100 %), as illustrated in Table 1.

Table 1. Effect of mineral additive on compost nutrient content (% D.M)

Nutrient content	Traditional Compost	Improved Compost	% increase
N	1.24	1.70	37.1
P_2O_5	0.53	1.37	158.5
K_2O	1.08	1.65	52.8
MgO	0.40	0.80	100
CaO	0.87	1.38	58.6

Unfortunately, this approach of using mineral additives to improve compost quality did not meet the interest of Burundian farmers. More used to direct applications of mineral fertilizers in the fields, most of the farmers consider adding mineral fertilizers to organic materials during the composting process as a waste of money.

Maize is one of the most grown cereal crop in Burundi. Recent statistics show that maize (*Zea mays* L.) is the most productive cereal (193,441 MT per year) representing 10.4 % [48] of the total cereal equivalent (CE) of the food

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consumption per year in the country, only surpassed by cassava (*Manihot esculenta* L.) (41 %), and bean (*Phaseolus vulgaris* L.) (17 %).

Calliandra calothyrsus Meisn is a leguminous species originating from South America which is meeting research interest beyond its area of origin [25, 49-50]. The species has been introduced in Burundi for its high N-fixing potential, abundant biomass production and rapid decomposition [50]. In a conclusive statement, these investigators eluded that co-composting low quality crop residues, such as maize (*Zea mays* L.) stover with succulent leguminous green manure could play a stimulatory effect on the overall decomposition and plant nutrient release.

As a follow up research action to the forefront suggestion and analysis, the present investigation aims at evaluating the effect of *Calliandra calothyrsus* Meisn green manure on quality improvement of maize (*Zea mays* L.) stover compost. For that purpose, two field studies were installed with maize (*Zea mays* L.) and a successive potato (*Solanum tuberosum* L.) crop. The successive potato (*Solanum tuberosum* L.) crop experiment was specifically set up to investigate the potential residual effects of applied organo-mineral fertilizers.

2. MATERIALS AND METHODS

2.1. Experimental site and soils

The experiments were installed at Bihunge, Matongo commune, Kayanza Province. The experimental site is characterized by 1970 m of altitude, 1604 mm of average annual rainfall and 20.1° C of mean temperature. Bihunge geographic information is as follows: Latitude = 3°4' South, Longitude = 29°37' East. Soils of Matongo commune are considered of poor quality, acidic, deficient in P, B, Ca, Mg and Al-saturated [51].

Composite soil samples collected at 0-20 cm depth were air-dried, crashed and sieved through a 2-mm sieve. Performed soil chemical analyses included pH, % C, % N, cation exchange capacity (CEC), exchangeable Ca^{2+}, Mg^{2+}, K^{+}, Al^{3+} and H^{+}. Soil pH was measured using a 1:1 soil-water mixture. Organic C was determined using the Walkely-Black wet oxidation method [53]. Organic N was measured as described by Bremner and Mulvaney [54]. Cation exchange capacity (CEC) was determined by the 1 M ammonium acetate saturation method (pH=7.0) [55]. Exchangeable cations were determined by ICP spectrophotometry after extraction by the Mehlich III method [56]. Selected chemical characteristics are shown in Table 2.

2.2 Planting materials and fertilization

Maize (*Zea mays* L.) crop was installed during season 2019A in September 2018. Maize variety used was ZM 605 variety adapted and recommended to medium altitude agro-ecological zone (1200-1800 m) with a potential yield of 3.5-4.5 T/ha [57]. Three maize (*Zea mays* L.) seeds were planted at 40 cm within lines and 75 cm between lines on the 16/10/2018 and harvested on the 2/3/2019 (166 days). Seedlings were thinned to two at the first weeding (66.666 plants/ha). The following potato (*Solanum tuberosum* L.) crop was planted at the same spacing as maize (40 cm x 75 cm) on the 20/3/2019 and harvested on the 21/7/2019 (160 days). Planted potato variety was the Victoria variety with a potential yield of 20-25 T/ha under experimental station conditions [57].

Two weeks before planting maize, an equivalent 1.500 kg/ha of dolomitic lime (CaCO3.MgCO3) was broadcasted over the entire experimental field. Manure and compost were applied at 10 T/ha at the seeding. In treatments receiving mineral fertilizers, all the required quantities of DAP and KCl were applied at planting, while urea application was split: half applied at the first weeding, the remainder at hilling. The potato (*Solanum tuberosum* L.) crop did not receive any fertilizer, either organic or mineral. As mentioned in the introductive remarks, it was set up to evaluate the residual effect of organo-mineral fertilizers applied to the precedent maize (*Zea mays* L.) crop.

2.3 Composting procedure

Maize (*Zea mays* L.) residues were chopped to 3-5 cm length to increase their specific surface area and contact with decomposing microorganisms. The layout of the composting pits measuring 2 m x 1 m with a 1 m-depth (2 m^3) is described in Figure 1 below.

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Figure 1. Composting pit layout

Three layers of maize (*Zea mays* L.) stover of 30 kg-fresh matter each were alternated with two layers of little top soil (as source of microbial inoculum) associated either with mineral fertilizer or 10 kg-fresh matter *Calliandra calothyrsus* Meisn green manure. Pits were covered throughout the composting duration and watered when needed. The pile was turned two times at 1.5-month interval during 4.5 months when the compost reached maturity. Mature compost was dark-brown with a soil-like smell without noticeable unpleasant odor and presence of observable undecomposed calliandra twigs.

Organic materials and manure were ground and kept in labelled polythene bags before chemical analysis using standard procedures. Samples were analysed for pH, % C, % N, % P, % Mg and % Ca. Total N was determined by digestion with sulphuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2) followed by steam distillation [54]. Total C was determined by wet combustion [53]. Total P, K, Ca and Mg were analyzed by ICP spectrometry after digestion with HNO_3 and H_2O_2 at 120°C for 3 hours [56]. Selected chemical properties of the organic materials used in the study are shown in Table 3.

2.4 Measured Parameters

Maize (*Zea mays* L.) grain yields, root biomass, above ground biomass and calculated parameters (Harvest Index and Root/Shoot ratio) were evaluated and compared among the tested treatments. At harvest, maize plants were cut at the stem base (1-2 cm height). Ears were harvested at physiological maturity with hands and grain yield was estimated at 15.5 % moisture. Roots excavation was performed on 4 plants (see Figure 2) with hoes at 0-20 cm soil depth. Soil particles adhering to the sampled roots were carefully removed. Root and shoot samples were subsequently dried at 60°C for 48 hours until constant weight for dry matter determination.

Maize (*Zea mays* L.) and potato (*Solanum tuberosum* L.) yields and yield components were evaluated on plot basis and extrapolated to a hectare basis. Potato yields were categorized into small size (SST < 35 mm), medium size (MST: 35-65 mm) and big size tubers (BST > 65 mm).

2.5 Experimental Design and Statistical Analyses

The experimental design was a randomized complete block with three replicates. Basic experimental plot was 1.6 m wide and 3 m long (4.8 m²). Sampled plants are highlighted in bold red character in figure 3. Treatments under evaluation were: T_1=Control, T_2=Maize stover co-composted with mineral additive, T_3=Maize stover co-composted with *Calliandra calothyrsus* Meisn green manure; T_4=Farm manure+45-60-30; T_5= Maize stover co-composted with *Calliandra calothyrsus* Meisn green manure+45-60-30.

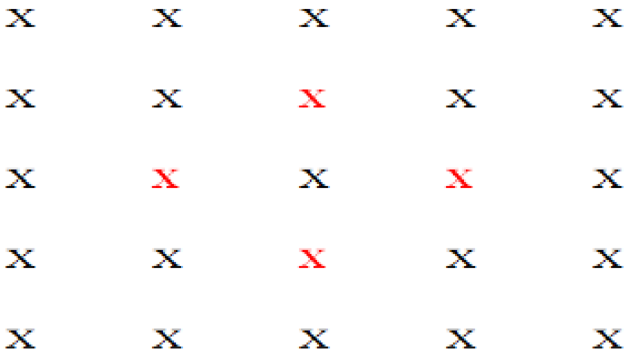

Figure 2. Layout of the experimental parcel, showing sampled plants in bold red character

Statistical analyses were performed using Rcommander software 4.0.2 [58] to determine significant differences between tested treatments. Additionally, a linear regression analysis was performed between maize root and shoot biomass using the same software to estimate the R/S ratio.

3. RESULTS AND DISCUSSION

3.1 Characteristics of the soil used in the study

Soil chemical characteristics of the used soil are given in Table 2. The used soil was acidic, low in organic C and available P content with pronounced deficiencies in Ca^{2+} and Mg^{2+}. However, it was characterized by optimal K^+ content.

Table 2. Soil chemical characteristics

Parameter	Value
pH_{eau}	5.04
% C	1.33
% N	0.13
C/N	10.23
P Olsen (ppm)	46
CEC ($cmol_c$/kg soil)	8.9
Ca^{2+} exchangeable ($cmol_c$/kg soil)	1.76
Mg^{2+} exchangeable ($cmol_c$/kg soil)	0.46
K^+ exchangeable ($cmol_c$/kg soil)	0.68
Al^{3+} exchangeable ($cmol_c$/kg soil)	0
H^+ exchangeable ($cmol_c$/kg soil)	0.25

3.2 Characteristics of the organic materials used in the study

Among used organic materials, maize (*Zea mays* L.) stover compost improved by *Calliandra calothyrsus* Meisn green manure (leaves + twigs) was characterized by lower values of pH, % C, % N, % P, % K, % Ca and % Mg (Table 3). Logically, maize (*Zea mays* L.) stover compost enhanced with mineral fertilizers (DAP, K_2SO_4) and dolomitic lime ($CaCO_3.MgCO_3$) had higher contents in all nutrients and pH. It was only surpassed by the farm manure treatment in pH, % C and % N. The highest pH value was observed in the farm manure, indicating a potential liming capacity of this type of organic material.

Table 3. Chemical analysis of organic materials used in the experiment

Organic material	pH_{H2O}	% C	% N	C/N	% P	C/P	% K	% Ca	% Mg
Farm manure	7.16	15.05	1.55	9.70	0.43	35	1.06	0.32	0.16
MS*+ mineral additive	6.82	13.50	1.42	9.51	0.68	19.85	1.37	0.72	0.28
MS + Calliandra	5.37	3.87	0.58	6.70	0.07	55.3	0.33	0.19	0.05
Maize stover (MS)	6.56	45	0.75	60	0.09	500	0.90	0.13	0.09
Calliandra green manure	5.56	42	3.47	12.1	0.25	168	0.83	0.86	0.26

* Denotes compost maize stover

Maize (*Zea mays* L.) stover compost improved by adding *Calliandra calothyrsus* Meisn green manure and *Calliandra calothyrsus* Meisn green manure itself showed acidic pH values. The highest N content was registered in *Calliandra calothyrsus* Meisn green manure which was also characterized by higher Ca, Mg and N/P (=13.9) values. Maize (*Zea mays* L.) stover alone was deficient in P, Ca and Mg, an indication that, based on the variation theory [24], the experimental site soil was deficient in those particular elements.

A decreased C/N of maize stover co-composted with *Calliandra calothysus* Meisn green manure because of C dissipation observed during the composting process, in accordance to results reported elsewhere [9, 33, 59, 63]. Generally, pH values situated between 6 and 8 are indicative of mature compost [62]. Immature compost with low pH values contain higher concentrations of phytotoxic organic acids with the risks of adversely decreasing crop germination and plant growth [33]. This could be the case of the maize stover co-composted (pH=5.37) with *Calliandra calothyrsus* Meisn green manure, itself of low pH value (=5.56).

Motsara and Roy [61] proposed a quality scale of organic materials based on nutrient content and ratios. The scale is as follows : % N=2-5 ; % P=0.2-0.5 ; % K=1-5 ; % Ca=0.1-1 ; % Mg=0.1-0.4 N/P=10. A high N/P ratio (> 10) is indicative of P deficiency, whereas N is limiting when N/P is low (< 10). Based on Motsara and Roy [61] quality scale, *Calliandra calothysus* Meisn green manure shows an optimal N content, while maize stover compost enriched with fertilizers and dolomitic lime, farm manure and *Calliandra calothyrsus* Meisn green manure were characterized by optimal P concentrations. On the contrary, maize stover compost enriched with *Calliandra calothysus* Meisn green manure was poor in N, P, K and Mg, added to its acidic pH value. Consequently, one would expect low performances of this organic fertilizer on tested crop yields (Table 4).

3.3 Maize yields, Root and Shoot biomass

Significant effects ($p < 0.001$) of tested fertilizer treatments were observed for maize grain yields (GY), above ground biomass (AGB) and root biomass (RB). Maize yields followed a decreasing order: T_4 (5 777 kg/ha) ≈ T_5 (5 647 kg/ha) > T_3 (3 211 kg/ha) ≈ T_2 (2 844 kg/ha) ≈ T_1 (2 166 kg/ha). Compared to the control (T_1), maize yields gains were as follow: + 166.7 % for T_4; + 160.7 % for T_5; + 48.2 % for T_3 and 31.3 % for T_2. A similar ranking order was observed for the above ground (AGB) and root (RB) biomass.

In a previous paper on this specific investigation topic based on growth parameters [62], it was reported that the best treatments T_4 (farm manure+45-60-30) and T_5 (maize stover co-composted with *Calliandra calothyrsus* Meisn green manure+45-60-30) were not significantly different from each other. However, they were significantly superior to T_1 (Control), T_2 (maize stover co-composted with mineral fertilizers and T_3 (maize stover co-composted with *Calliandra calothyrsus* Meisn green manure). The authors concluded that maize stover co-composted with *Calliandra calothyrsus* Meisn green manure could be an effective substitute to farm manure for those farmers without farm animals. Our results shown in Table 4 below confirm and consolidate this assertion.

Table 4. Maize grain yields, biomass productions and harvest indexes

Treatment	GY	AGB	RB	H.I
	--------------------- kg/ha ----------------------			
MS + mineral additive (T_2)	2843.8±515.5**b**	5732.2±507.6**b**	461.8±20.9**b**	0.33±0.02**a**
MS + Calliandra (T_3)	3210.7±496.5**b**	5395.7±1327.2**b**	476.1±170.6**b**	0.38±0.05**a**
MS + Calliandra + 45-60-30 (T_5)	5646.7±367.6**a**	13504.8±957.3**a**	1064.3±40.6**a**	0.30±0.02**a**
FM + 45-60-30 (T_4)	5777.2±479.1**a**	12816.5±741.4**a**	1299.9±45.3**a**	0.31±0.01**a**
Control (T_1)	2165.9±147.6**b**	3840.0±425.1**b**	333.8±28.0**b**	0.36±0.01**a**
Test F	15.53	28.10	28.83	2.00
Probability	0.0003***	< 0.0001***	< 0.001***	0.20NS

Mean values (+ standard deviation) with identical letters within the same column are not statistically different at $p < 0.05$.

3.4 Maize Harvest Index

The harvest index (HI) is a measure of the relative investment of plant resources in reproductive parts (reproductive efficiency). It is the ratio of harvested grain to total shoot dry matter [63]. No effect ($p > 0.05$) of fertilizer treatments could be noticed on the harvest index (HI) ranging from 0.31 (T_4) to 0.38 (T_3), comparable to results observed by Khan et al. [64]. These investigators reported HI values ranging from 0.32 to 0.34 following a wide range of sheep manure (3, 4, 5 T/ha) and N fertilization (0, 90, 120 T/ha) application rates on a maize (*Zea mays* L.) crop.

Table 5 compares HI results generated through our study on maize (*Zea mays* L.) to HI values associated with some commonly grown crops. HI maize values obtained in our study are in the same range as those reported by Khan et al. [64] and Ion et al. [65] on the same crop. They are also comparable to HI values published by Unkovich et al. [66] for peanut (*Arachis hypogea* L.), pea (*Pisum sativum* L.), wheat (*Triticum aestivum* L.), triticale (*Titicum durum x Secale cereale*), barley (*Hordeum vulgare* L.) and canola (*Brassica napus* L.) crops. However, oat (*Avena sativa* L.) shows a lower HI value, while soybean (*Glycine max* L.), sunflower (*Helianthus annus* L.) and sorghum (*Sorghum bicolor* L.) are reported with superior HI values [66-67]. The last investigators also observed a higher HI value for maize (0.52), comparatively to values found in our study as well as those reported by other researchers [64-65].

Table 5. Examples of HI indexes for selected crops

Crop species	HI value	Reference
Canola (*Brassica napus* L.)	0.28	Unkovich et al., 2010 [66]
Peanut (*Arachis hypogea* L.)	0.33	Unkovich et al., 2010 [66]
Soybean (*Glycine max* L.)	0.42	Jiang et al. 2019 [67]
Sunflower (*Helianthus annus* L.)	0.44	Unkovich et al., 2010 [66]
Pea (*Pisum sativum* L.)	0.36	Unkovich et al., 2010 [66]
Wheat (*Triticum aestivum* L.)	0.37	Unkovich et al., 2010 [66]
Triticale (*Titicum durum x Secale cereale*)	0.34	Unkovich et al., 2010 [66]
Barley (*Hordeum vulgare* L.)	0.38	Unkovich et al., 2010 [66]
Oat (*Avena sativa* L.)	0.21	Unkovich et al., 2010 [66]
Sorghum (*Sorghum bicolor* L.)	0.46	Unkovich et al., 2010 [66]
Maize (*Zea mays* L.)	0.52	Unkovich et al., 2010 [66]
Maize (*Zea mays* L.)	0.33	Khan et al., 2017 [64]
Maize (*Zea mays* L.)	0.38	Ion et al., 2015[65]
Maize (*Zea mays* L.)	0.34	This study

It is clear and expected that HI values associated with different crops cover a wide range. Breeding advances aimed at increasing crop yields and targeting short-statured cultivars shifted to higher HI values throughout the years [66]. This could be one of the explanations of the higher HI values reported by Unkovich et al. [66] for maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* L.) in Table 5. Besides the effect of the genetic impact, soil nutrient availability, soil water limitation or excess, and rainfall distribution are some of the abiotic factors that control crop HI variability [68-70]. In addition, maize (*Zea mays* L.) grown under temperate conditions show higher HI values than under tropical conditions, because of shorter grain-filling period in the tropics due to water limitation [66]. Nevertheless, maize harvest index is globally stable [71], as such, it is consequently considered a useful index of crop responses to changing climates [63, 72].

Globally, differences in HI values among crops could also be explained by their growth strategies [66]. Cereal crops like maize (*Zea mays* L.) are determinate crops that allocate more resources to grain production and therefore have high contents of carbohydrates. On the other hand, legume (e.g. soybean) and oil (e.g. sunflower) crops are indeterminate crops with competition between vegetative and reproductive sinks for resources [66].

3.5 Maize Root/Shoot ratios

The R/S parameter represents the relative plant biomass allocated to plant tissues that have supportive functions (roots) to the amount of those (shoots) that have growth functions [71, 73]. Among cereals, maize is characterized by high R/S values [67]. In the investigation reported here, no effect ($p > 0.05$) of tested fertilizer treatments (data not shown) was observed on the root (R) shoot (S) ratio (R/S) which ranged from 0.079 (T_5) to 0.088 (T_3). Our R/S data are corroborated by Khan et al. [64], who reported an absence of either sheep manure or N fertilization application rates on maize (*Zea mays* L.) R/S. Moreover, on 6 maize varieties concomitantly evaluated in China and in the USA, Yu et al. [74] found R/S ratios values ranging from 0.047 to 0.088, with a mean value of 0.08, identical to the value found in our study. In another study conducted in the US Midwest, R/S ranged from 0.04 to 0.13 for maize (*Zea mays* L.) and 0.09 to 0.26 for soybean (*Glycine max* L.) [73].

Estimation of root biomass as a carbon sink in the context of climatic changes is of great interest for agronomists and ecologists alike [75]. These investigators advance that root biomass could be estimated without considering shoot biomass. Although it is tedious, time consuming and not very practical, root biomass estimation through excavation (a destructive method) remains the most accessible methodology, especially when it is completed by correlative analytical methods between root biomass and shoot biomass (easier to measure) [74].

A significant ($p < 0.001$) linear relationship between maize root biomass (Y) and above ground biomass (X) performed on pooled data is illustrated by Equation 1 and Figure 4. The maize R/S value observed in our experiment is 0.088 with a coefficient of variation of 10 %, indicating its narrow variability and stability across organo-mineral fertilizers treatments tested in our maize (*Zea mays* L.) experiment.

$$Y = \mathbf{-}\ 1.998\ (\pm 85.190) + \mathbf{0.088\ (}\pm 0.009)\ X\ ;\ n=15,\ 95\ \%\ \text{confidence intervalle},\ R^2 = 0.87 \qquad \text{Equation 1}$$

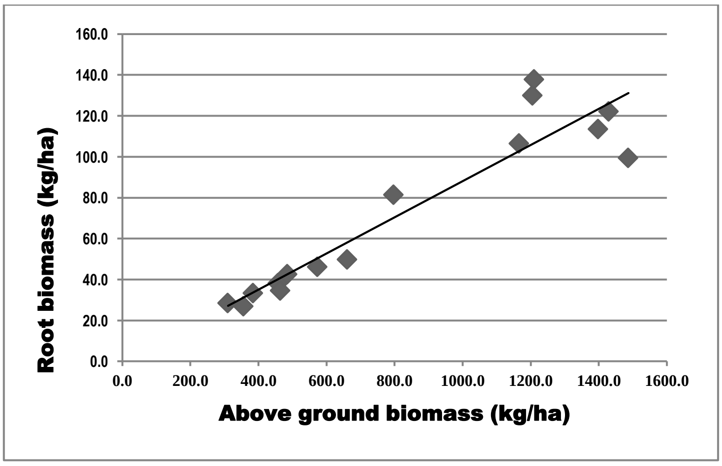

Figure 3. Linear regression between maize root and shoot biomass

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As handy as they could be, allometric relationships between below ground (roots) and above ground (shoots) biomass are affected by some limitations. They rarely take into account the effects of environmental and management factors [73-76]. Fertilisation generally decreases root growth and R/S values, whereas nutrient deficiency increases root growth and subsequently R/S values [74]. Plants under soil nutrient and water stresses increase allocation of photosynthetic resources to roots (high R/S ratios), while plants under light limiting conditions develop and allocate photosynthetic resources to shoot growth (low R/S ratios) [73]. Based on this analytical statement, we can consider that the maize (*Zea mays* L.) crop installed in an open field experiment was not subjected to nutrient or water limitations.

A number of investigators reported that the R/S parameter might be largely variable between and within the same species [75, 77], as in the case of wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.) and oat (*Avena sativa* L.) in Table 6. This variability is believed to be under the control of hormones, abiotic stresses (temperature, rainfall, soil aeration, nutrient deficiencies), genetic variability and farming systems. Organic farming, as in the case of wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.), increases R/S ratios in comparison to conventional farming [75], while high R/S values are indicative of more crop resistance to biotic and abiotic stresses [74, 78].

Table 6. Root shoot (R/S) values associated to selected major crop species.

Crop Species	R/S Values	Reference
Soybean (*Glycine max* L.)	0.18	Ordóñez et al., 2020 [73]
Wheat (*Triticum aestivum* L.)		
Organic farming	0.22	Hu et al., 2010 [75]
Conventional farming	0.12	Hu et al., 2010 [75]
Wheat (*Triticum aestivum* L.)	0.50	Akman, 2018 [79]
Triticale (*Titicum durum x Secale cereale*)	0.30	Akman, 2018 [79]
Barley (*Hordeum vulgare* L.)		
Organic farming	0.20	Hu et al., 2010 [75]
Conventional farming	0.12	Hu et al., 2010 [75]
Barley (*Hordeum vulgare* L.)	0.40	Hu et al., 2010 [75]
Rye (*Secale cereale* L.)	0.51	Hu et al., 2010 [75]
Rye (*Secale cereale* L.)	0.50	Akman, 2018 [79]
Oat (*Avena sativa* L.)	0.25	Hu et al., 2010 [75]
Oat (*Avena sativa* L.)	0.45	Akman, 2018 [79]
Maize (*Zea mays* L.)	0.08	Yu et al., 2015 [74]
Maize (*Zea mays* L.)	0.09	Ordóñez et al., 2020 [73]
Maize (*Zea mays* L.)	0.08	This study

3.6 Residual effect on potato yields and yield components

No significant effect ($p > 0.05$) of tested treatments was observed on yields of small size tubers (SST), big size tubers (BST) and the overall potato yield (Table 7). However, a significant effect ($p < 0.001$) of tested organo-mineral fertilizer treatments was observed for the medium size tuber (MST) potato yield. The highest medium size tuber potato yields were observed for T_3 (8.4 T/ha) closely followed by T_2 (8.2). The lowest MST potato yields were obtained with the T_1 (4.5 T/ha), and to some extent T_5 (6.5) and T_4 (6.3 T/ha).

Considering potato yields of MST (35 mm < diameter < 65 mm), mostly oriented towards seed production, comparatively to the control (T_1), gains in yields were as follow: + 88.4 % for T_3, + 83 % for T_2, + 44.5 % for T_5 and 41.4 % for T_4. Medium size tuber (MST) potato yields represented between 72 (T_1) to 96 % (T_4) of the total potato yield.

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Table 7. Potato yields and yield components

Treatment	**SST**	**MST**	**BST**	**Total**
	------------------------------- T/ha-------------------------------			
MS + mineral additive (T_2)	0.17±0.09**a**	8.18±0.72**a**	0.77±0.41**a**	9.12±1.05**a**
MS + Calliandra (T_3)	0.66±0.30**a**	8.42±0.46**a**	0**a**	9.08±0.74a
MS + Calliandra + 45-60-30 (T_5)	0.45±0.26a	6.46±0.51**ab**	1.28±0.80**a**	8.19±1.07**a**
FM + 45-60-30 (T_4)	0.29±0.11a	6.32±0.14**ab**	0**a**	6.61±0.22**a**
Control (T_1)	0.58±0.25**a**	4.47±0.16**b**	1.15±0.70**a**	6.20±0.59**a**
Test F	0.85	12.39	1. 46	2.91
Probability	0.52NS	0.0007***	0.29NS	0.08NS

Mean values (+ standard deviation) with identical letters within the same column are not statistically different at $p < 0.05$.

Data in Table 7 indicate a reduced non-commercial potato production (sizer < 35 mm) in all treatments, as well as the production of big size tubers (> 65 mm). A similar effect of organic fertilizer on potato size was reported elsewhere [16]. On the contrary, seed-oriented potato production was high (35 mm<diameter<65 mm), particularly for treatment T_3 (maize stover co-composted with *Calliandra calothyrsus* Meisn green manure) and T_2 (maize stover co-composted with mineral fertilizer). The two treatments registered the highest total and medium size tuber potato yields.

In the maize experiment presented and discussed above, these two treatments (T_3 and T_2) were surpassed by treatments T_4 (Farm manure+45-60-30) and T_5 (maize stover co-composted with *Calliandra calothyrsus* Meisn green manure+45-60-30). This lag response of T_3 (maize stover co-composted with *Calliandra calothyrsus* Meisn green manure) and T_2 (maize stover co-composted with mineral fertilizer) is an indication of their potential residual effects. A similar lag effect was reported by other researchers who observed residual effects of compost on successive crops at the second or third cropping season [31, 80, 81].

4. CONCLUSION

Most poor subsistence farmers are economically unable to compensate for nutrients lost through crop exportations out of the farm, erosion and runoff. One of the way out of this dilemma is the valorisation via composting of organic (crop and non crop) sources available on farm. As a reliable component of organic agriculture, compost is a viable economical and environmental alternative or complement to chemical fertilization. As a matter of fact, composts and composting currently meet an increasing interest, especially for poor subsistence farmers, in Burundi and beyond.

In the investigation presented in this paper, significant effects of tested fertilizer treatments were observed for maize grain yields (GY), above ground biomass (AGB) and root biomass (RB). No effect of fertilizer treatments could be noticed on the harvest index (HI), and R/S ratio. For the successive potato crop, a significant effect of tested treatments was only observed for the seed-oriented medium size tuber (MST) potato yield. Overall, the most relevant observation of the maize (*Zea mays* L.) experiment is that farm manure+45-60-30 (T_4) and compost + *Calliandra calothyrsus* green manure+45-60-30 (T_5) gave similar grain and biomass yields. From there, we derive that maize stover compost biologically enriched with *Calliandra calothyrsus* Meisn green manure could be a sound substitute of farm manure, especially for those farmers with few or without domestic animals. Additionally, the potato (*Solanum tubersosum* L.) experiment highlighted the residual effect of the T_3 treatment (maize stover co-composted with *Calliandra calothyrsus* Meisn green manure), comparable to that associated with the treatment T_2 composed of farm manure + inorganic fertilizer (45-60-30). From the second finding, we conclude that effects of organic and organo-mineral fertilizers on crop yields should be evaluated beyond a single seasonal crop, in order to fully catch their residual fertilizer potentials and their sustainability.

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