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Direct and residual fertilizer values of maize (*Zea mays* L.) stover co-composted with *Tithonia diversifolia* (Hemsl.) A. Gray green manure

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ABSTRACT

The present investigation highlights and compares the direct and residual fertilizer values of maize (Zea mays L.) stover composted with Calliandra calothyrsus Meisn and Tithonia diversifolia (Hemsl.) A. Gray green manure on maize (Zea mays L.) and successive potato (Solanum tuberosum L.). Two field studies were installed with maize and a successive potato crops in a completely randomized block design (CRBD) with three replicates. Statistical analyses were performed using Rcommander, version 4.0.2. Grain yields, root biomass, above ground biomass and calculated parameters (Root/Shoot ratio, Harvest Index and GinningRate) were evaluated for maize. Total potato yields were evaluated and categorized into small size tubers (SST < 35 mm) medium size tubers (MST: 35-65 mm) and big size tubers (BST > 65 mm). Treatments under evaluation were: T_1*=Control,* T_2*=Farm (cow) manure alone,* T_3*=Maize stover co-composted with Calliandra calothyrsus Meisn green manure;* T_4*= Maize stover co-composted with Tithonia diversifolia (Hemsl.) A. Gray green manure;* T_5*= Farm (cow) manure+45-60-30;* T_6*= Maize stover co-composted with Calliandra calothyrsus Meisn green manure+45-60-30;* T_7*=Maize stover co-composted with Tithonia diversifolia (Hemsl.) A. Gray green manure+45-60-30; and* T_8*=Farm (cow) manure+FOMI Imbura+FOMI Totahaza. Obtained results indicated highest maize yields with FOMI organo-mineral fertilizers (2.7 T/ha) seconded by the recommended fertilizer practice* T_5 *(2 T/ha). In the same line, highest R/S value (=0.38) was registered with the same FOMI treatment (*T_8*), while the highest HI value (0.21) was observed with the maize stover co-composted with Tithonia diversifolia (Hemsl.) A. Gray (*T_4*). Highest potato total yields were observed with the maize stover compost enriched with Tithonia diversifolia (Hemsl.) A. Gray and supplemented with mineral fertilizer (7.61 T/ha), followed by the same compost without mineral fertilizer addition (6.35 T/ha). We conclude our study with the following statements: i) the highest direct fertilizer value was observed with the FOMI treatment; ii) the residual fertilizer effects were more expressed with the maize stover co-composted with Tithonia diversifolia A. Gray green manure with or without mineral additive, followed by farm manure and maize stover enriched with Calliandra calothyrsus Meisn green manure. Consequently, we restate that the effects of compost-based organo-mineral fertilizers on crop yields should be definitely evaluated on a multiseasonal basis so as to fully capture their residual fertilizer potentials.*

Keywords: Co-composting, Maize, Tithonia, Calliandra, FOMI, Yields, Residual Effect, R/S, HI.

1. INTRODUCTION

Animal manures and crop residues are the main sources of nutrients for plant productivity in Burundi, because farmers are so poor to afford mineral fertilizers [1]. Manure application rates recommended for most crops vary between 5 and 10 T/ha. Such high amounts of organic manure are not or rarely accessible to an average Burundian farmer [2]. Calculations of needed manure made on the basis of the average manure production per animal per year show that for a farmer to access needed amount of manure should possess at least 6 cows (850 kg/year dry matter), 20 pigs or 30 goats/sheeps (250 kg/year D.M). It is evident that very few Burundian farmers could be in possession of such a number of livestock. Consequently, like in most developping countries [3], Burundian farmers are in the obligation of searching and combining other sources of organic sources of fertilizers to sustain crop and food production [4-5].

Moreover, animal manures and crop residues are not only insufficient on the farm, but they are also low in crop nutrient content (see Table 3) [6]. However, such main compost materials could be improved in quality by addition of succulent stems and green leaves of agroforestry species such as: *Tithonia diversifolia* (Hemsl.) A. Gray and *Calliandra calothyrsus* Meisn as complementary sources of N and other nutrients [6-8]. For the last few years, crop residues and green manure management as sources of crop nutrients through the composting process have captured the interest of Burundi soil scientists as a way to increase soil productivity and crop production [1, 8-15].

Although most composting studies have used microrganisms and inorganic fertilizers as compost activators to improve compost quality [1,16-18], soil additives as compost activators could be of different sources. They could be biochar, sappy green manure from fast-growing shrubs (*Calliandra calothyrsus* Meisn, *Gliricidia sepium* (Jacq.) Walp, *Tithonia diversifolia (Hemsl.) A. Gray*), animal wastes (poultry manure, cattle dung, swine manure), earthworms and micro-organisms (*Trichoderma horzianum*) [19-28]. Of recent, Kaboneka et al. (2021) [8] used green manure from *Calliandra calothyrsus* Meisn to improve the fertilizer value of maize (*Zea mays* L.) crop residues. These investigators highlighted the direct and residual fertilizer values of maize (*Zea mays* L.) stover co-composted with *Calliandra calothyrsus* Meisn green manure on maize and successive potato (*Solanum tuberosum* L.) yields and yield components.

Orginated from Mexico (Mexican sunflower), *Tithonia diversifolia* (Hemsl.) A. Gray is an annual, soil restorer and decontaminant, nutrient scavenger, invasive and aggressive weed of 2.5-m height interesting in soil rejuvenation, rehabilitation and soil fertility recuperation. Nowadays widely distributed on farm boundaries, along the roads and pathways in Burundi, this species of the Asteraceae family is also associated to numerous products and services [29-39].

The present investigation was initiated to extent the previous *Calliandra calothyrsus* Meisn study to *Tithonia diversifolia* (Hemsl.) A. Gray. Similary to the previous *Calliandra calothyrsus* Meisn experiment, 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 evaluate the potential residual effects of applied organo-mineral fertilizers.

2. MATERIALS AND METHODS

2.1 Experimental site and soils

The maize (*Zea mays* L.) and potato (*Solanum tuberosum* L.) experiment was installed at Bihunge, Matongo commune, Kayanza Province in the vicinity of the VLIR/UOS-University of Burundi experimental erosion research station. Soils of Matongo commune are considered of poor quality, acidic, deficient in P, B, Ca, Mg and Al-saturated [40].

To characterize the soil used in the experiment, 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, available P, Cation Exchange Capacity (CEC), exchangeable Ca^{2+}, Mg^{2+}, K^{+}, Al^{3+} and H^{+}. Analytical techniques were previously described elsewhere [8]. Selected chemical characteristics of the used soils are indicated in Table 1.

2.2 Planting materials and fertilization

Maize (*Zea mays* L.) crop (variety ZM 605) was installed during season 2020A in September 2019. It was planted on the 6/10/2019 and harvested on the 5/4/2020. The successive potato (*Solanum tuberosum* L.) crop was planted on the 25/4/2020 and harvested on 28/7/2020. All other required cultural operations were executed as previously stated in a recently published paper [8].

Two weeks before planting maize, an equivalent 1.500 kg/ha of dolomitic lime ($CaCO_3.MgCO_3$) was broadcasted over the entire experimental field. Manure and compost were applied at 10 T/ha at maize (*Zea mays* L.) planting. Fertilizers used were DAP, KCl and Urea together with the newly released FOMI organo-mineral fertilizers: Imbura (N-P_2O_5-K_2O-CaO-MgO: 9-22-4-13-2) as the main source of P, and Totahaza (N-P_2O_5-K_2O-CaO-MgO: 21-0-8-4-2) as a source of N. The combined FOMI formulations brought 45 kg N, 60 Kg P_2O_5, 19 kg K_2O, 39 kg of CaO and 8 kg of MgO from 270 kg FOMI Imbura and 100 kg FOMI Totahaza. The 45-60-30 recommended mineral formula for maize (*Zea mays* L.) was obtained with the combination of 130 kg DAP, 50 Kg of KCl and 50 kg Urea. Compared to the classic mineral fertilizers (DAP, KCl, and Urea), the FOMI formulations brought about half of the recommended K_2O. However, it added Ca and Mg nutrients. FOMI Imbura, DAP and KCl were totally applied at maize (*Zea mays* L.) planting, while Urea and FOMI Totahaza were applied half at the first weeding, the remainder half at hilling as was previously reported [8].

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2.3 Composting procedure, chemical analyses of organic materials and measured field parameters

Composting procedures as well as chemical analyses performed on organic materials used in the study can be found in a recently published paper [8]. Measured maize (*Zea mays* L.) parameters were grain yields, root biomass, above ground biomass, ginning rate (GR) and calculated parameters were Root/Shoot ratio (R/S) and Harvest Index (HI). Potato yields were categorized into small size (< 35 mm), medium size (MC: 35-65 mm) and big size tubers (> 65 mm). Both crop yields and yield components were evaluated on plot basis and extrapolated to a hectare basis.

2.4. Experimental Design and Statistical Analyses

The experimental design and field protocol were similar to those used in the *Calliandra calothyrsus* Meisn experiment recently published [8]. Treatments under evaluation in the present field study were: T_1=Control, T_2=Farm (cow) manure alone, T_3=Maize stover co-composted with *Calliandra calothyrsus* Meisn green manure; T_4= Maize stover co-composted with *Tithonia diversifolia* (Hemsl.) A. Gray green manure; T_5= Farm (cow) manure+45-60-30; T_6= Maize stover co-composted with *Calliandra calothyrsus* Meisn green manure+45-60-30; T_7=Maize stover co-composted with *Tithonia diversifolia* (Hemsl.) A. Gray green manure+45-60-30; and T_8=Farm (cow) manure+FOMI Imbura+FOMI Totahaza.

Statistical analyses were performed using Rcommander, version 4.0.2 [41] to determine significant differences between tested treatments. Additionally, a linear regression analysis was performed between maize root and shoot biomass using the same statistical package 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 1 which shows a soil characteristically very acidic, deficient in available P, deficient in Ca^{2+} and Mg^{2+} with a high risk of Al toxicity [42].

Table 1. Soil chemical characteristics of used soil

Parameter	Value
pH_{H2O}	4.03
% C	4.12
% N	0.48
C/N	8.50
P Olsen (ppm)	10.20
CEC ($cmol_c$/kg soil)	6.80
Exchangeable Ca^{2+} ($cmol_c$/kg soil)	2.84
Exchangeable Mg^{2+} ($cmol_c$/kg soil)	0.25
Exchangeable K^+ ($cmol_c$/kg soil)	0.15
Exchangeable Al^{3+} ($cmol_c$/kg soil)	3.29
Exchangeable H^+ ($cmol_c$/kg de soil)	1.49
Al Saturation (%)	48.38
Ca^{2+}/Mg^{2+}	11.36
Mg^{2+}/K^+	1.67
$(Ca^{2+}+Mg^{2+})/K^+$	20.6

3.2 Characteristics of organic materials used in the study

Nutrient contents of organic materials used in the present study shown in Table 2 were evaluated based on Motsara and Roy norms [43]. These are as follows: N: 2-5 %; P : 0.2-0.5 % ; K : 1-5 % ; Ca : 0.1-1 % ; Mg : 0.1-0.4 %. Other normative indicators of organic materials and mature composts are: pH=7 for plant-made compost and pH=9 for animal manure compost; C/N=25-30; C/P=200; C/S=400 ; N/P=10 ; Ca/Mg=1-2.5 ; Mg/K = 0.08-0.1 ; (Ca+Mg)/K=0.2-0.28 [22, 44].

Based to the above indicators, alkaline to near neutral pH values were observed for farm manure, *Tithonia diversifolia* (Hemsl.) A. Gray green manure and maize stover composted with *Tithonia diversifolia* (Hemsl.) A. Gray. On the contrary, *Calliandra*

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calothyrsus Meisn green manure showed an acidic tendency, which did not tanslate in the maize stover co-composted with *Calliandra calothyrsus* Meisn green manure. Maize (*Zea mays* L.) stover composted with *Tithonia diversifolia* (Hemsl.) A. Gray green manure showed a very low % C content (4.15) and subsequantly low C/N (3.35), indicating a strong C dissipation during the 4.5-month composting process. To little extent, a similar situation could have occurred for maize stover co-composted with *Calliandra calothyrsus* Meisn green manure with % C=10.48 and C/N ratio of 14.36. We deduct from these findings that maize stover improved with *Tithonia diversifolia* (Hemsl.) A. Gray and *Calliandra calothyrsus* Meisn green manures should be shortened.

It is widely accepted that, for organic materials to easily decompose and release N, their C/N ratios are to be equal to 25 or less and their C/P ratios equal to 200 or less [45], supposedly ideal for crop production without any restrictions [46]. Based on the criteria, set aside maize (*Zea mays* L.) stover with high C/N (=54.51) and C/P (=244.7), all other organic materials are characterized by values lower than critical C/N and C/P thresholds for immobilisation/mineralization of organic materials [35].

Among compost and farm manure treatments, farm manure had a higher % N content, followed by maize (*Zea mays* L.) stover compost improved with *Tithonia diversifolia* (Hemsl.) A. Gray green manure. The same trend could be noticed for % P, % K, % Ca and % Mg contents which were higher in farm manure. When uncomposted organic materiels are scrutinized, it is apparent that *Tithonia diversifolia* A. Gray green manure contained higher % N, % P, % K and % Ca contents, which did not translate in a better derived compost quality. It is also worth noting that *Tithonia diversifolia* (Hemsl.) A. Gray green manure has a unique trait to contain as much N as K, as was also reported elsewhere [37].

Interestingly, compared to farm manure, maize (*Zea mays* L.) stover compost improved with *Calliandra calothyrsus* Meisn and *Tithonia diversifolia* (Hemsl.) A. Gray green manure were poorer in K, although the original organic materials, particularly *Tithonia diversifolia* (Hemsl.) A. Gray green manure, contained substantial K content (Table 2).

Table 2. Chemical composition of used organic materials

Organic material	pH_{H2O}	% C	% N	C/N	% P	C/P	% K	% Ca	% Mg
Farm manure	7.77	17.84	1.89	9.44	0.40	44.8	1.78	1.08	0.25
Compost + Calliandra	6.11	10.48	0.73	14.36	0.13	83.2	0.22	0.53	0.10
Compost + Tithonia	6.69	4.15	1.24	3.35	0.14	29.6	0.26	0.38	0.07
Maize stover	6.19	44.05	0.81	54.51	0.18	244.7	1.52	0.36	0.03
Tithonia green manure	6.82	42.77	3.87	11.05	0.50	85.54	3.79	1.35	0.25
Calliandra green manure	5.56	43.46	3.46	15.56	0.36	120.72	1.18	1.04	0.25

Among the six major plant nutrients (N, P, K, Ca, Mg, S), K is the only non-structural element of plant tissue [46]. Wether a nutrient is a structural or non-structural component of plant tissues will affect its release dynamics during plant material composting and decomposition. Potassium (K) is present in the plant tissues as a freely moving cation in the cell fluid in the xylem and phloem, regulating plant osmotic pressure and stomata movement [47]. Thus, it is easily leached out and lost when the cell mebranes disintegrate during crop residue decay following direct soil application or composting [9,48]. For that matter, K release from organic residues is not correlated with biotic factors as compared to other nutrients, such N, S, P, Ca and Mg [46]. Thus, K requires a particular management during composting. It should be recuperated in the leachate juice and used in the composting watering process.

Many investigators [29, 32, 43] have shown interests to the potentialities of *Tithonia diversifolia* (Hemsl.) A. Gray green biomass. These investigators advanced that *Tithonia diversifolia* A. Gray green manure increase soil microbial activity, as well as P desorption under acidic conditions [49-50]. The potentialities of the species are associated with symbiosis of arbuscular fungi of the Glomaceae family. Such symbiosis increase macronutrient (P) and micronutrients (Zn, Cu, B) plant uptake even on degraded soils. Sharrock et al (2004) [32] studied mycorrhizas infection of *Tithonia diversifolia* (Hemsl.) A. Gray in 11 countries of America, Asia and Africa (Costa Rica, Nicaragua, Honduras, Mexico, Colombia, Venezuela, Ecuador, Indonesia, the Philippines, Kenya, Rwanda). These researchers did not identify ectomycorrhizas but observed arbuscular mycorrhizas (Glomaceae) with colonization ranging from 0 to 80 % with an average of 40 %.

Partley et al. [35] rightly stressed the relevance of plant biomass quality in the decomposition and plant nutrient release to subsequent crops. Table 3 compares the two agroforestry species used in the present study together with common cereal residues to commonnly disseminated leguminous species, in terms of nutrient contents and nutrient ratios.

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Table 3. Nutrient content and ratios of common agroforestry species

Species	% N	% P	% K	% Ca	% Mg	% C	C/N	C/P	N/P
Senna spectabilis (1)	2.99	0.26	0.54	0.65	0.51	46.62	15.61	179.7	14.33
Leucaena leucocephala (1)	2.56	0.20	0.62	1.28	0.61	47.87	18.70	240.7	10.75
Gliricidia sepium (1)	2.87	0.30	0.64	0.80	0.65	47.10	16.41	157.4	9.57
Tithonia diversifolia (2)	3.87	0.50	3.79	1.35	0.25	42.77	11.05	85.54	7.74
Calliandra calothyrsus (2)	3.46	0.36	1.18	1.04	0.25	43.46	15.56	130.72	9.61
Maize stover (2)	0.81	0.18	1.52	0.36	0.03	44.05	54.51	244.7	4.50
Wheat straw (3)	0.55	0.04	1.04	0.29	0.06	42.00	76.4	1054	13.75

(1) Partley et al. (2011) [35] (2) This study (3) Kaboneka et al. (2021) [14]

Interestingly, *Tithonia diversifolia* (Hemsl.) A. Gray, a member of the Asteraceae family is characterized by higher N, P, K and Ca but lower Mg contents as compared to the common leguminous species indicated in Table 3. This is an indication of the high potential of *Tithonia diversifolia* (Hemsl.) A. Gray species, as a green manure source of major nutrients, a potential not fully exploited and valorized in the Burundi context of poor and nutrient depleted soils [40] through co-composting with cereal crop residues characterized by very low concentrations in nutrients such as N, P, Ca and Mg (Table 3).

3.3 Maize yields, Root and Shoot biomass

Table 4 indicates significant effects of organo-mineral fertilizers on maize yields, aboveground and root biomass productions ($p < 0.001$). Only two treatments (T_8 and T_5) were significantly superior to the control (T_1) based on the Newman and Keuls mean comparison test. The highest maize yield was obtained with the FOMI organo-mineral fertilizer (2.7 T/ha) seconded by the currently recommended fertilizer practice T_5 (2 T/ha). Other treatments, including farm manure alone as well as calliandra- and tithonia-improved maize stover compost were characterized by low (1-1.5 T/ha) to insignificant maize yields (0.1 T/ha for the control). The extremely low yields obtained with the unfertilized control treatment is an indication of the low soil fertility level of the experimental site (Table 1).

When treatments receiving mineral fertilizer (45-60-30) are compared, maize grain yields (GY) followed the decreasing order: $T_5 \geq T_6 \geq T_7$, highligting that farm manure with fertilizer performed better than maize stover co-composted with *Calliandra calothyrsus* Meisn and *Tithonia diversifolia* (Hemsl.) A. Gray green manure. Addition of 45-60-30 mineral fertilizer to maize + calliandra compost increases the yields of the former treatment by 77 %. Similar comparisons between T_5 (FM +45-60-30) and T_2 (FM alone) show an addititive fertilizer value of 61 %. Fertilizer addition to maize compost improved with *Tithonia diversifolia* A. Gray green manure improved maize yields by only 18 %. This difference is presumably due to the farm manure higher nutrient contents comparatively to calliandra- and Tithonia-maize compost, as it was shown in Table 2. In actual fact, the farm manure effect is also observed when we consider and compare maize yields between treatments without fertilizer application, the order becomes as follows: $T_2 \geq T_4 \geq T_3$.

Table 4. Effect of organo-mineral fertilizers on maize grain yields, above ground and root biomass

Treatment	GY	AGB	RB
	T/ha		
Compost+Tithonia+45-60-30 (T_7)	1.20±0.66abc	18761.4±2478.79a	4633.4 ±376.0ab
Compost+Tithonia (T_4)	1.02±0.11bc	5220.1±540.7c	1340.8 ±321.1cd
FM+45-60-30 (T_5)	2.00±0.15ab	19627.0±300.1a	6317.0 ±1080.5a
Compost + Calliandra (T_3)	0.85±0.03bc	4454.5±305.8c	814.8 ±164.9d
FM+Imbura+Totahaza (T_8)	2.70±0.50a	14884.6±2267.7ab	5527.9 ±955.3a
Farm Manure (T_2)	1.24±0.18abc	9010.1±691.2bc	1961.5 ±211.7bcd
Compost+Calliandra+45-60-30 (T_6)	1.50±0.31abc	17407.2±3220.9a	3594.7 ±572.6abc
Control (T_1)	0.09±0.03c	1373.4±409.8c	266.7 ±57.4d
Test F	5.67	5.81	15.28
Probability	0.0006***	0.0005***	< 0001***

Mean values with identical letters within the column are not statistically different at $p < 0.05$.

Production of the above ground biomass (AGB) followed the order: $T_5 \geq T_7 \geq T_6$, indicating that the three treatments were statistically equivalent. However, they were not statistically different from treatment T_8 (Farm manure + Imbura + Totahaza),

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itself not significantly different from the treatment receiving farm manure alone. Lowest AGB values were observed with the control treatment (T_1) and maize stover co-composted with *Calliandra calothyrsus* Meisn (T_3) and *Tithonia diversifolia* (Hemsl.) A. Gray (T_4) green manures. Highest root biomass (RB) values were registered for treatments T_5, T_8, T_7 followed by T_6 treatment. The remaining treatments were characterized by lower RB values ranging from 266.7 (T_1) to 1961.5 (T_2) T/ha.

3.4 Maize Harvest Index and Root/Shoot ratios

Table 5 shows the effect of tested organo-mineral fertilizer treatments on maize Root/Shoot ratio (R/S), harvest index (HI) and ginning rate (G.R). Analysis of variance completed with the test of Newman and Keuls indicates the absence of effects of tested treatments on R/S and G.R ($p > 0.05$), but a significant effect for HI instead. The highest R/S rations were registered with farm manure (FM)+Imbura+Totahaza (R/S=0.38) and the FM+45-60-30 (R/S=0.32) treatments, while the lowest R/S value (=0.19) was obtained with the treatment consisting of maize stover co-composted with *Calliandra calothyrsus* Meisn green manure (T_3).

Linear equation below indicates that the average maize R/S value observed in our experiment was 0.276 with a coefficient of variation of 5 %, indicating its narrow variability and stability across organo-mineral fertilizers treatments tested.

$Y = - 224.80 (\pm 171.692) + 0.276 (\pm 0.013) X$ (n=15, 95 % confidence interval, $R^2 = 0.935$)

Table 5. Effect of organo-mineral fertilizers on maize R/S ratios, H.I index and ginning rate (G.R)

Treatment	R/S	HI	G.R
Compost+Tithonia+45-60-30 (T_7)	0.26±0.03a	0.06±0.03c	0.61±0.07a
Compost+Tithonia (T_4)	0.28±0.10a	0.21±0.03a	0.78±0.01a
FM+45-60-30 (T_5)	0.32±0.05a	0.10±0.01abc	0.67±0.02a
Compost + Calliandra (T_3)	0.19±0.04a	0.19±0.02ab	0.73±0.01a
FM+Imbura+Totahaza (T_8)	0.38±0.04a	0.18±0.02ab	0.66±0.06a
Farm Manure (T_2)	0.22±0.01a	0.14±0.01abc	0.75 ±0.01a
Compost+Calliandra+45-60-30 (T_6)	0.22±0.04a	0.09±0.01bc	0.65 ±0.03a
Control (T_1)	0.23±0.06a	0.10±0.04abc	0.54 ±0.18a
Test F	1.48	5.14	1.16
Probability	0.22 NS	0.0011**	0.36NS

Mean values with identical letters within the column are not statistically different at $p < 0.05$.
NS = non significant ($p > 0.05$).

The average R/S value accross treatments was equal to 0.28, three times higher than the R/S value obtained in a previous similar research work on maize stover co-composted with *Calliandra calothyrsus* Meisn green manure [8]. The latter experimental study was installed on a soil of better fertility level than the current study. It is accepted that fertilisation generally decreases root growth and R/S values, whereas nutrient deficiency increases root growth and subsequentlt R/S values [51]. Plants under soil nutrient stresses increase allocation of photosynthates to roots leading to highe R/S ratios [51-54], as it was the case in the present study.

The harvest index (HI) parameter was significantly affected by the organo-mineral fertilizer treatments ($p < 0.05$). Observed HI ranged from the highest value of 0.21 registered with the maize stover compost enriched with *Tithonia diversifolia* (Hemsl.) A. Gray green manure (T_4), to the lowest values of 0.1 noted with T_5 (FM+45-60-30), T_6 (Compost+Calliandra+45-60-30) and T_1 (control). Purely organic treatments (T_4, T_3, T_2) and the organo-mineral fertilizer FOMI (T_8) were characterized by highest HI values as compared to treatments with mineral additions (T_7, T_6) and the control (T_1). However, values of H.I. obtained in the present experiment performed on a chemically marginal soil (see Table 1) were lower than those obtained in a previous and similar research work performed on a better soil [8]. We deduct from the two studies that R/S ratios evolve inversely to HI values. Lower R/S values were associated with higher HI values in the previous study [8], while the present study conducted on a poor soil shows that higher R/S values are associated with lower HI values. Increased root growth is related to the plant's strategy of maximizing the absorption of nutrients present in small amounts. This means that plants subjected to nutrient stress invest in root growth with high R/S ratios, while plants under optimal soil nutrient conditions optimize their reproductive growth with high HI values. These observations are supported by other investigators [55-56].

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The ginning rate (GR) parameter is calculated as the ratio between the grain weight over the weight of the grain+cob weight of maize (*Zea mays* L.). It is an indication of the grain filling potential of maize (*Zea mays* L.). Statistical analysis completed with mean separation using Newman and Keuls test did not show any effect of the organo-mineral fertilizer treatments on GR parameter ($p > 0.05$). Ginning rate (GR) varied between 0.54 to 0.78. Highest GR values (0.78) were observed for the maize (*Zea mays* L.) stover compost enriched with *Tithonia diversifolia* (Hemsl.) A. Gray green manure(T_4), followed by the farm manure treatment alone (T_2) and the maize (*Zea mays* L.) stover co-composted with *Calliandra calothyrsus* Meisn green manure (T_3). The organo-mineral fertilizer FOMI was characterized by a GR value (0.66) close to that of the FM+45-60-30 (T_5) and maize compost+Calliandra+45-60-30 (T_6). The lowest GR value (0.54) was registered for the control treatment (T_1).

3.5 Residual effect on potato yields and yield components

Table 6 shows total yield and yield components of Victoria potato veriety in response to tested organo-mineral treatments.

Table 6. Residual effects of organo-mineral fertilizers on yield and yield components of potato

Treatment	SST	MST	BST	Total
	------------------------------------T/ha	--------------------------------------		
Compost+Tithonia+45-60-30 (T_7)	0.58±0.11a	6.88±0.92a	0.15±0.15a	7.61±0.90a
Compost+Tithonia (T_4)	0.35±0.12a	5.80±0.38ab	0.20±0.20a	6.35±0.31a
FM+45-60-30 (T_5)	0.63±0.18a	5.38±0.55ab	0a	6.01±0.67a
Compost + Calliandra (T_3)	0.55±0.15a	5.33±0.89ab	0a	5.88±0.96a
FM+Imbura+Totahaza (T_8)	0.55±0.12a	4.48±0.19abc	0.65±0.65a	5.68±0.44a
Farm Manure (T_2)	0.78±0.15a	3.70±0.19bc	0.60±0.38a	5.08±0.40ab
Compost+Calliandra+45-60-30 (T_6)	0.65±0.33a	3.98±0.72bc	0.30±0.30a	4.93±0.59ab
Control (T_1)	0.20±0.04a	2.23±0.41c	0a	2.43±0.37ab
Test F	1.11	5.81	0.77	5.34
Probability	0.39NS	0.0005***	0.62NS	< 0.001***

Mean values with identical letters within the column are not statistically different at $p < 0.05$.
NS = non significant ($p > 0.05$).

No effect of the treatments was observed for small (SST)- and big-sized (BST) potato calibers ($p > 0.05$), while significant differences were noticed for potato total yields and medium-sized caliber ($p < 0.001$). Most of the potato yield (70-92 %) belongs to the medium-sized tubers (MST) in the following proportions: T_1 (91.8 %), T_4 (91.3 %), T_3 (90.6 %), T_7 (90.4), T_5 (89.5 %), T_6 (80.7 %), T_8 (78.9 %) and T_2 (72.8 %).

The highest total potato yield (7.61 T/ha) was observed with the maize (*Zea mays* L.) stover compost enriched with *Tithonia diversifolia* (Hemsl.) A. Gray green manure (T_4) supplemented with mineral fertilizer (45-60-30), followed by the maize stover co-composted with *Tithonia diversifolia* (Hemsl.) A. Gray alone (6.35 T/ha), and the recommended organo-mineral treatment (6.01 T/ha). The control treatment had the lowest total yield (2.43 T/ha). Total yields of remaining treatments varied from 4.93 T/ha (T_6) to 5.88 T/ha (T_3).

It can surprisingly be drawn from Table 5 that the maize stover compost improved with *Calliandra calothyrsus* Meisn green manure (T_3) was superior to the same compost supplemented with mineral fertilizer (T_6). However, in the maize study, it was the opposite: the yield associated with T_6 treatment 1.5 T/ha) was nearly twice of the T_3 treatment (0.85 T/ha). This is an indication that T_3 treatment had a higher residual effect than T_6 treatment. However, this observation was not verified for treatments receiving *Tithonia diversifolia* (Hemsl.) A. Gray green manure.

In general, maize (*Zea mays* L.) yields followed the decreasing order: $T_8 \geq \mathbf{T_5} \geq T_6 \geq T_2 \geq \mathbf{T_7} \geq \mathbf{T_4} \geq T_3 \geq T_1$. An inversion of the yield tendency for potato as compared to maize yield was observed. Potato yields followed the order: $\mathbf{T_7} \geq \mathbf{T_4} \geq \mathbf{T_5} \geq T_3 \geq T_8 \geq T_2 \geq T_6 \geq T_1$. Comparing the maize (*Zea mays* L.) and potato (*Solanum tuberosum* L.) yields ranking, we deduct that residual effects are more expressed for maize (*Zea mays* L.) stover co-composted with *Tithonia diversifolia* (Hemsl.) A. Gray green manure with (T_7) or without (T_4) mineral additive.

An analysis of variance performed on total number of potato tubers per plant and its distribution in small, medium and big-sized caliber is shown in Table 7. No significant differences were observed between tested treatments for the small-sized and big-sized Victoria potato calibers ($p > 0.05$). On the contrary, significant effects of treatments on medium and total number of tubers per

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plant were noticed ($p < 0.05$). In the same line, only treatments T_7 and T_4 were statistically superior to the control (T_1) for the number of medium-sized number of tubers per plant, whereas treatments T_7, T_3 and T_2 yielded significantly higher total number of tubers as compared to the control treatment (T_1).

Most of the potato tubers (64-76 %) were in the medium-sized category which is oriented towards seed production. The remainder was in the small-sized category with proportions varying between 20 % (T_7, T_4) to 35 % (T_5, T_2, T_6, T_1). Proportion of the big-sized category was nil or almost nil for all treatments.

Table 7. Residual effects of organo-mineral fertilizers on number of potato tubers

Treatment	SST	MST	BST	Total
	----------------------------	number/plant	----------------------------	
Compost Maize +Tithonia+45-60-30 (T_7)	1.03±0.28a	3.50±0.39a	0.05±0.05a	4.58±0.32a
Compost+Tithonia (T_4)	0.93±0.11a	3.20±0.20a	0.05±0.05a	4.18±0.20ab
FM+45-60-30 (T_5)	1.43±0.14a	2.60±0.23ab	0a	4.03±0.25ab
Compost + Calliandra (T_3)	1.30±0.42a	2.95±0.46ab	0a	4.25±0.68a
FM+Imbura+Totahaza (T_8)	1.33±0.31a	2.58±0.17ab	0a	3.91±0.19ab
Farm Manure (T_2)	1.50±0.53a	2.70±0.68ab	0.05±0.05a	4.25±0.41a
Compost+Calliandra+45-60-30 (T_6)	1.40±0.62a	2.53±0.16ab	0.05±0.05a	3.98±0.64ab
Control (T_1)	0.80±0.15a	1.50±0.18b	0a	2.30±0.07b
Test F	0.51	5.81	0.57	2.97
Probability	0.82NS	0.0005***	0.77NS	< 0.02*

Mean values with identical letters within the column are not statistically different at $p < 0.05$.
NS = non significant ($p > 0.05$).

Results obtained in the maize (*Zea mays* L.) and potato (*Solanum tuberosum* L.) experiments with regard to residual effects are supported by other investigators [4-5, 57]. More specifically, Gachengo et al. (2000) [30] reported a large residual effect of *Tithonia diversifolia* (Hemsl.) green manure applied at 5 T/ha DM. Additionnally, in an experiment conducted by Ademiluyi et al. (2007) [58], it was shown that application of *Tithonia diversifolia* (Hemsl.) A. Gray green manure drastically increased grain yields, plant height and girth, root and shoot biomass. Addditionally, in a 2-year field study with Triple Superphosphate (TSP), Mijingu and *Tithonia diversifolia* (Hemsl.) A. Gray green manure, Ikerra et al., 2006 [59] reported a significant increase in P availability in soil coupled with increases in maize (Zea mays L.) yields, soil pH (biological liming effect), exchangeable Ca, and a concommittant decrease in exchangeable Al and P-sorption. The findings were also supported by the extensive works of Jama et al. (2000) [29], Nziguheba et al. (2002) [31], Olabode et al. (2007) [33] and Oludare and Muoghalu (2014) [60]. It is worth mentionning that the last investigators additionnally stressed the invasiveness of *Tithonia diversifolia* (Hemsl.) A. Gray leading to reduction in biodiversity in its vegetative surroundings. This might be one of the few drawbacks of *Tithonia diversifolia* (Hemsl.) A. Gray species, which could otherwise be indeniably essential in restoring soil productivity and soil fertility restoration in Burundi, as a green manure with high plant nutrient contents (Table 3).

3.6 Effects on soil pH, % C and N

Table 8 illustrates pH, % C and % N changes following lime and organo-mineral fertilizers application. An analysis of variance performed on the three soil parameters did not show any significant effect of organo-mineral fertilizers application ($p > 0.05$). Nevertheless, in comparison to the original values, soil pH was increased from 4.03 to between 4.9 (+ 22 %) to 5.2 (+29 %), while % N increased from 0.48 to 0.55. On the contrary, % soil organic C decreased from the original value of 4.9 % to 4.13 %. At the moment, we are unable to point out or speculate the reason of this observation on % soil organic C.

Table 8. Residual effect on pH, % C and N

Treatment	pH	% C	% N

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Compost+Tithonia+45-60-30 (T_7)	5.06±0.19a	4.25±0.72a	0.49 ±0.07a
Compost+Tithonia (T_4)	4.92±0.19a	4.31±0.55a	0.47 ±0.06a
FM+45-60-30 (T_5)	4.99±0.04a	4.37±0.46a	0.50 ±0.05a
Compost + Calliandra (T_3)	5.10±0.24a	4.25±0.67a	0.54 ±0.02a
FM+Imbura+Totahaza (T_8)	4.91±0.24a	4.59±0.71a	0.49 ±0.06a
Farm Manure (T_2)	5.23±0.11a	4.62±0.57a	0.55 ±0.03a
Compost+Calliandra+45-60-30 (T_6)	4.99±0.21a	4.46±0.69a	0.55 ±0.03a
Control (T_1)	4.94±0.18a	4.13±0.68a	0.50 ±0.07a
Test F	1.32	0.29	1.26
Probability	0.28 NS	0.95 NS	0.31 NS

Mean values with identical letters within the column are not statistically different at $p < 0.05$.
NS = non significant ($p > 0.05$).

4. CONCLUSION

The present investigation highlights and compares the direct and residual fertilizer values of maize stover composted with *Calliandra calothyrsus* Meisn and *Tithonia diversifolia* (Hemsl.) A. Gray green manure on maize (*Zea mays* L.) and successive potato (*Solanum tuberosum* L.) crop yields and yield components. Grain yields, root biomass, above ground biomass and calculated parameters (Root/Shoot ratio, Harvest Index and ginning rate) were evaluated for maize (*Zea mays* L.). Total potato yields were evaluated and categorized into small size tubers (SST < 35 mm), medium size tubers (MST: 35-65 mm) and big size tubers (BST > 65 mm).

Treatments under evaluation were: T_1=Control, T_2=Farm (cow) manure alone, T_3=Maize stover co-composted with *Calliandra calothyrsus* Meisn green manure; T_4= Maize stover co-composted with *Tithonia diversifolia* (Hemsl.) A. Gray green manure; T_5= Farm (cow) manure+45-60-30; T_6= Maize stover co-composted with *Calliandra calothyrsus* Meisn green manure+45-60-30; T_7=Maize stover co-composted with *Tithonia diversifolia* (Hemsl.) A. Gray green manure+45-60-30; and T_8=Farm (cow) manure+FOMI Imbura+FOMI Totahaza.

Obtained results indicated highest maize yields with FOMI organo-mineral fertilizers (2.7 T/ha) seconded by the recommended fertilizer practice T_5 (2 T/ha). In the same line, highest R/S value (=0.38) was registered with the same FOMI treatment (T_8), while the highest HI value (0.21) was observed with the maize stover co-composted with *Tithonia diversifolia* (Hemsl.) A. Gray (T_4). On the other hand, highest potato total yields were observed with the maize stover compost enriched with *Tithonia diversifolia* (Hemsl.) A. Gray and supplemented with mineral fertilizer (7.61 T/ha), followed by the same compost without mineral fertilizer addition (6.35 T/ha).

We conclude our study by stessing out that the highest direct fertilizer value was observed with the FOMI treatment (T_8). However, the residual fertilizer effects were more expressed with the maize stover co-composted with *Tithonia diversifolia* A. Gray green manure with (T_7) or without mineral additive (T_4), followed by farm manure alone (T_2), and maize stover enriched with *Calliandra calothyrsus* Meisn green manure (T_6). In our precedent publication on *Calliandra calothyrsus* Meisn, we stated that « the effects of compost-based organo-mineral fertilizers on crop yields should be evaluated beyond a single seasonal crop, in order to fully capture their residual fertilizer potentials », this conclusive remark remains pertinent and relevant for the present study.

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