Original Research Article

Maize response to leguminous biomass composted with phosphate rocks in the Northern zone of Tanzania

Mawazo Shitindi[1,2*], Kokoasse Kpomblekou-A[1], Wendell H. McElhenney[1], Ramble Ankumah[1], Johnson Semoka[2], Mateete Bekunda[3], and Conrad Bonsi[1]

*Corresponding author's email: mshitindi@tuskegee.edu / shitindi@sua.ac.tz

[1] Department of Agriculture and Environmental Sciences, Tuskegee University, 36088 AL
[2,] Department of Soil and Geological Sciences, Sokoine University of Agriculture, Morogoro -Tanzania
[3,] IITA- Africa RISING Project, Arusha – Tanzania

ABSTRACT

A study was conducted to evaluate maize response to leguminous biomass composted with phosphate rocks (PRs) in a split plot design. Field experiments were conducted at Wang'waray Farmers Training Center (F.T.C) located in Babati District of Manyara region in the Northern zone of Tanzania between December 2013 and June 2015. Three leguminous (*Crotalaria juncea*, *Lablab purpureus* and *Mucuna pruriens*) strips were cultivated in 2013/14 to produce a biomass which was harvested at flowering to early podding stage and air dried. Air-dry biomass was composted with PRs from Minjingu (medium reactive PR) and Panda Hill (low reactive PR). Maize response to different treatments was evaluated across the field strips in 2014/15 season. The strips previously used to produce leguminous biomass were used as main plots and each strip was divided into seven subplots receiving different treatments at random. A medium term maize variety SC. 627 was used as a test crop. Average maize grain yields obtained from Crotalaria, Lablab and Mucuna strips reached 5.3, 4.5 and 4.0 t ha^{-1}, respectively and were statistically different (P=.05). Application of Minjingu or Panda Hill PR alone didn't increase maize grain yield above the control while Minjingu PR applied with urea or composted with biomass increased maize grain yield by 2.40 and 1.58 t ha^{-1}, respectively above the control. Application of Panda Hill PR with urea or composted with biomass increased grain yield by 1.20 and 1.06 t ha^{-1}, respectively above the control. The observed differences (0.82 and 0.14 t ha^{-1}) were not statistically significant indicating that biomass composted with PR was as effective as the PR applied with urea.

Key words: *Crotaralia, Lablab Mucuna, phosphate rocks, compost, maize yield*

The present address of Mawazo Shitindi is Sokoine University of Agriculture, Department of Soil and Geological Sciences, P.O. Box 3008 Morogoro Tanzania.

1. INTRODUCTION

Maize (*Zea mays*) is Tanzania's most important staple food with an estimated annual per capita consumption of 113 kg, contributing about 60% of dietary calories [1] and [2]. According to [3], the crop also contributes about 50% of Tanzania's rural cash income. However, current production of maize in Tanzania is far below the national average yield potential of 4.8 t ha^{-1}, fluctuating between 1.0 and 1.5 t ha^{-1} [4]. Continuous maize production without or with limited fertilizer application coupled with crop residue removal have been reported as major factors for soil fertility decline and low crop yields [5; 6; 7]. Limited fertilizer use in most developing countries has been attributed to their high costs and limited availability [8; 9].

While food production per unit land is declining because of soil fertility deterioration, the population of Tanzania has more than tripled from 12.3 million to 44.9 million between 1967 and 2012. Based on 2012 census projections, the population was expected to reach 47.42 million people by the year 2016 [10]. This increase in the population will cause additional pressure on arable land because more than 70% of Tanzanians depend entirely on agriculture for their food and income [10]. This calls for integrated soil fertility management programs based on locally available resources so as to improve soil fertility and reduce smallholders' dependence on imported industrial fertilizers.

Phosphate rock (PR) deposits located in Tanzania could serve as alternative source of phosphorus (P) for smallholders but P contained in the rocks is not readily available for plant uptake. Upon decomposition, plant biomass releases low- molecular-weight organic acids that may complex calcium and other metals in the rock to free P for plant uptake [11]. Thus, composting the rocks with leguminous biomass may improve the availability of nitrogen (N) and P for plant uptake. The objective of the field experiment was to investigate carbon (C), N, and P content of three common leguminous plants (*Crotalaria juncea, Lablab purpureus and Mucuna pruriens*) used in Tanzania and the effect of each leguminous biomass when composted with PRs on maize yield. The PRs used were those of Mijingu (a PR of medium reactivity) and Panda Hill (a PR of low reactivity).

2. MATERIALS AND METHODS

2.1 Site Description, Soil Characterization and Fertility Assessment

This study was conducted at Wang'waray Farmers Training Center (F.T.C) located in Babati District of Manyara region in the Northern zone of Tanzania. The site is about 167 km from Arusha and 4.5 km to the South East of Babati town along the road to Mamire Ward. The center is at 1410 m above sea level on the foot hills of mount Kwaraa, and receives a bimodal rainfall with average precipitation around 700-900 mm year^{-1}. However, as with other areas in Tanzania, rainfall distribution at Wang'waray F.T.C and Babati District as a whole has been altered by climate change to such an extent that the two seasons are now not very distinct and average precipitation is less than 700 mm year^{-1}. Figure 1 presents total amount of rainfall[*] received at the site in the year 2015 when maize field experiment was conducted plotted relative to average amount of rainfall recorded in four years preceding the experiment.

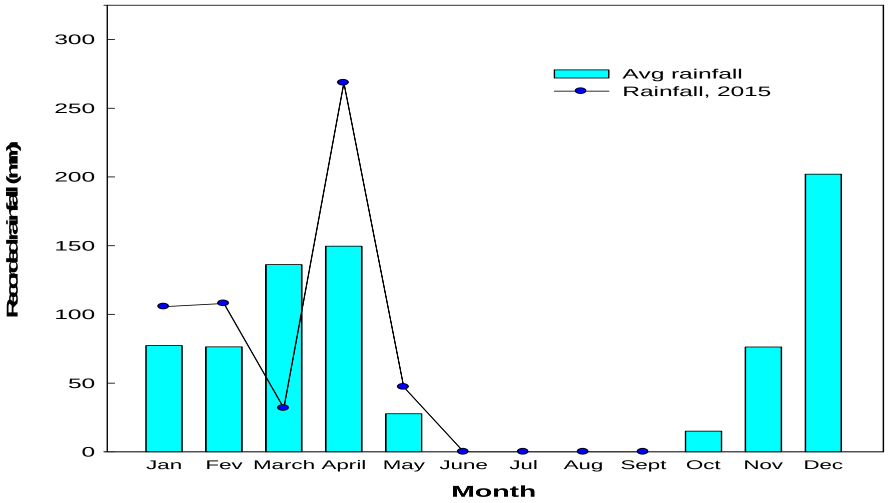

Figure 1. Average (2011-2015) rainfall recorded at Wang'waray F.T.C meteorological station.
[*],*The dots represent rainfall in 2015*

Crop production is a major land use activity at Wang'waray F.T.C. dominated by maize-legume intercropping and rotation systems. Because soils at Wang'waray FTC were not characterized before, a profile was opened and described according to FAO guidelines [12]. Representative profile and surface (0-15 cm) soil samples were collected and shipped to the Soil and Geological Sciences (SGS) laboratory at Sokoine University of Agriculture (SUA) in Morogoro for physical and chemical analyses (Table1). Based on morphological description of the site, and laboratory analyses performed on the profile samples, the soil was classified down to sub group as *Rhodic Eutrostox* using the USDA-NRCS Keys to soil taxonomy [13]. Analyses of representative surface (1-15cm) soil samples collected from the rest of the field were used for assessment of general fertility status of soils.

2.2 Leguminous Biomass Production

Following soil characterization, two portions of the field separated by a contour band were ploughed and harrowed. On each portion of the field, three strips of 5 m x 76 m each were established and randomly assigned to one of the three legume crops (two strips for each cover crop) as shown in Figure 1. *Mucuna pruriens* and *Lablab purpureus* were planted at 50 cm x 30 cm spacing, while *Crotalaria juncea* was drilled at 50 cm inter row spacing. The first weeding was done two weeks after germination and weeding was repeated whenever weeds emerged to keep the competition for moisture and nutrients to a minimum.

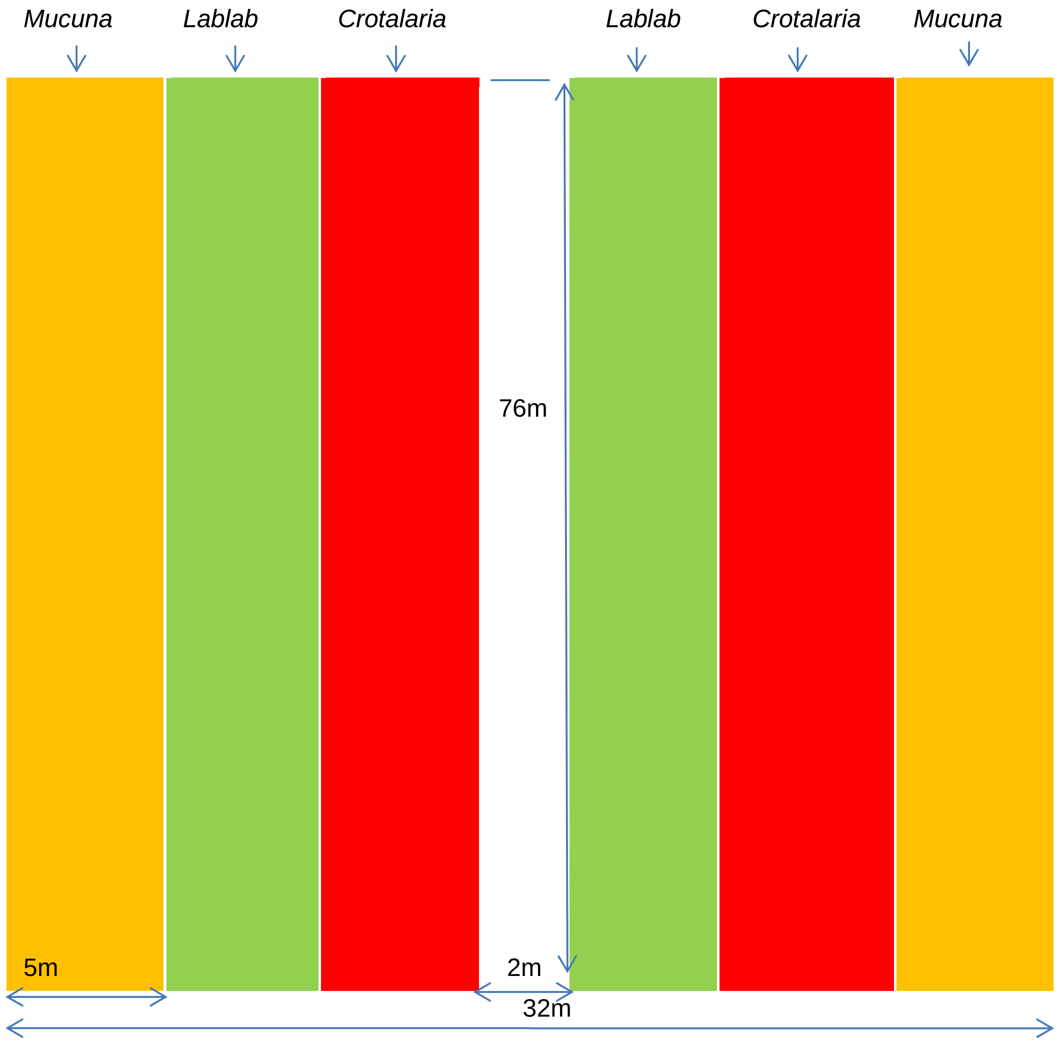

Figure 2. Layout of the field for leguminous crop biomass production at Wang’waray F.T.C

2.3 Carbon, nitrogen and phosphorus contents of the biomass

At flowering - podding initiation stage, the biomass was cut close to the soil surface and air dried by species for later composting with Minjingu or Panda Hill PR. Before composting, the air-dry biomass was chopped into small pieces to increase surface area and thoroughly mixed. Subsamples were collected, oven dried at 55°C for 72 hours, and finely ground to < 0.5mm using a CT 193 Cyclotec™ Sample Mill [Foss Allé 1 Post box 260 DK-3400 Hillerød Denmark] for chemical analyses. Organic carbon (OC) was determined following the Walkely Black procedure [14], while total N was determined following Kjeldahl procedures [15]. For the determination of P and sulfur (S) in the biomass, a 0.5 g sample < 0.5 mm was digested following the HNO_3 - H_2O_2 wet digestion procedure using a 40 space Foss Tecator block digester. Phosphorus content of the digest was determined by a procedure using ascorbic acid method [16], while S content was determined by a turbidity method [17].

2.4 Phosphate Rock Collection, Processing, and Chemical Analysis

Minjingu PR was collected from Minjingu Mines and Fertilizers Company in Manyara region while Panda Hill PR was obtained from a storage facility at SUA. Both PRs were ground to pass a 100-mesh sieve at the Geological Survey of Tanzania (GST) laboratory in Dodoma region. A representative sample was collected from each PR and shipped to the Southern and Eastern Africa Mineral Center (SEAMIC) laboratory in Dar es Salaam for X-ray fluorescence (XRF) analysis.

2.5 Production of Biomass-PR Composts

Previously chopped leguminous biomass (< 2 cm) and ground PRs (< 100 mesh) were composted by the pit method [18] with some modifications. In the modifications, the size of an individual pit was 2 m x 2 m x 1m; floor and walls of each pit were lined with a polyethylene plastic sheet to avoid leaching losses during decomposition. The biomass was composted with a PR in alternating layers (i.e. PR was applied over every layer of biomass) followed by 500g of dried cattle manure to inoculate the biomass. The biomass:PR ratio varied from 12:1 to 18:1 based on the biomass size and N contents. Following inoculation, water was applied to bring the moisture content of the compost mixture to about 60%.

Three PVC aeration pipes were inserted into each compost mix at regular intervals and the material was covered with polyethylene plastic sheets to protect it from rain water and undesirable/ foreign materials. The compost material in each pit was turned into a different pit every 30 days for 120 days to allow optimum decomposition and water was sprinkled at every turn to maintain the moisture at 60%. After the last turn, representative samples were collected from each pit for laboratory analysis and all composts were air dried to around 20% moisture content and stored for later use as source of N and P for maize. Representative samples taken from each pit were shipped to the SUA-SGS laboratory for chemical analysis. In the laboratory, representative compost samples were dried and ground to pass through 0.5 mm for total N, P and SO_4-S analysis as previously described.

2.6 Evaluation of Maize Response to Treatments

The field strips previously used for cover crop biomass production were used in the next season to evaluate maize response to newly imposed treatments (Figure 3).

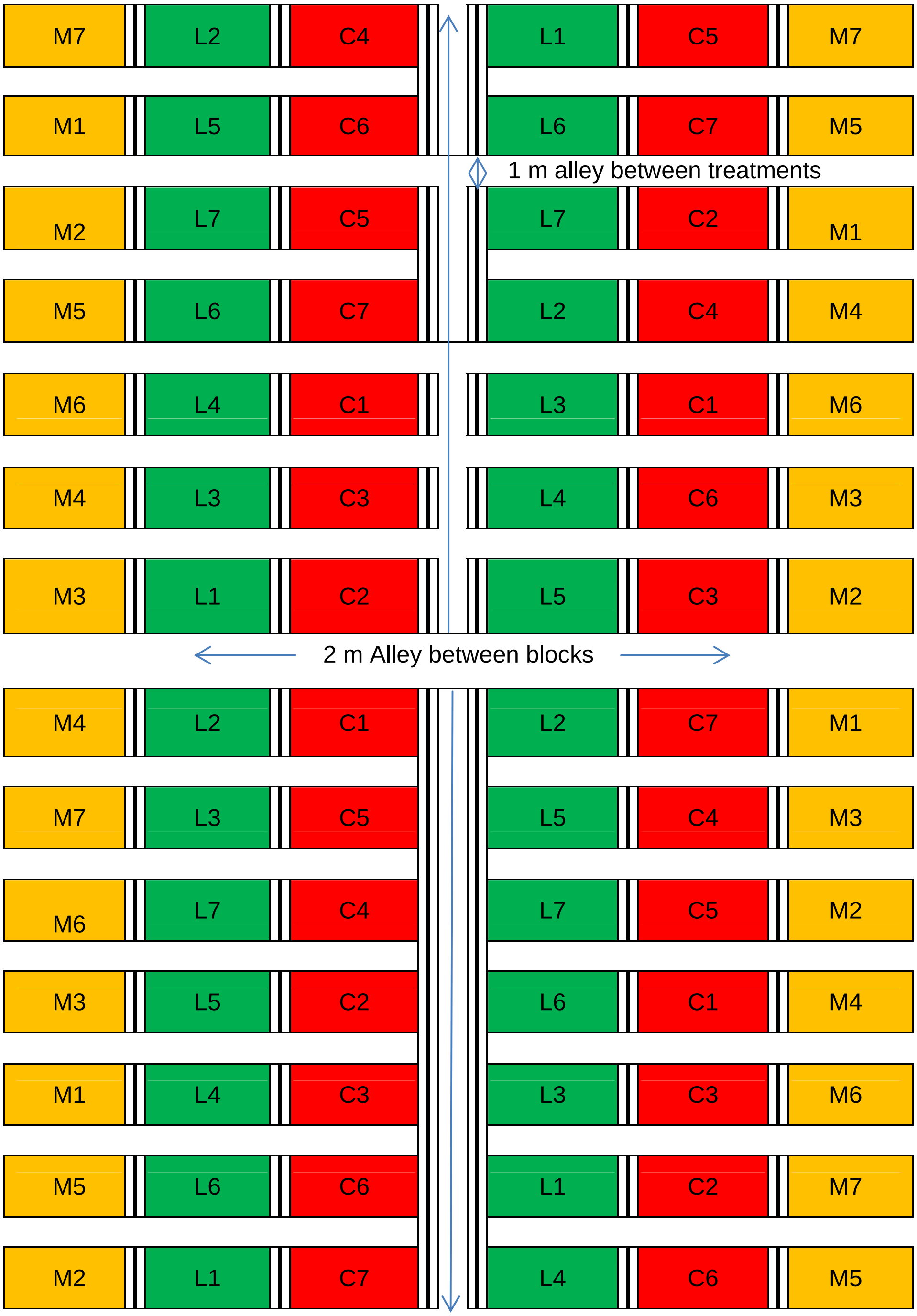

Figure 3. Layout of maize field experiment at Wang'waray FTC

Letters represent legumme species preceding maize on each strip (M = Mucuna, L = Lablab, C = Crotalaria) while numbers (1 - 7) represent treatments imposed on experimental units.

The experiment was designed as a split plot arranged in a randomized complete block design (RCBD). The field was divided into four blocks where half of each strip initially used to produce the crop biomass was used as a main plot within a block and each main plot was divided into seven sub plots (16 m^2) which received randomly assigned treatments. Seven treatments were evaluated on each main plot. These include a common control where maize was grown without external inputs after removal of the crop biomass (1), Minjingu PR alone applied (2), Minjingu PR + urea (3), composted Minjingu PR + biomass (4). Panda Hill PR alone (5), Panda Hill PR + urea (6), and composted Panda hill PR + biomass (7). Thus, treatment combinations were identified as C1to C7, L1 to L7, and M1 to M7 where C, L, and M stand for Crotalaria, Lablab, and Mucuna strip, respectively.

The composts were applied at a rate corresponding to 112 kg N ha^{-1} recommended for maize in the Northern Zone [19]. The PRs were applied at 45kg P ha^{-1} with or without urea while urea was applied at 112kg N ha^{-1} (split application at planting and two weeks following germination) on selected plots based on treatment scheme. A medium term hybrid maize variety (SC.627) was planted at 90 x 30 cm spacing (five rows per plot). At tasselling stage, nine representative ear leaf samples were collected from each plot for nutrient analysis. At maturity stage, maize ears of the three inner rows in each plot were harvested for yield determination. Maize grain yield was reported at 13% moisture content, while maize stover yield from the three inner rows of each plot was reported on oven-dry basis.The data collected were subjected to analysis of variance (ANOVA) using a mixed procedure of SAS software version 9.4 (SAS Instit. Inc. Cary, NC) and the means were separated at P = .05 by Tuckey-Kramer procedure**.**

3. RESULTS AND DISCUSSION

3.1 Fertility status of soil at Wang’waray FTC

Selected physical-chemical analyses of soil at Wang’waray FTC were as presented in table 1. The soil had a medium pH value suitable for production of most crops with a very low electrical conductivity indicating that there were no limitations for crop production due to salt accumulation.

Table 1. Selected chemical properties of surface (0 -15 cm) soil samples at Wang'waray F.T.C

Soil property	Mean value†	Rating	Reference
pH – H_2O	6.88	Medium	[20]
EC (MScm^{-1})	0.05	Very low	[20]
Organic Carbon (g kg^{-1})	14.3	Low	[20]
Total N (g kg^{-1})	1.03	Low	[21]
Bray 1 P (mg kg^{-1})	5.54	Low	[20]
SO_4 – S (mg kg^{-1})	9.38	High	[22]
Exch. Ca (Cmol kg $^{-1}$)	7.40	High	[20]
Exch. Mg (Cmol kg $^{-1}$)	2.96	High	[20]
Exch. K (Cmol kg $^{-1}$)	3.28	High	[20]
Exch. Na (Cmol kg $^{-1}$)	0.27	Low	[20]
PBS (%)	70.9	High	[20]
DTPA Extract. Cu (mg kg^{-1})	3.6	High	[20]
DTPA Extract. Zn (mg kg^{-1})	0.5	Low/medium	[20]
DTPA Extract. Mn (mg kg^{-1})	116.5	High	[20]
DTPA Extract. Fe (mg kg^{-1})	22.0	High	[21]
Sand (g kg^{-1})	643		
Silt (g kg^{-1})	87		
Clay (g kg^{-1})	270		
Textural class	Sandy Clay Loam		[23]

†**,** *Each value is an average of readings of six representative surface soil samples*

Levels of extractable S, exchangeable bases and DTPA extractable Fe, Cu and Mn were all high but the levels of organic carbon, total N, Bray-1 extractable P were low, and therefore limiting. The low levels of organic carbon, N, and P have been reported in highly weathered tropical soils like those of Babati [24].

3.2 Carbon, Nitrogen, and Phosphorus Content of Leguminous Biomass Used

Carbon contents of the leguminous biomass used varied significantly (P=.05) while P contents were not statistically different (P = .05). Chemical composition of plant species grown for compost production is an important factor to take into account because it has effect on the rate at which plant material is acted upon by decomposers to release nutrients in plant available forms. On average, OC contents of the biomass used were 48.7%, 41.6% and 44.5% for Crotalaria, Lablab, and Mucuna biomass, respectively. On the other hand, total N content of the biomass used were 2.4%, 2.3% and 2.0%, while the C:N ratios were 20.1, 18.1, and 22.3 for Crotalaria, Lablab and Mucuna biomass, respectively.

Table 2. Chemical composition of the leguminous biomass used

Crop species	C	N	P	C:N	C:P	N:P
	------------------------	%	---------------------			
Crotalaria juncea	48.7 a	2.44 a	0.37 a	20.1	136	6.74
Lablab purpureus	41.6 ab	2.30 a	0.34 a	18.1	124	6.76
Mucuna pruriens	44.5 b	2.00 b	0.36 a	22.3	122	5.75
LSD	6.30	0.14	0.05	-	-	-

†, Values in the same column followed by the same letter are similar (P = .05)

The total N values determined in all leguminous crop biomass were below 3.0 % which is considered as critical value for sufficiency in most legume plants. However, the tropical soil biology and fertility program data base cited by [25] specified total N in the range of 1.6-5.7%, 1.7-6.3% and 1.4-6.5%, as normal for of Crotalaria, Lablab and Mucuna biomass respectively when harvested at flowering stage depending on soil properties and environmental condition of a given area. The data base also specified the C:N ratios in the range of 8.0-32.1, 7.4-29.1, and 9.8-30.8 for Crotalaria, Lablab and Mucuna biomass, respectively when harvested at flowering stage. Based on these specifications, the OC, total N and C:N ratios were all within the normal range for the crop species used. Furthermore, the C:N ratios of the biomass used were below 30:1 which is the recommended highest value acceptable for an effective decomposition and mineralization of plant biomass [26].

3.3 Selected Chemical Properties of PRs Used

Selected chemical properties of PRs are as presented in Figures 3, 4, and 5. Solubility of PR depends largely on soil moisture status, soil pH, exchangeable Ca, available P and P adsorption capacity of a soil [27]. Composition of PRs also affects relationships between concentrations of their dissolution products and their sinks in the soil hence affecting dissolution reactions in equilibrium. Apart from affecting the nature and rates of dissolution reactions, chemical constituents of the PRs also play different roles in plant nutrition hence contributing to variations in crop responses following application of PRs of different chemical compositions [28].

Minjingu PR as shown in figure 3, has higher concentrations of P_2O_5, CaO, MgO_2, K_2O and NaO than Panda Hill PR. The differences are characteristic of geological origin i.e. dependent upon parent material and dictate the relative availability of P, Ca, Mg, K and Na from the two PRs. Apart from Na which is only essential in some plants where it has been reported to take over the function of K when the latter is not readily available; P, Ca, K and S are essential elements for all plants and therefore contribute to the fertilizer value of Minjingu PR. Furthermore, with the exception of Ca, most of the elements found in higher concentrations in Minjingu PR have low affinity for P. This explains the reason for higher reactivity and therefore positive crop response reported following applications of Minjingu PR than that of Panda Hill PR [29; 30; 31; 32].

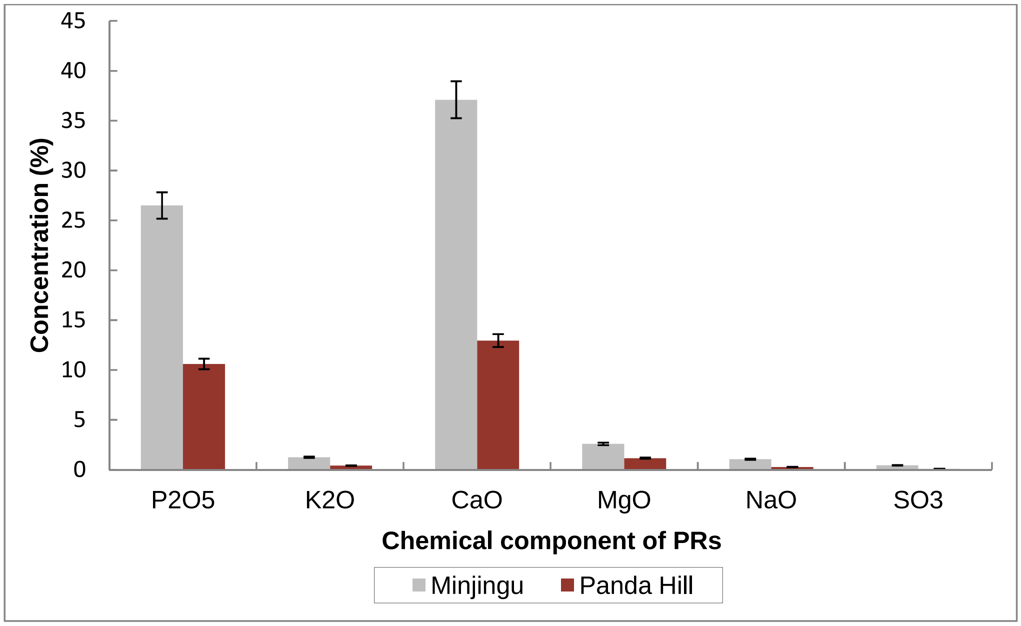

Figure 4. Concentrations of P_2O_5, K_2O, MgO, NaO and SO_3 in Minjingu and Panda Hill PRs.

High concentration of Ca in Minjingu PR is also in agreement with the liming effects reported following application of Minjingu PR on acid soils [20; 33]. Apart from creating a more favorable environment for plant root growth, the liming effect of Minjingu PR on acid soils can also correct imbalance of exchangeable cations in the soil system. A combination of these effects explains the reason for higher crop response reported following application of Minjingu PR than Panda Hill PR. Figure 5 indicates that Panda Hill PR has higher concentrations of FeO_3, SiO_2, and AlO_3 than Minjingu PR. Higher concentrations of these oxides are undesirable as far as reactivity of the PR is concerned because Fe, Si, and Al have high affinity for P and therefore tend to form complex compounds with P, making it difficult to be released from the PR for plant uptake. High concentrations of these metal oxides explains the reason for low reactivity of Panda Hill PR as compared with Minjingu PR and associated differences in crop response following applications of the two PRs on soils with similar characteristics.

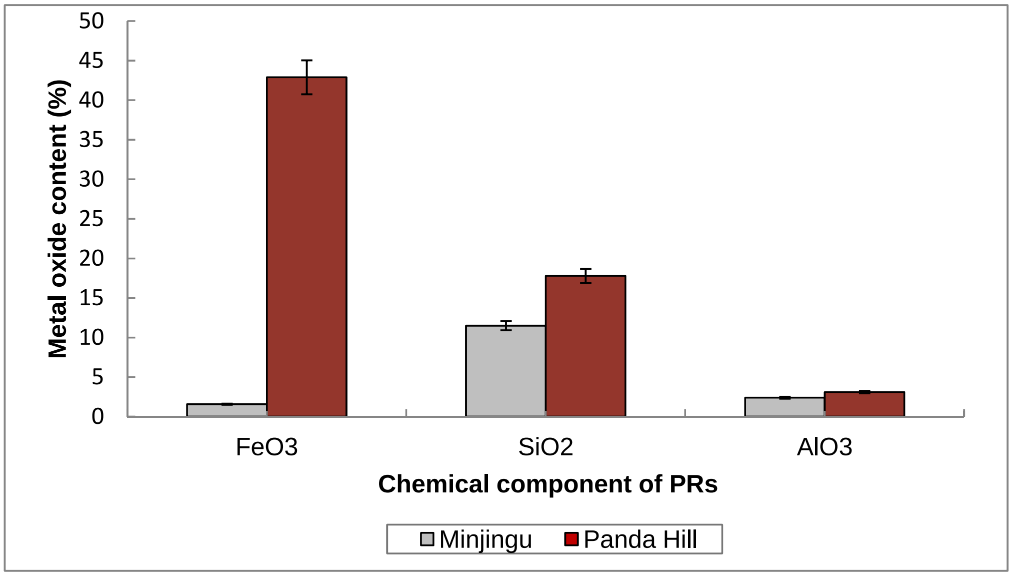

Figure 5. Concentrations of FeO_3, SiO_2 and AlO_3 in Minjingu and Panda Hill PRs.

With the exception of MnO_3 content of Panda Hill PR, all oxides determined in the two PRs indicate low concentrations of micronutrients Zn and Cu for the two PRs to be considered as promising source of micronutrients (Figure 6). This implies that direct application of Mijnjingu or Panda Hill PR as source of P for crops will require an alternative source of micronutrient for a balanced fertilization. Co-application of the PRs with manure or composts may benefit plants more than just PR application alone or with industrial N fertilizers because animal manures and composts contain most nutrients though in small amounts [18].

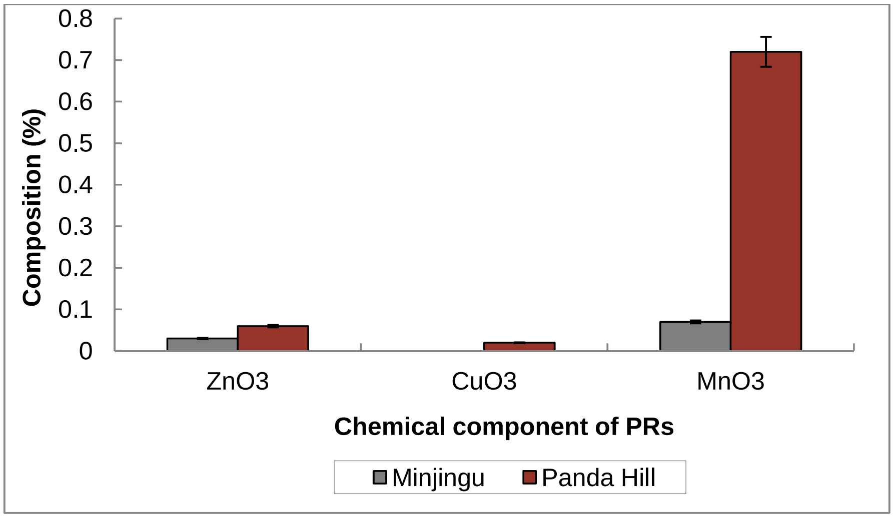

Figure 6. Concentrations of ZnO_3, CuO_3, and MnO_3 in the PRs

3.4 Chemical composition of the PR-biomass Composts

Organic carbon, total N and P content of the composts produced are presented in Table 3. Chemical analysis results indicate that OC content of the composts produced from Mucuna biomass mixed with either Minjingu or Panda Hill PR was different (P=.05) from OC determined in the composts of Crotalaria and Lablab biomass mixed with the same PRs. Panda Hill PR composted with Mucuna biomass was found to have the highest and significant (P=.05) total N concentration, followed by Minjingu PR composted with Crotalaria biomass. Lablab composted with Panda Hill PR had the lowest N content of all composted materials (P=.05).

Table 3. Selected chemical properties of composts used

Compost composition	OC	N	P	C:N	C:P	N:P
	--------------------	%	------------------			
Minjingu PR + *Crotalaria juncea*	22.4 b	1.98 b	0.51 a	11.3	42.7	4.02
Minjingu PR + *Lalab purpureus*	24.0 a	1.64 c	0.52 a	14.7	46.4	3.18
Minjingu PR + *Mucuna pruriens*	22.1 b	1.69 c	0.55 a	13.1	40.9	3.12
Panda Hill PR + *Crotalaria juncea*	23.3 a	1.70 c	0.49 a	14.1	45.4	3.80
Panda Hill PR + *Lablab purpureus*	23.2 a	1.36 d	0.48 a	16.6	49.0	2.96
PandaHill PR + *Mucuna pruriens*	21.8 b	2.16 a	0.38 b	10.8	58.0	5.37
LSD (P=0.05)	0.87	0.15	0.07	-	-	-

[†] *, Values in the same column followed by different letter(s) are statistically different (p=.05)*

In general, composted materials showed $^{3}/_{2}$, $^{3}/_{2}$, and ½ lower contents of OC, total N and C:N ratio as compared with the initial biomass. A decrease in OC, N and C:N ratio as shown in Table 3 for the composts as compared with the initial biomass (Table 2) was caused by oxidation of OC to produce carbon dioxide that was lost as CO_2 gas while portion of the OC is incorporated into microbial cells. Lower total N content in the compost than previously determined in the biomass was probably caused by a dilution effect due to addition of PR to the compost material. Similar trend of total N decrease was reported when coffee pulp was composted with Minjingu PR using surface soil for inoculation of the compost mix [34].

Other research findings [35] reported a slight increase in total N of the compost relative to N content of the raw material when coffee pulp and coffee husks were mixed with cow dung and composted with phosphate rock after inoculation with P-solubilizing bacteria (*Bacillus megatherium*). However, the increase in N content reported [35] could be due to relatively high amount of cow dung (12 kg) equivalent to 20% of total weight of the compost mix used to enrich the compost.

3.5 Effect of Leguminous Crop Strips on Maize Grain Yield

Leguminous crop strips had a significant effect on maize grain yield only when Panda Hill PR was used as P source and the yields under Crotalaria strip was significantly greater than those under Mucuna strip. (Figure 7). Maize grain yield obtained from the three leguminous crop strips were 5.3, 4.5, and 4.0 t ha^{-1} from Crotalaria, Lablab and Mucuna strips, respectively.

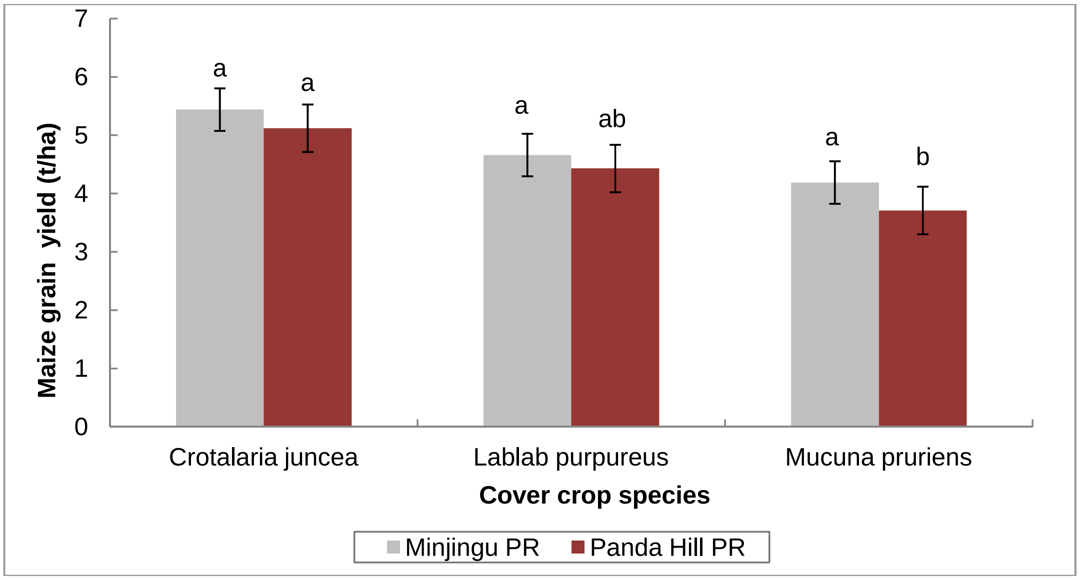

Figure 7. Effect of cover crop strips (species) on maize grain yield
†, Values for the same PR type followed by the same letter(s) are statistically similar (p=0.05)

In Bukoba District of Tanzania, maize grain yield of 0.7 t ha^{-1} was reported following incorporation of crotalaria residues while lablab residues increased maize grain yield by 57-103% above the control crop yield although the effect of lablab was below yield increase obtained from crotalaria strips [36]. Other studies conducted in Tanzania reported maize grain yield ranging from 1.2 to 4.0 t ha^{-1} following incorporation of crotalaria as green manure [37]. In South Africa, maize grain yields ranging from 2.6 to 10.6 t ha^{-1} were reported following incorporation of Crotalaria, Lablab, and Mucuna [38]. Among all the leguminous crops tested, maize biomass and grain yields were highest on Crotalaria plots [38]. Superior influence of Crotalaria on maize grain yields over Lablab and Mucuna was also reported in Malawi [38]. Maize grain yield obtained in this work is therefore within the range reported by other researchers in Sab Saharan Africa (SSA); suggesting that legume biomass composted with PRs could effectively substitute for the application of PRs with urea. Superior performance of Crotalaria over Lablab and Mucuna also agrees with majority of research works conducted in Tanzania and neighbor countries using these leguminous crops as source of N for maize. Other studies [39; 40] obtained results showing that incorporation of Lablab produced more maize grain yield than Crotalaria and Mucuna. Variations reported in different studies could be attributed to differences in soil property, local climatic conditions, yield potentials of maize varieties used and management practices such as timing of biomass incorporation as green manure vs. composting.

3.6 Effect of treatments on maize grain yield

Figure 8 presents maize grain yield obtained following application of different treatments. Application of Minjingu or Panda Hill PR alone failed to increase maize grin yield above the control. This observation is in agreement with findings reported by other researchers [29 and 41] following direct application of Minjingu and Panda Hill PRs on soils with varying properties. Such observations were attributed to application of PRs on soils where P is not the primary limiting factor for crop performance, as well as masking effect of moisture stress, soil acidity and deficiencies of other nutrients which affect maize yield [29, 41].

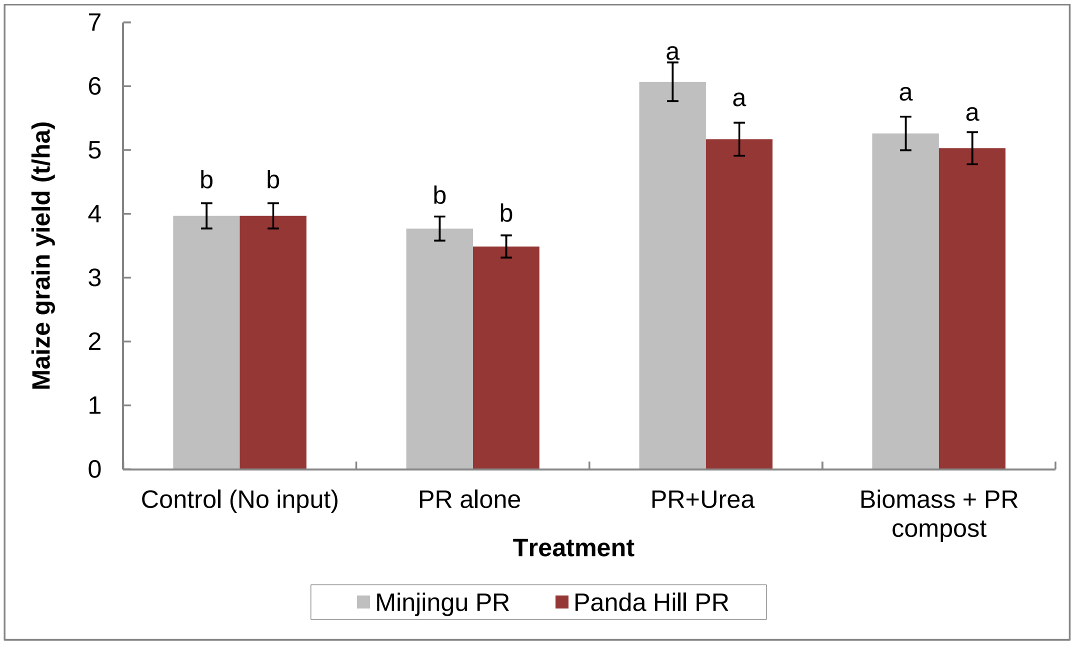

Figure 8. Maize grain yield obtained with different treatment combinations following leguminous crop biomass removal.
†, *Values for the same PR type followed by the same letter(s) are statistically similar (P=.05)*

Addition of urea with Minjingu PR and Minjingu PR composted with leguminous crop biomass increased maize grain yield by 2.40 and 1.58 t ha^{-1}, respectively above the control while addition of urea to Panda Hill PR and Panda Hill PR composted with leguminous crop biomass increased grain yield only by 1.20 and 1.06 t ha^{-1}, respectively above the control. Difference observed in maize grain yields following the application of Minjingu PR or Panda Hill PR alone were not significant (P=.05) even though the two PRs have different reactivity and chemical composition.

Average maize grain yield produced when legume biomass was removed but Minjingu or Panda Hill PR + urea was applied reached 5.62 t ha^{-1} compared with 5.15t ha^{-1} when biomass-PR compost was applied. However, the observed difference (0.47 t ha^{-1}) was also not statistically significant (P=.05) indicating that biomass composted with PR was as effective as the PR applied with urea. This suggests that legume biomass composted with PRs could effectively substitute for the application of PRs with urea at Wang'waray FTC and other areas with similar soil type and climatic conditions in the long run.

3.7 Effect of Treatments on Maize Stover Yield

Figure 9 indicates that stover yield was significantly different (P=.05) between PR alone and PR + urea treatments.

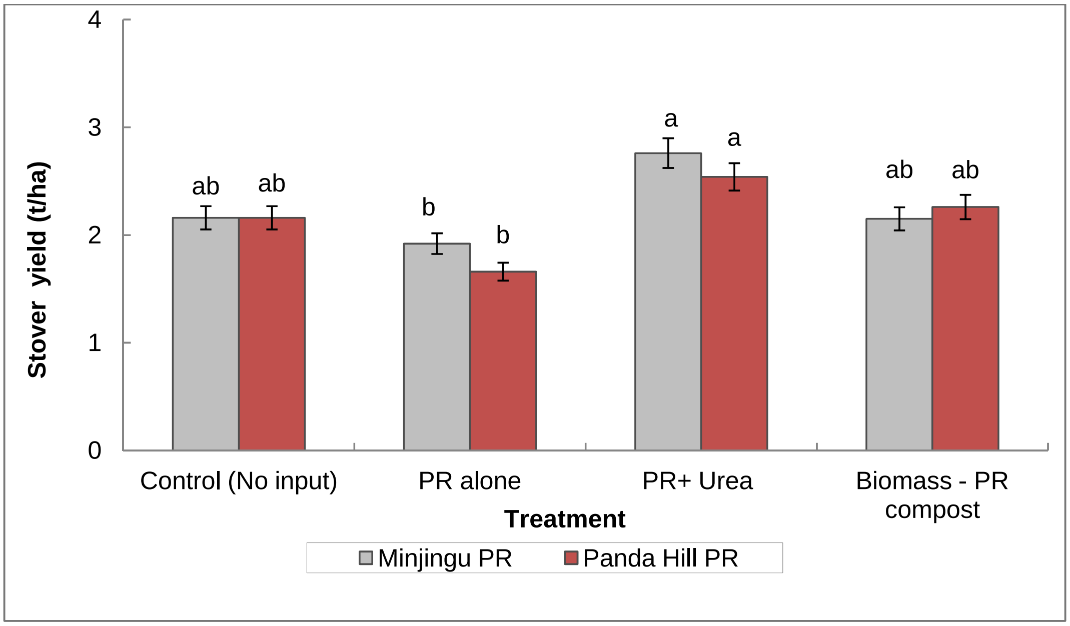

Figure 9. Effects of treatments on maize stover yield following leguminous crop biomass removal.
Values for the same PR type followed by the same letter(s) are statistically similar (P=.05)

Application of Minjingu or Panda Hill PR with Urea produced the highest (2.76 t ha^{-1} and 2.54 t ha^{-1}) yield of maize stover, respectively as compared with Minjingu or Panda Hill PR alone (1.92 and 1.66 t ha^{-1}). However, maize stover yield obtained following application of PRs with urea and PRs composted with cover crop biomass were not statistically different (P=.05) from stover yields obtained in the control plots. The lowest stover yield obtained following application of PR alone could be due to limited supply of N and further distortion of the balance between nutrient supply levels in the soil. This observation is in agreement with the lowest maize grain yield obtained when PRs were applied alone and highest grain yield following application of PR with urea. As we seek for alternatives of synthetic fertilizers, PRs + biomass composting makes a good case, better still, if a reactive PR is used.

3.8 Interaction of legume crop strips x fertilizer treatments effect on maize grain yield

With the exception of Crotalaria strips, when above ground crop biomass was removed and no external input was applied, maize grain yield was below 4 t/ha. (Figures 10 and 11).

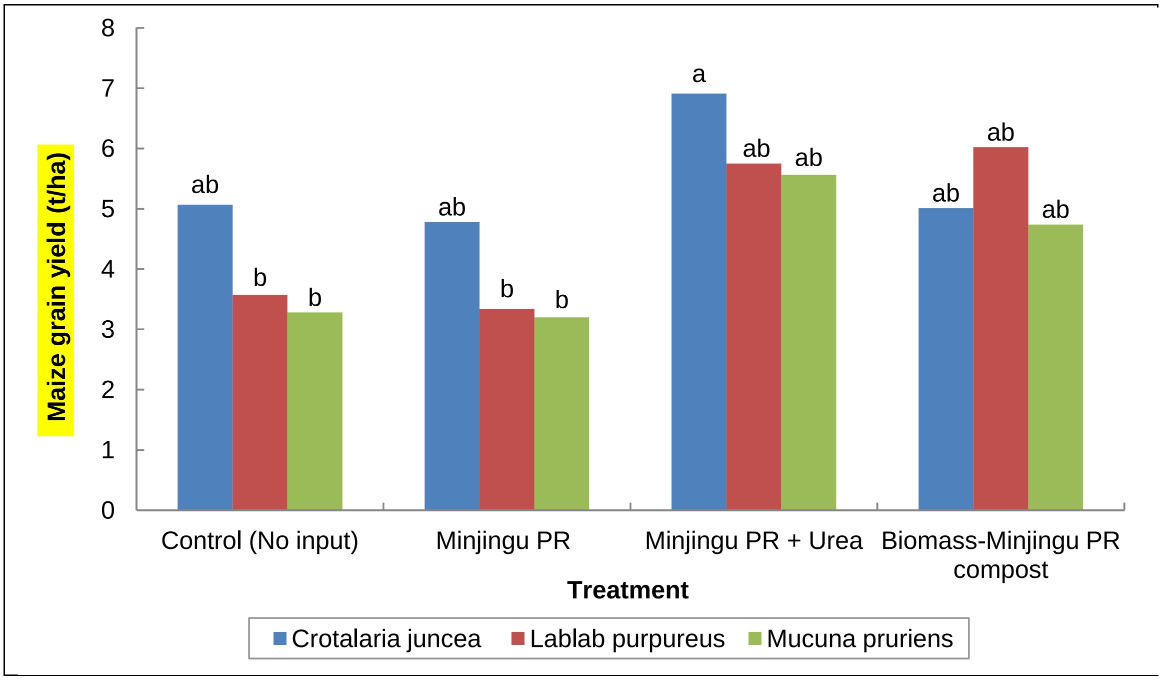

Figure 10. Interactional effect of leguminous crop strips and treatments with Minjingu PR on maize grain. MPR = Minjingu PR
Values followed by the same letter(s) are similar (P=.05)

Following removal of *Mucuna pruriens* and *Lablab purpureus* above ground biomass, the application of PRs without urea or compost did not increase maize grain yield compared with the control plot.

Although not significant (P=.05), higher maize yield was generally obtained on crotalaria strips. Superior performance of maize on crotalaria strips implies that crotalaria has additional positive effects on rhizosphere processes. This makes another case for our study though additional research is required to confirm such processes.

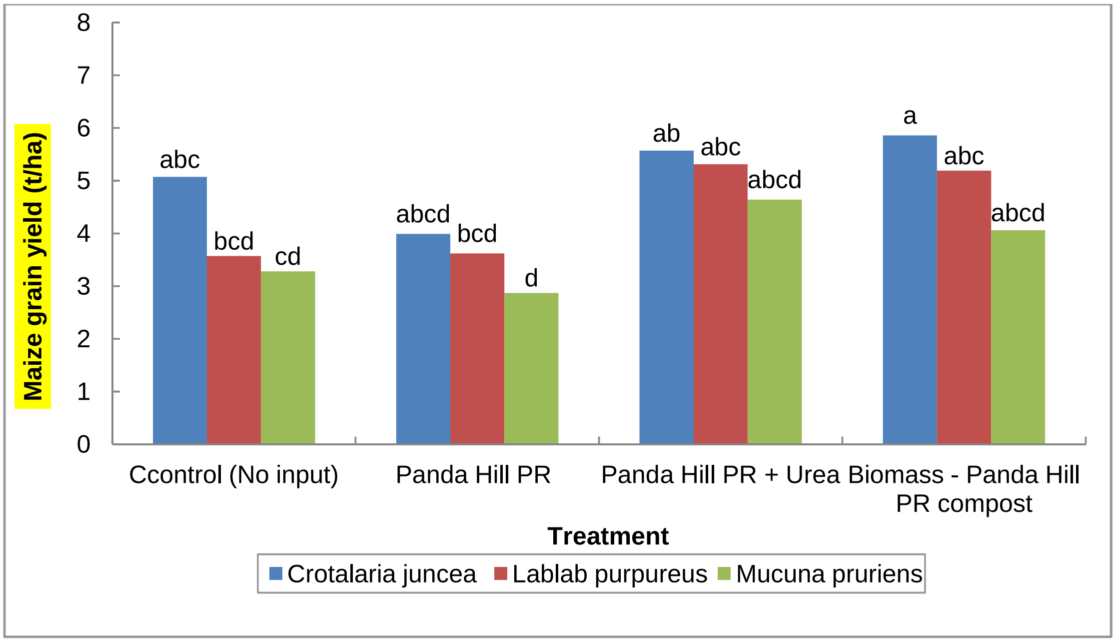

Figure 11. Interactional effect of cover crop strips and treatments with Panda Hill PR on maize grain yield. PPR = Panda Hill PR
Values followed by the same letter(s) are statistically similar (P=.05)

4.0 CONCLUSION

This study investigated the effect of three leguminous crops (*Crotalaria juncea*, *Lablab purpureus* and *Mucuna pruriens*) biomass composted with Minjingu (medium reactivity) or Panda Hill (low reactivity) PR on maize yield. The effect of each PR composted with leguminous crop biomass on maize grain and stover yield was found to be similar to that of the PRs applied with urea, while PRs applied alone failed to increase maize yield above the controls. Similar maize yields obtained with PR-urea and PR-biomass compost treatments imply that leguminous crop biomass composted with PRs was as effective as PRs applied with urea in terms of P and N supply for maize. Based on these results, it was concluded that leguminous crop biomass composted with PRs have a potential for improving maize yield and could replace the use of urea for maize production in the long run. Cost-benefit analysis is however required to justify substituting urea for PR – biomass composts in maize production.

ACKNOWLEDGEMENTS

Authors greatly acknowledge the USAID – Innovative Agricultural Research Initiative (*i*AGRI) project based at Ohio State University for funding this study and the Norman E. Borlaug Leadership Enhancement in Agriculture Program (Borlaug LEAP) at the University of California DAVIS for a fellowship grant which facilitated part of research work in Tanzania. Financial facilitation for research stay in Babati and human resource support provided by IITA Africa RISING (ESA) project in Arusha, Tanzania is also highly acknowledged. Thanks to Tuskegee University in Alabama USA and Sokoine University of Agriculture in Tanzania for co- mentorship, laboratories and other facilities which made this work possible. Minjingu Mines and Fertilizers Co. L.T.D. in Manyara region is acknowledged for providing Minjingu PR sample and the Geological Survey of Tanzania in Dodoma Tanzania for processing PR samples. Babati District council, all workers at Wang'waray F.T.C and the local community at Wang'waray Village in Babati District are also acknowledged for accommodating the field experiments as well as keeping the experimental site safe.

COMPETING INTEREST

The authors declare that no competing interests exist.

AUTHORS' CONTRIBUTION

This work was carried out in collaboration between all authors. Author MS did field work, laboratory analyses, literature search and prepared the first draft of the manuscript, Author KK designed the study and co-supervised field and laboratory experiments with MB, JS, and RA. Author WHM managed statistical analysis while author CKB managed logistics for research work and co-reviewed the manuscript with KK, MB, JS, and RA. All authors read and approved the final manuscript.

REFERENCE

1. Saidia PS, Chilagane DA, Alexander W, Janet FM. Evaluation of EM technology on maize (*Zea mays* L.) growth, development and yield in morogoro Tanzania. 2010; Accessed 10 Aug. 2015. Available: kilimo.org/.../wp.../Saidia-Paul-Sabas-Chilagane-Daudi-Amos-et-al.pdf

2. Mboya R, Tongoona, P, Derera J, Mudhara M, Langyintuo A. The dietary importance of maize in Katumba ward, Rungwe district, Tanzania, and its contribution to household food security. African journal of Agricultural Research. 2011; Vol. 6 (11) 2617 – 2626

3. USAID. The legal, regulatory, and institutional consntraints to the growth of maize and rice in Tanzania. Tanzania MicroCLIR Report. 2010; Accessed 25 September 2015. Available: egateg.usaid.gov/sites/default/files/Tanzania_MicroCLIR.pdf

4. Rowhani P, Lobel DB, Linderman M, Ramankutty N. Climate variability and crop production in Tanzania. Agric.Forest Meteor. 2011; 151:449-460

5. Bekunda MA, Bationo A, Sali H. Soil fertility management in Africa. A review of selected research trials. In: Buresh RJ, Sanchez PA, Calhoun F. Eds. Replenishing soil fertility in Africa.Soil Science Society of America Special Publication No. 51. Madison, Wisconsin; 1997.

6. Sizlas C, Semoka JMR, Borggard, OK. Establishment of an agronomic database for Minjingu phosphate rock and examples of its potential use. Nutr Cycl Agroecosyst. 2007; 78:225-237.

7. Kamhabwa F, Consumption of Fertilizers and Fertilizer Use by Crop in Tanzania. International Fertilizer Development Center (IFDC); 2014.

8. Kpomblekou-A K, Tabatabai MA. Effect of low-molecular weight organic acids on phosphorus release and phytoavailabilty of phosphorus in phosphate rocks when added to soils. Agric. Ecosyst. Environ; 2003; (100):275-284.

9. Mowo JG, Janssen BH, Oenema O, German LA, Mrema, JP, Shemdoe RS. Soil fertility evaluation and management by smallholder farmer communities in the Northern Tanzania. *Agriculture, Ecosystems & Environment.* 2006; 116 (1-2): 47-59 http://www.wsi.nrcs.usda.gov/products/w2q/awm/docs/neh637c2.pdf.

10. National Bureau of Statistics (NBS); Office of Chief Government Statistician (OCGS) Zanzibar. 2012 Population and Housing Census: Population Distribution by Administrative Units; Key Findings. Dar es Salaam, Tanzania; 2013.

11. Kpomblekou K, Tabatabai MA. Effect of organic acids on release of phosphorus from phosphate rocks. Soil Sci. 1994; (158) 442–453.

12. FAO. Guide line for soil description. FAO, Rome, Italy; 2006

13. Soil survey staff. Keys to Soil Taxonomy 12th Edition. USDA-NRSA; 2014

14. Nelson DW and Sommers L E. Total carbon, organic carbon and organic matter. In: Sparks DL, editor. Methods of Soil Analysis Part 3. Chemical Methods. SSSA Book series No.5. SSSA and ASA, Madson, Wisconsin; 1996.

15. Bremner JM. Nitrogen Total. In: DL Sparks, editor. Methods of Soil Analysis Part 3. Chemical Methods. SSSA Book series No.5. SSSA and ASA, Madson, Wisconsin; 1996.

16. Kuo S. Phosphorus. In: Sparks DL, editor. Methods of Soil Analysis Part 3. Chemical Methods. SSSA Book series No.5. SSSA, ASA. Madson, Wisconsin; 1996.

17. Okalebo JR, Gathua KW, Woomer PL.Laboratory methods of soil and plant analysis. Working manual. UNESCO Press, Nairobi, Kenya; 1993.

18. FAO. On farm composting methods. Land and water discussion paper 2. Rome; 2003.

19. Nkonya E, Xavery P, Ankomay H, Mwangi F, Ponia, A, Moshi A. Maize production technologies in the Northern Zone Tanzania. Mimeo. Kansas University; 1998.

20. Landon J R, editor. Booker Tropical Soil Mannual.A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Addison Wesley Longman Limited, England;1991.

21. Dierolf T S, Fairhust TH, Mutert EW. Soil Fertility Kit: A Toolkit for Acid Upland Soil Fertility Evaluation and Management in South East Asia. Potash and Phosphate Institute, Canada; 2001.

22. Reisenauer HM, Walsh LM, Hoeft RG. Testing soil for S, B, Mo, and Cl. In: Walsh, M.L. and Beaton JD, editors. Soil testing and plant analysis, SSSA Inc. Madson, Wisconsin;1973.

23. Gee GW, Bauder J.W. Particle-size analysis. In: Klute A, editor. Methods of soil analysis: Part 1—physical and mineralogical methods. SSSA Book Series 5.1. SSSA, ASA. Madson, Wisconsin; 1986.

24. Maranguit D, Nguillaume T, Kuzyakov Y. Land use change affects phosphorus fractions in highly weathered tropical soils. *Catena.* 2017; 149: 385-393.

25. Sakala WD, Kumwenda JDT, Saka AR. The potential of green manure to increase soil fertility and maize yield in Malawi. *Biol Agr & Hort.* 2002; 21(2):121-130.

26. Graves ER, Hattemer G M. Composting: National Engineering Handbook. 2000. Accessed 30 June 2009. Aavailable: www.springerlink.com/index/11P842T5VW685N40.pdf

27. Van Straaten P. Rocks for crops: Agrominerals of sub-Saharan Africa. ICRAF, Nairobi, Kenya; 2002.

28. FAO *Use of phosphate rock for sustainable agriculture*. FAO Fertilizer and Plant Nutrition Bulletin No. 13. Rome; 2004.

29. Semoka JMR, Mnkeni PNS, Ringo HD. Effectiveness of Tanzania phosphate rocks of igneous and sedmentary origin as source of phosphorus for maize. *Zimb Jour Agr Res.* 1992; 30 (2):127 - 136.

30. Van Straaten P, Editor. Rock for Crops. Agro minerals of sub-saharan Africa. Fidelity National Information Solutions Canada, Scarborough, ON, MIB. 3C3, Canada; 2002.

31. Mnkeni PNS, Semoka JMR, Kaitaba EG. Effects of Mapogoro phillipsite on availability of phosphorus in phosphate rocks. Trop. Agric. 1994;71:249-253.

32. Szilas C, Semoka JMR, Borggaard OK. Can local Minjingu phosphate rock replace super phosphate on acid soils in Tanzania? 2006. Accessed 8 June 201. Available:

33. Szilas C. The Tanzanian Minjingu phosphate rock - possibilities and limitations for direct application. PhD Thesis. Royal Veterinary and Agricultural University, Copenhagen, Denmark; 2002.

34. Shitindi MJ. Response of tomato (*Lycoperscon esculentum M.)* to coffee pulp compost, Minjingu phosphate rock and coffee pulp - minjingu phosphate rock compost applied to a Chromic acrisol. MSc. Thesis . Sokoine University of Agriculture. Morogoro, Tanzania; 2011.

35. Preethu DC, Bhanu Prakash BNUH, Srinivasamurthy CA, Vasanthi BG. Maturity indices as an index to evaluate the quality of compost of coffee waste blended with other organic wastes. Proceedings of the International Conference on Sustainable Solid Waste Management.5-7 September 2007, Chennai India. 2007.

36. Baijukya FP, de Ridder N. Giller KE. Nitrogen release from decomposing residues of leguminous cover crops and their effect on maize yield on depleted soils of Bukoba District, Tanzania. *Pant and Soil.* 2006; 279: 77-93.

37. Lupatu M, Kilimwiko L. Natural fertilizers: New life for tired soils. Africa Farmer No.6; December 1991. Hunger Project Savaccon gallery, 240 E. 13th street New York; 1991.

38 Odhiambo JJO, Ogola JBO, Madzivhandila T. Effect of green manure legume – maize rotation on maize yield and weed infestation levels. Afr. J. Agric. Res. 2010; 5(8): 618-625.

39. Mureiythi JG Gachene CKK, Ojien J. The role of green manure legumes in smallholder farming systems in Kenya. The legume research network project. *Tropical and Subtropical Agro ecosystems*. 2003; 1:57-70.

40. Odhiambo JJO. Potential use of green manure legume cover crops in smallholder maize production systems in Limpopo province, South Africa. Afr Jour Agr Res. 2011; Vol. 6(1): 107-112.