

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

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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

32 differences (0.82 and 0.14 t ha⁻¹) were not statistically significant indicating that biomass composted
33 with PR was as effective as the PR applied with urea.

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

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40 1. INTRODUCTION

41 Maize (*Zea mays*) is Tanzania's most important staple food with an estimated annual per
42 capita consumption of 113 kg, contributing about 60% of dietary calories [1] and [2]. According to [3],
43 the crop also contributes about 50% of Tanzania's rural cash income. However, current production of
44 maize in Tanzania is far below the national average yield potential of 4.8 t ha⁻¹, fluctuating between
45 1.0 and 1.5 t ha⁻¹ [4]. Continuous maize production without or with limited fertilizer application coupled
46 with crop residue removal have been reported as major factors for soil fertility decline and low crop
47 yields [5; 6; 7]. Limited fertilizer use in most developing countries has been attributed to their high
48 costs and limited availability [8; 9].

49 While food production per unit land is declining because of soil fertility deterioration, the
50 population of Tanzania has more than tripled from 12.3 million to 44.9 million between 1967 and
51 2012. Based on 2012 census projections, the population was expected to reach 47.42 million people
52 by the year 2016 [10]. This increase in the population will cause additional pressure on arable land
53 because more than 70% of Tanzanians depend entirely on agriculture for their food and income [10].
54 This calls for integrated soil fertility management programs based on locally available resources so as
55 to improve soil fertility and reduce smallholders' dependence on imported industrial fertilizers.

56 Phosphate rock (PR) deposits located in Tanzania could serve as alternative source of
57 phosphorus (P) for smallholders but P contained in the rocks is not readily available for plant uptake.
58 Upon decomposition, plant biomass releases low- molecular-weight organic acids that may complex
59 calcium and other metals in the rock to free P for plant uptake [11]. Thus, composting the rocks with
60 leguminous biomass may improve the availability of nitrogen (N) and P for plant uptake. The
61 objective of the field experiment was to investigate carbon (C), N, and P content of three common

62 leguminous plants (*Crotalaria juncea*, *Lablab purpureus* and *Mucuna pruriens*) used in Tanzania and
 63 the effect of each leguminous biomass when composted with PRs on maize yield. The PRs used were
 64 those of Mijingu (a PR of medium reactivity) and Panda Hill (a PR of low reactivity).

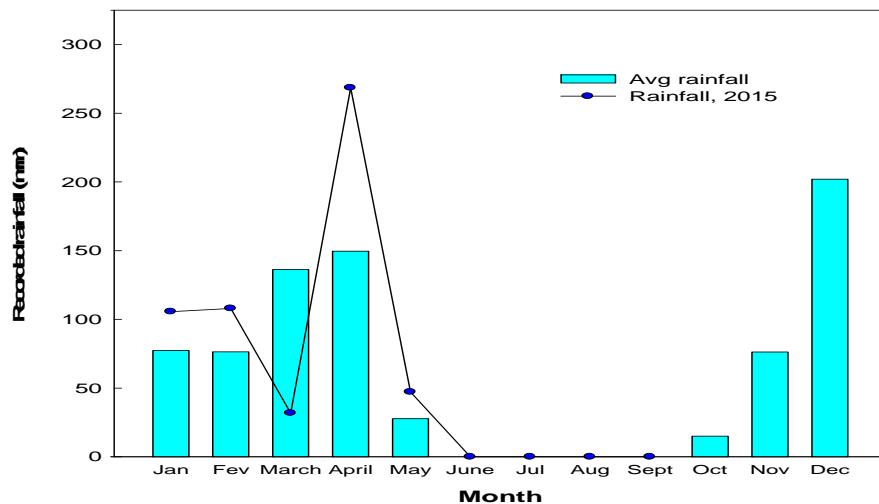
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66 **2. MATERIALS AND METHODS**

67 **2.1 Site Description, Soil Characterization and Fertility Assessment**

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

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

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

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93 **2.2 Leguminous Biomass Production**

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

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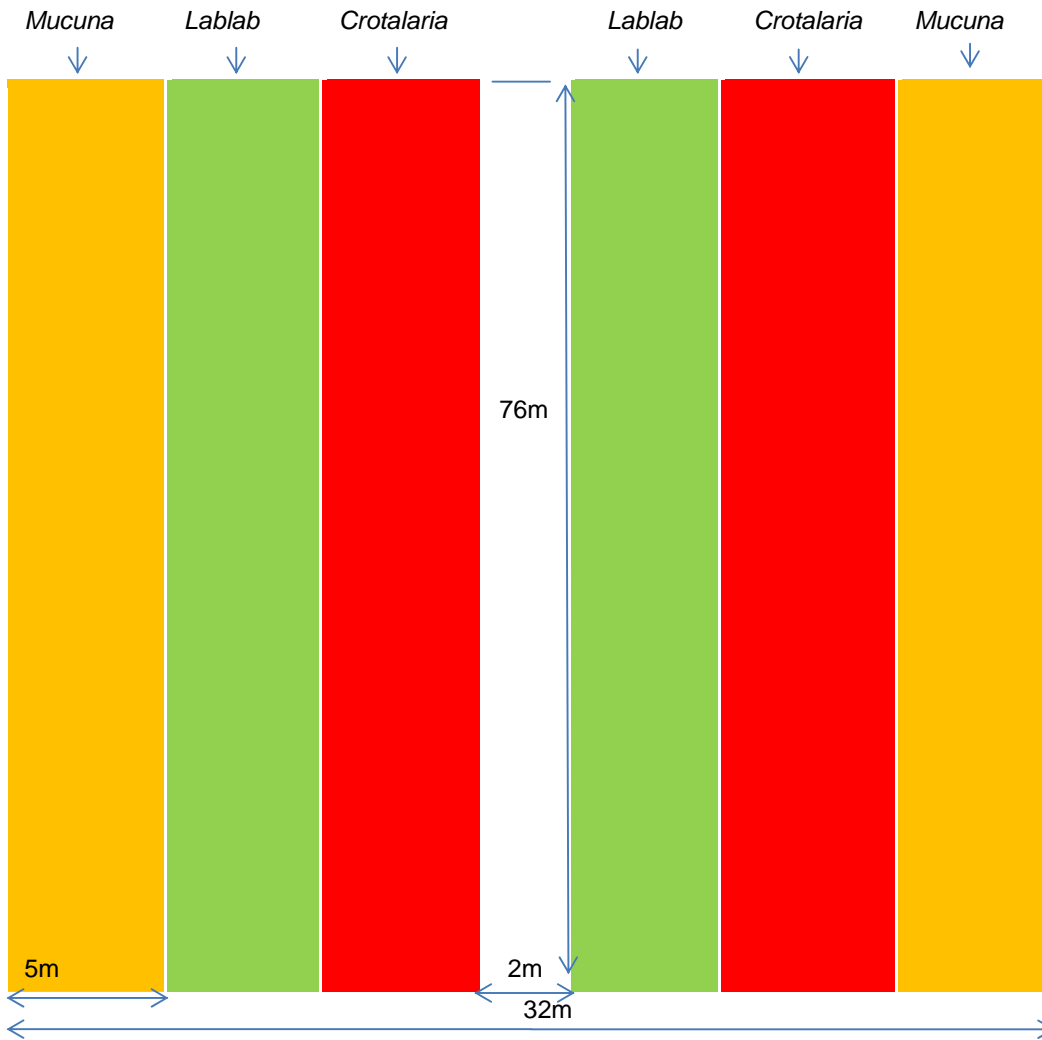
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Figure 2. Layout of the field for leguminous crop biomass production at Wang'waray F.T.C

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2.3 Carbon, nitrogen and phosphorus contents of the biomass

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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 HNO₃ - H₂O₂ wet digestion procedure using a 40 space Foss Tecator block digester. Phosphorus content of the digest was determined by a

126 procedure using ascorbic acid method [16], while S content was determined by a turbidity method
127 [17].

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129 **2.4 Phosphate Rock Collection, Processing, and Chemical Analysis**

130 Minjingu PR was collected from Minjingu Mines and Fertilizers Company in Manyara region
131 while Panda Hill PR was obtained from a storage facility at SUA. Both PRs were ground to pass a
132 100-mesh sieve at the Geological Survey of Tanzania (GST) laboratory in Dodoma region. A
133 representative sample was collected from each PR and shipped to the Southern and Eastern Africa
134 Mineral Center (SEAMIC) laboratory in Dar es Salaam for X-ray fluorescence (XRF) analysis.

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136 **2.5 Production of Biomass-PR Composts**

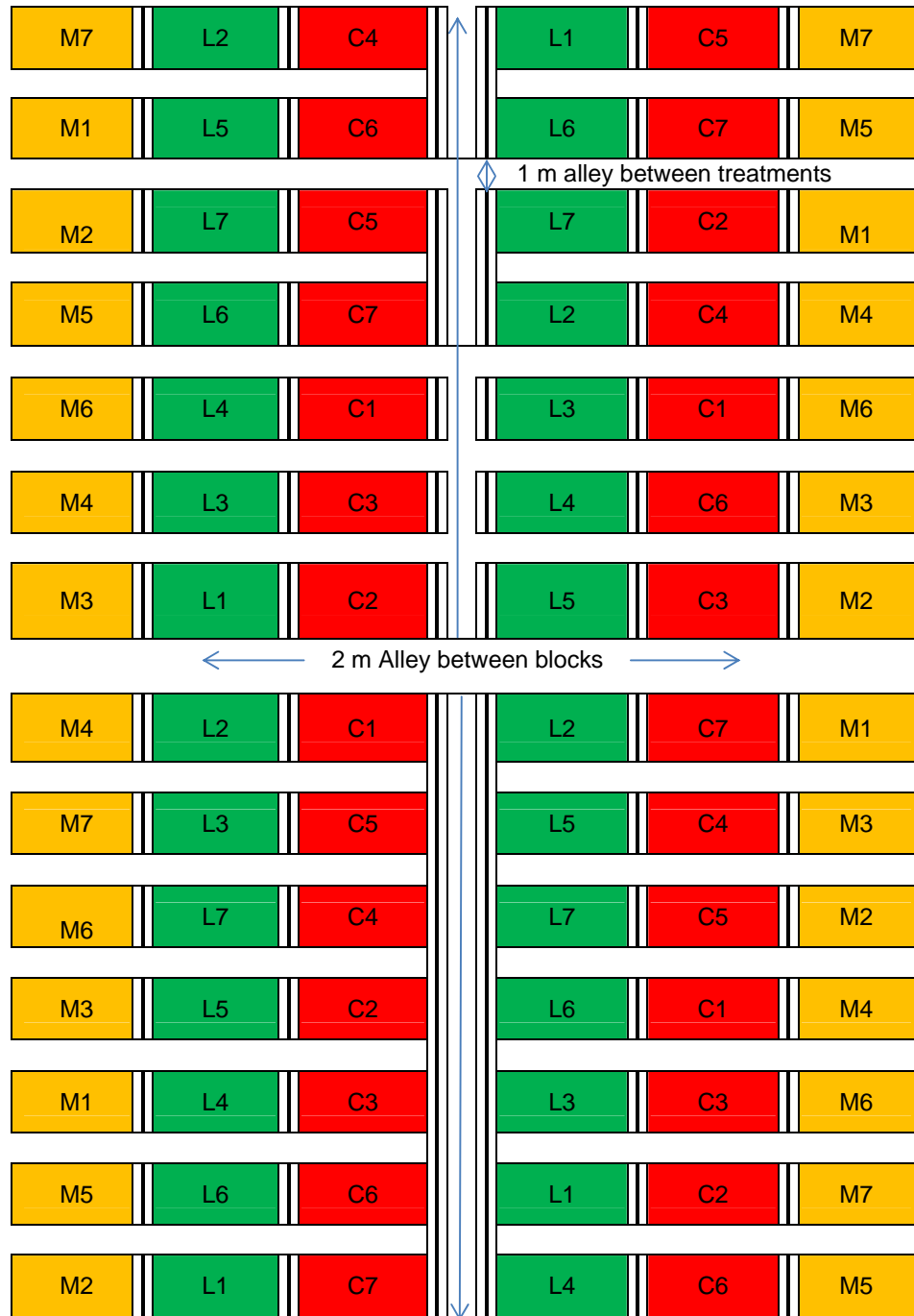
137 Previously chopped leguminous biomass (< 2 cm) and ground PRs (< 100 mesh) were
138 composted by the pit method [18] with some modifications. In the modifications, the size of an
139 individual pit was 2 m x 2 m x 1m; floor and walls of each pit were lined with a polyethylene plastic
140 sheet to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

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146 Three PVC aeration pipes were inserted into each compost mix at regular intervals and the
147 material was covered with polyethylene plastic sheets to protect it from rain water and undesirable/
148 foreign materials. The compost material in each pit was turned into a different pit every 30 days for
149 120 days to allow optimum decomposition and water was sprinkled at every turn to maintain the
150 moisture at 60%. After the last turn, representative samples were collected from each pit for
151 laboratory analysis and all composts were air dried to around 20% moisture content and stored for
152 later use as source of N and P for maize. Representative samples taken from each pit were shipped
153 to the SUA-SGS laboratory for chemical analysis. In the laboratory, representative compost samples
154 were dried and ground to pass through 0.5 mm for total N, P and SO₄-S analysis as previously
155 described.

156 **2.6 Evaluation of Maize Response to Treatments**

157 The field strips previously used for cover crop biomass production were used in the next
 158 season to evaluate maize response to newly imposed treatments (Figure 3).
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Figure 3. Layout of maize field experiment at Wang'waray FTC

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

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165 The experiment was designed as a split plot arranged in a randomized complete block design
166 (RCBD). The field was divided into four blocks where half of each strip initially used to produce the
167 crop biomass was used as a main plot within a block and each main plot was divided into seven sub
168 plots (16 m²) which received randomly assigned treatments. Seven treatments were evaluated on
169 each main plot. These include a common control where maize was grown without external inputs after
170 removal of the crop biomass (1), Minjingu PR alone applied (2), Minjingu PR + urea (3), composted
171 Minjingu PR + biomass (4). Panda Hill PR alone (5), Panda Hill PR + urea (6), and composted Panda
172 hill PR + biomass (7). Thus, treatment combinations were identified as C1 to C7, L1 to L7, and M1 to
173 M7 where C, L, and M stand for Crotalaria, Lablab, and Mucuna strip, respectively.

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175 The composts were applied at a rate corresponding to 112 kg N ha⁻¹ recommended for maize
176 in the Northern Zone [19]. The PRs were applied at 45kg P ha⁻¹ with or without urea while urea was
177 applied at 112kg N ha⁻¹ (split application at planting and two weeks following germination) on selected
178 plots based on treatment scheme. A medium term hybrid maize variety (SC.627) was planted at 90 x
179 30 cm spacing (five rows per plot). At tasselling stage, nine representative ear leaf samples were
180 collected from each plot for nutrient analysis. At maturity stage, maize ears of the three inner rows in
181 each plot were harvested for yield determination. Maize grain yield was reported at 13% moisture
182 content, while maize stover yield from the three inner rows of each plot was reported on oven-dry
183 basis. The data collected were subjected to analysis of variance (ANOVA) using a mixed procedure of
184 SAS software version 9.4 (SAS Instit. Inc. Cary, NC) and the means were separated at P = .05 by
185 Tuckey-Kramer procedure.

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187 3. RESULTS AND DISCUSSION

188 3.1 Fertility status of soil at Wang'waray FTC

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

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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 ₂ O	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]

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

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Levels of extractable S, exchangeable bases and DTPA extractable Fe, Cu and Mn were all **high but**

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the levels of organic carbon, total N, Bray-1 extractable P were low, and therefore limiting. The low

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levels of organic carbon, N, and P have been reported in highly weathered tropical soils like those of

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Babati [24].

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

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Carbon contents of the leguminous biomass used varied significantly (P=.05)

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while P contents were not statistically different (P = .05). Chemical composition of plant

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species grown for compost production is an important factor to take into account because it has effect

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on the rate at which plant material is acted upon by decomposers to release nutrients in plant

208 available forms. On average, OC contents of the biomass used were 48.7%, 41.6% and 44.5% for
 209 Crotalaria, Lablab, and Mucuna biomass, respectively. On the other hand, total N content of the
 210 biomass used were 2.4%, 2.3% and 2.0%, while the C:N ratios were 20.1, 18.1, and 22.3 for
 211 Crotalaria, Lablab and Mucuna biomass, respectively.

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213 **Table 2. Chemical composition of the leguminous biomass used**

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

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

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217 The total N values determined in all leguminous crop biomass were below 3.0 % which is considered
 218 as critical value for sufficiency in most legume plants. However, the tropical soil biology and fertility
 219 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
 220 normal for of Crotalaria, Lablab and Mucuna biomass respectively when harvested at flowering stage
 221 depending on soil properties and environmental condition of a given area. The data base also
 222 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
 223 Mucuna biomass, respectively when harvested at flowering stage. Based on these specifications, the
 224 OC, total N and C:N ratios were all within the normal range for the crop species used. Furthermore,
 225 the C:N ratios of the biomass used were below 30:1 which is the recommended highest value
 226 acceptable for an effective decomposition and mineralization of plant biomass [26].

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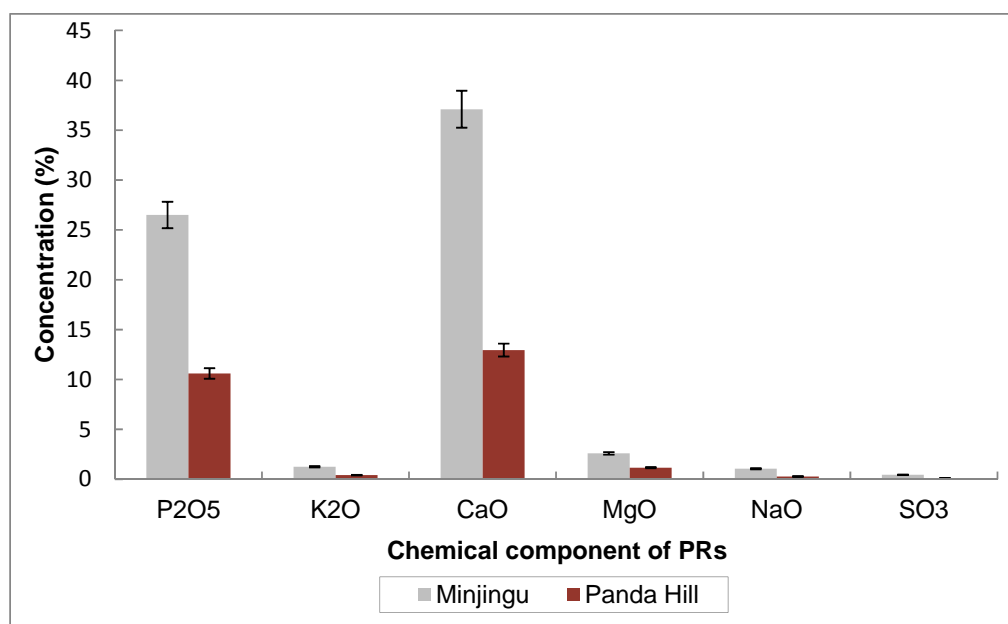
228 **3.3 Selected Chemical Properties of PRs Used**

229 Selected chemical properties of PRs are as presented in Figures 3, 4, and 5. Solubility of PR
 230 depends largely on soil moisture status, soil pH, exchangeable Ca, available P and P adsorption
 231 capacity of a soil [27]. Composition of PRs also affects relationships between concentrations of their

232 dissolution products and their sinks in the soil hence affecting dissolution reactions in equilibrium.
233 Apart from affecting the nature and rates of dissolution reactions, chemical constituents of the PRs
234 also play different roles in plant nutrition hence contributing to variations in crop responses following
235 application of PRs of different chemical compositions [28].

236
237 Minjingu PR as shown in figure 3, has higher concentrations of P_2O_5 , CaO, MgO_2 , K_2O and
238 NaO than Panda Hill PR. The differences are characteristic of geological origin i.e. dependent upon
239 parent material and dictate the relative availability of P, Ca, Mg, K and Na from the two PRs. Apart
240 from Na which is only essential in some plants where it has been reported to take over the function of
241 K when the latter is not readily available; P, Ca, K and S are essential elements for all plants and
242 therefore contribute to the fertilizer value of Minjingu PR. Furthermore, with the exception of Ca, most
243 of the elements found in higher concentrations in Minjingu PR have low affinity for P. This explains the
244 reason for higher reactivity and therefore positive crop response reported following applications of
245 Minjingu PR than that of Panda Hill PR [29; 30; 31; 32].

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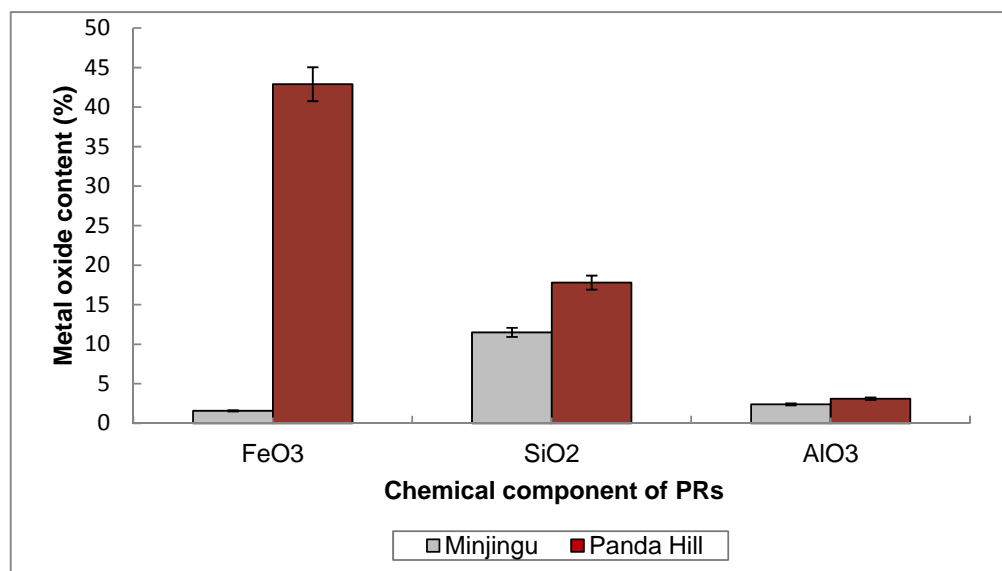


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248 **Figure 4.** Concentrations of P_2O_5 , K_2O , MgO, NaO and SO_3 in Minjingu and Panda Hill PRs.
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250 High concentration of Ca in Minjingu PR is also in agreement with the liming effects reported
251 following application of Minjingu PR on acid soils [20; 33]. Apart from creating a more favorable
252 environment for plant root growth, the liming effect of Minjingu PR on acid soils can also correct

253 imbalance of exchangeable cations in the soil system. A combination of these effects explains the
254 reason for higher crop response reported following application of Minjingu PR than Panda Hill PR.
255 **Figure 5** indicates that Panda Hill PR has higher concentrations of FeO_3 , SiO_2 , and AlO_3 than Minjingu
256 PR. Higher concentrations of these oxides are undesirable as far as reactivity of the PR is concerned
257 because Fe, Si, and Al have high affinity for P and therefore tend to form complex compounds with P,
258 making it difficult to be released from the PR for plant uptake. High concentrations of these metal
259 oxides explains the reason for low reactivity of Panda Hill PR as compared with Minjingu PR and
260 associated differences in crop response following applications of the two PRs on soils with similar
261 characteristics.



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263 **Figure 5.** Concentrations of FeO_3 , SiO_2 and AlO_3 in Minjingu and Panda Hill PRs.
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265 With the exception of MnO_3 content of Panda Hill PR, all oxides determined in the two PRs
266 indicate low concentrations of micronutrients Zn and Cu for the two PRs to be considered as
267 promising source of micronutrients (**Figure 6**). This implies that direct application of Minjingu or Panda
268 Hill PR as source of P for crops will require an alternative source of micronutrient for a balanced
269 fertilization. Co-application of the PRs with manure or composts may benefit plants more than just
270 PR application alone or with industrial N fertilizers because animal manures and composts contain
271 most nutrients though in small amounts [18].

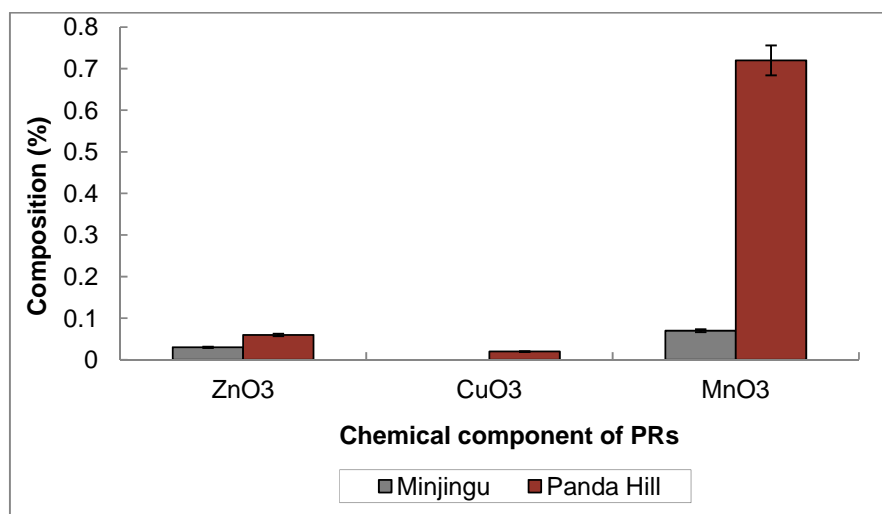


Figure 6. Concentrations of ZnO₃, CuO₃, and MnO₃ in the PRs

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 ($P=0.05$) 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 ($P=0.05$) 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 ($P=0.05$).

Table 3. Selected chemical properties of composts used

Compost composition	OC	N	P	C:N	C:P	N:P
	----- % -----					
Minjingu PR + <i>Crotalaria juncea</i>	22.4 b	1.98 b	0.51 a	11.3	42.7	4.02
Minjingu PR + <i>Lablab purpureus</i>	24.0 a	1.64 c	0.52 a	14.7	46.4	3.18
Minjingu PR + <i>Mucuna pruriens</i>	22.1 b	1.69 c	0.55 a	13.1	40.9	3.12
Panda Hill PR + <i>Crotalaria juncea</i>	23.3 a	1.70 c	0.49 a	14.1	45.4	3.80
Panda Hill PR + <i>Lablab purpureus</i>	23.2 a	1.36 d	0.48 a	16.6	49.0	2.96
Panda Hill PR + <i>Mucuna pruriens</i>	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 ($p=0.05$)

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288 In general, composted materials showed $\frac{3}{2}$, $\frac{3}{2}$, and $\frac{1}{2}$ lower contents of OC, total N and C:N
289 ratio as compared with the initial biomass. A decrease in OC, N and C:N ratio as shown in Table 3 for
290 the composts as compared with the initial biomass (Table 2) was caused by oxidation of OC to
291 produce carbon dioxide that was lost as CO₂ gas while portion of the OC is incorporated into microbial
292 cells. Lower total N content in the compost than previously determined in the biomass was probably
293 caused by a dilution effect due to addition of PR to the compost material. Similar trend of total N
294 decrease was reported when coffee pulp was composted with Minjingu PR using surface soil for
295 inoculation of the compost mix [34].

296 Other research findings [35] reported a slight increase in total N of the compost relative to N
297 content of the raw material when coffee pulp and coffee husks were mixed with cow dung and
298 composted with phosphate rock after inoculation with P-solubilizing bacteria (*Bacillus megatherium*).
299 However, the increase in N content reported [35] could be due to relatively high amount of cow dung
300 (12 kg) equivalent to 20% of total weight of the compost mix used to enrich the compost.

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302 **3.5 Effect of Leguminous Crop Strips on Maize Grain Yield**

303 Leguminous crop strips had a significant effect on maize grain yield only when Panda Hill PR
304 was used as P source and the yields under Crotalaria strip was significantly greater than those under
305 Mucuna strip. (Figure 7). Maize grain yield obtained from the three leguminous crop strips were 5.3,
306 4.5, and 4.0 t ha⁻¹ from Crotalaria, Lablab and Mucuna strips, respectively.

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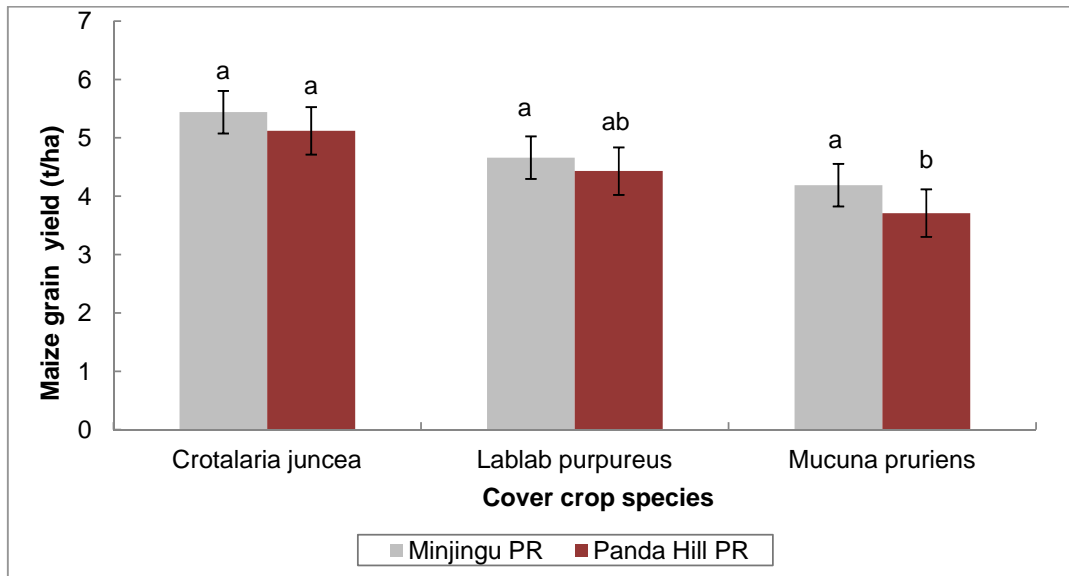
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Figure 7. Effect of cover crop strips (species) on maize grain yield

[†] Values for the same PR type followed by the same letter(s) are statistically similar ($p=0.05$)

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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

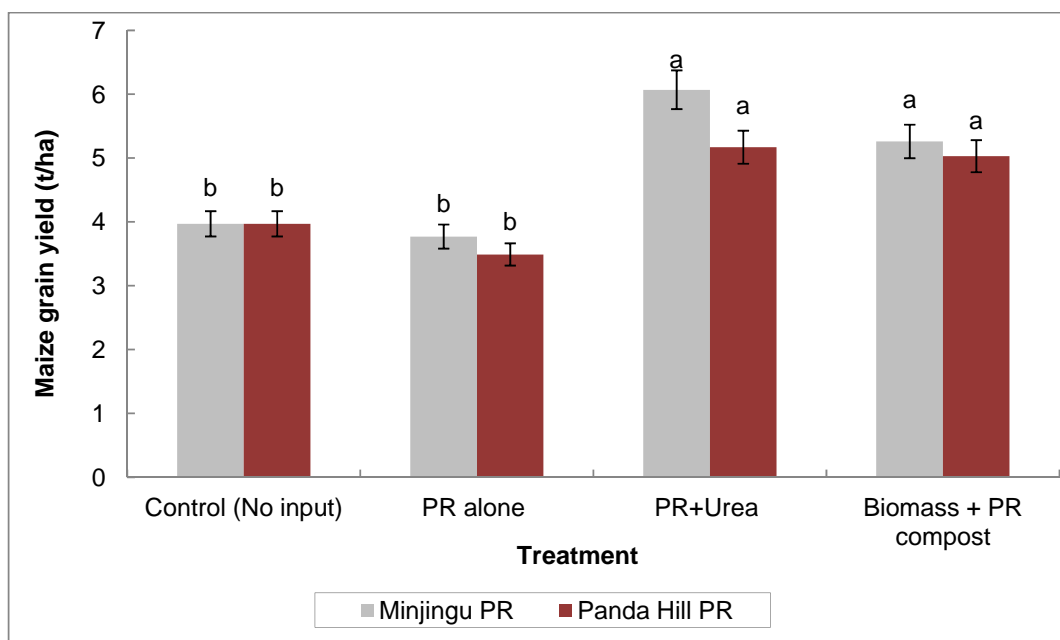
344 used and management practices such as timing of biomass incorporation as green manure vs.
345 composting.

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347 **3.6 Effect of treatments on maize grain yield**

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

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357 **Figure 8. Maize grain yield obtained with different treatment combinations following**
358 **leguminous crop biomass removal.**

359 *[†] Values for the same PR type followed by the same letter(s) are statistically similar (P=0.05)*

360

361 Addition of urea with Minjingu PR and Minjingu PR composted with leguminous crop biomass
362 increased maize grain yield by 2.40 and 1.58 t ha⁻¹, respectively above the control while addition of
363 urea to Panda Hill PR and Panda Hill PR composted with leguminous crop biomass increased grain

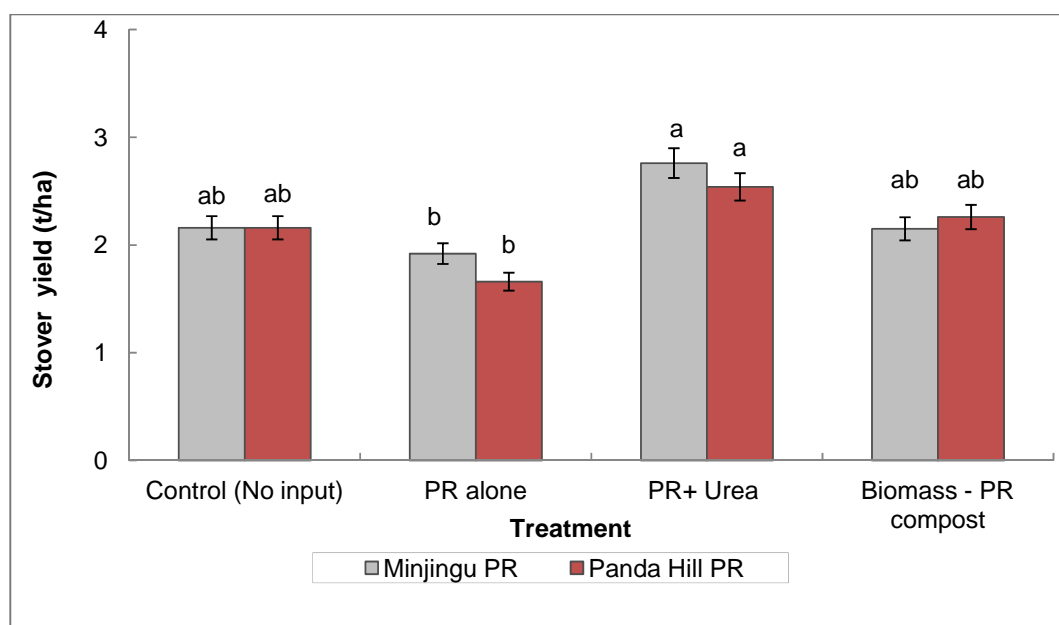
364 yield only by 1.20 and 1.06 t ha⁻¹, respectively above the control. Difference observed in maize grain
365 yields following the application of Minjingu PR or Panda Hill PR alone were not significant (P=.05)
366 even though the two PRs have different reactivity and chemical composition.

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

374

375 **3.7 Effect of Treatments on Maize Stover Yield**

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



378

379 **Figure 9.** Effects of treatments on maize stover yield following leguminous crop biomass
380 removal.

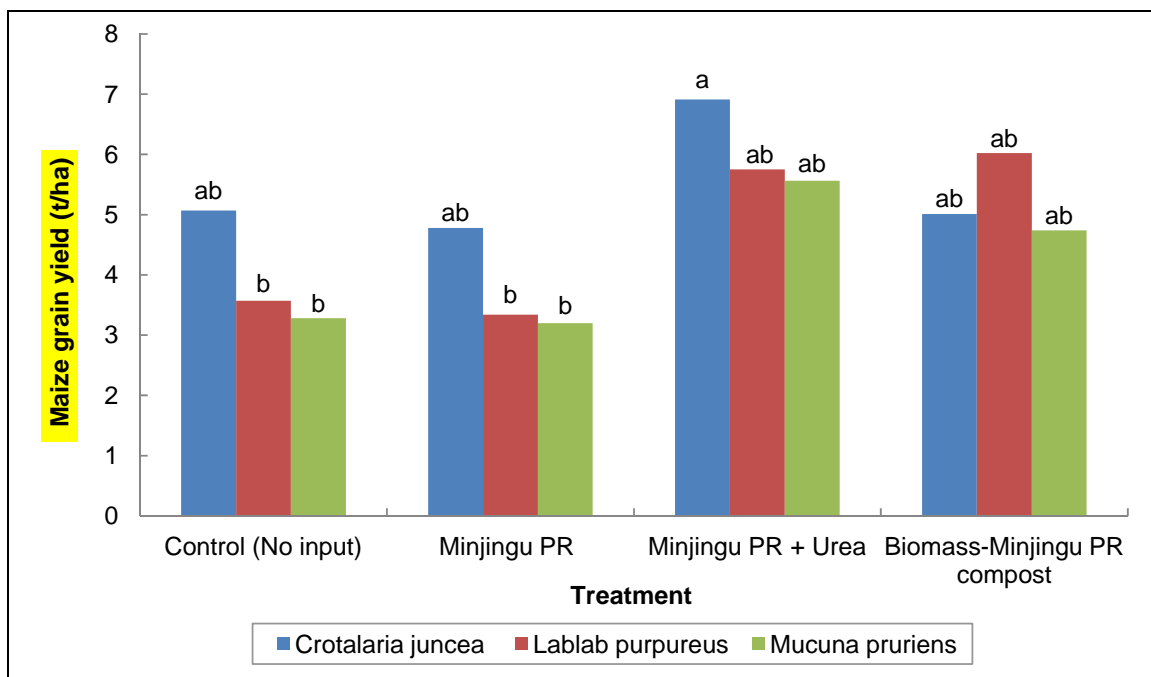
381 *Values for the same PR type followed by the same letter(s) are statistically similar (P=.05)*

382

383 Application of Minjingu or Panda Hill PR with Urea produced the highest (2.76 t ha⁻¹ and 2.54
 384 t ha⁻¹) yield of maize stover, respectively as compared with Minjingu or Panda Hill PR alone (1.92 and
 385 1.66 t ha⁻¹). However, maize stover yield obtained following application of PRs with urea and PRs
 386 composted with cover crop biomass were not statistically different (P=.05) from stover yields obtained
 387 in the control plots. The lowest stover yield obtained following application of PR alone could be due to
 388 limited supply of N and further distortion of the balance between nutrient supply levels in the soil. This
 389 observation is in agreement with the lowest maize grain yield obtained when PRs were applied alone
 390 and highest grain yield following application of PR with urea. As we seek for alternatives of synthetic
 391 fertilizers, PRs + biomass composting makes a good case, better still, if a reactive PR is used.

392 **3.8 Interaction of legume crop strips x fertilizer treatments effect on maize grain yield**

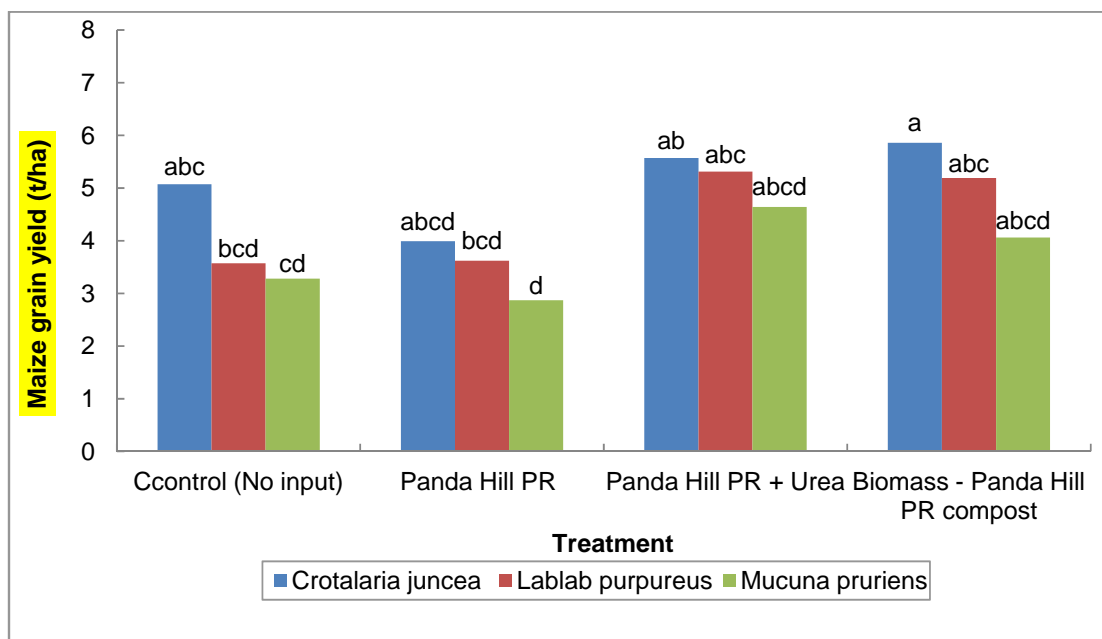
393 With the exception of *Crotalaria* strips, when above ground crop biomass was removed and
 394 no external input was applied, maize grain yield was below 4 t/ha. (Figures 10 and 11).



395
 396 **Figure 10.** Interactional effect of leguminous crop strips and treatments with Minjingu PR on maize
 397 grain. MPR = Minjingu PR
 398 Values followed by the same letter(s) are similar (P=.05)
 399

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

403 Although not significant ($P=0.05$), higher maize yield was generally obtained on crotalaria strips.
 404 Superior performance of maize on crotalaria strips implies that crotalaria has additional positive
 405 effects on rhizosphere processes. This makes another case for our study though additional research
 406 is required to confirm such processes.



407
 408 **Figure 11. Interactional effect of cover crop strips and treatments with Panda Hill PR on maize**
 409 **grain yield. PPR = Panda Hill PR**
 410 Values followed by the same letter(s) are statistically similar ($P=0.05$)
 411

412 4.0 CONCLUSION

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

424

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426

427

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439

440

COMPETING INTEREST

441 The authors declare that no competing interests exist.

442

443 **AUTHORS' CONTRIBUTION**

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

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