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Dry Bean Response to Fertilization Using Minjingu Phosphate Rock and Composted Tughutu (*Vernonia subligera* O. Hoffn)

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Author's contribution

This whole work was carried out by author PAN.

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ABSTRACT

Aims: The objectives of the study were toevaluate the effects of organic materials from Tughutu (*Vernonia subligera* O. Hoffn) and locally available Minjingu phosphate rock or commercial Triple super phosphate fertilizer on the plant growth and amount of phosphorus (P) and calcium (Ca) content in bean shoots (*Phaseolus vulgaris* L.) and their residual effects in the soil after harvest.
Study Design: The experiments were set up as a randomized complete block design
Place and Duration of Study: Field experiments were conducted in famers' fields in the Western Usambara Mountains in Tanzania.
Methodology: Each farmer's field was assigned as a replicate. The experimental treatments consisted of six plots as follows: control, Minjingu Phosphate Rock (MPR) or Triple Super Phosphate (TSP) each at 26 kg P ha^{-1}, Tughutu at 2.5 t dry matter ha^{-1} and Tughutu at 2.5 t dry matter ha^{-1} combined with Minjingu Phosphate Rock or Triple Super Phosphate at 26 kg P ha^{-1}.
Results: The dry matter yield and amount of P and Ca in bean shoots significantly increased by supplying the organic and inorganic fertilizers above the control treatment. Addition of P fertilizers alone or in combination with Tughutu also modified the soil pH and significantly increased the concentration of P and Ca in the soil at harvest.
Conclusion: Overall, combination of Minjingu phosphate rock or Triple super phosphate with

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Tughutu enhanced the effectiveness of these fertilizers and resultedin better growth and greater P and Ca amount in the shoots as well as their concentration in the soil at harvest.

Keywords: Dry matter; pH; triple super phosphate; minjingu phosphate rock.

1. INTRODUCTION

The densely populated areas of the Western Usambara Mountains (WUM) in northern Tanzania suffer from low soil nutrient levels [1,2] owing to intensive cultivation of crops without the application of external inputs. This practice has of late resulted in the depletion of essential plant nutrients, including P and Ca that are important for plant growth [2]. These constraints, amongst others, have been reported to be the cause of poor growth of bean and a major threat to the sustainability of the small-scale production systems in Western Usambara Mountains [2,3] Phosphorus deficiency is known to impair early nodule functioning [4], retard plant growth and reduce the ability of the plant roots to release protons that may be useful in the solubilization of organic and inorganic P sources in the soil [5,6]. Calcium deficiency in legumes is also known to impair N_2 fixation and retard plant growth [7-12].

The majorities of small-scale farmers living in Western Usambara Mountains are poor and cannot afford to purchase expensive agricultural inputs such as Triple super phosphate or lime that could supply phosphorus and calcium to the commonly grown crops in the area, including beans [13]. Therefore, there is a great need to explore the available indigenous sources of nutrients that will ultimately be affordable to the poorly resourced farmers.

Incorporating some organic materials in the soil may contribute significantly in providing mineral nutrients needed by the plants [14,15] and hence increase the crop yields. The organic matter may consist of a wide range of mineral nutrients, upon the process of decomposition and mineralization, they may be made readily available for plant uptake and growth [16,17]. Additionally, the use organic plant materials may improve other important soil characteristics such as their water retention and the microbiological activities in the soil [18].

The exploratory work by [17] revealed that traditional shrub Tughutu contained more P and Ca than *Tithonia diversifolia*, the most researched shrub species in East Africa [18-21]. A number of studies also reported that Minjingu phosphate rock fertilizer has higher contents of water soluble P and Ca [22-24]. From this background, it is evident that these two indigenous resources could be used to boost agricultural production and improve people's livelihood in poor soils of the Western Usambara Mountains.

A few studies conducted in East Africa have shown improved growth and increased concentration of P and Ca nutrition in plants following the application of organic materials and phosphate rocks as fertilizers [1,15,16,24-33]. Significant synergistic effects were reported in growth or yield by combining the organic and inorganic P fertilizers such as rock phosphates or Triple Super Phosphate [1,14-16,29-31,34].

This study was conducted with the objective of evaluating the effects of supplying Tughutu alone, or in combination with locally available Minjingu phosphate rock or commercial Triple Super Phosphate fertilizer on plant growth, and amounts of P and Ca in bean shoots. Furthermore, soil chemical properties such as pH, P and Ca availability were assessed at harvesting.

2. MATERIALS AND METHODS

2.1 SiteLocation and Description

Six sites in farmers' fields were planted to beans in Western Usambara Mountains (04°47.976 S, 38°17.623' E) during the 2000 - 01 cropping season. The Western Usambara Mountains are located in an altitude ranging from 900 to 2300 m. a.s.l. and the major soils are classified as Humic and Chromic Acrisols, Luvisols and Lixisols [28]. Before planting, soil samples were collected from each site, bulked and analysed separately for pH, P, and Ca content for each site. Details of soilcollection and analysis are described in [2].

2.2 Field Trials

The fields were ploughed by a hand hoe. The experiments were set up as a randomized complete block design. Each farmer's field was assigned as a block. The experimental treatments consisted of six plots assigned to each block as follows: control, Minjingu phosphate rockor Triple Super Phosphate each at 26 kg P ha^{-1}, Tughutu at 2.5 t dry matter ha^{-1} and Tughutu at 2.5 t dry matter ha^{-1} combined with Minjingu phosphate rock or Triple Super Phosphate at 26 kg P ha^{-1}. P levels from Minjingu phosphate rock and Triple Super Phosphate were calculated considering the water soluble P in each fertilizer. Each treatment was planted in 25 m^2 plot. Inter-row and intra-row spacing of 50 cm and 20 cm respectively were used. Tughutu used in this study was collected from the Magamba forest reserve in Western Usambara Mountains. Fresh Tughutu leaves were surface applied and incorporated into the soil to 15 cm depth by hand hoe one week before sowing and allowed to decompose [17]. Recommended that Minjingu phosphate rock be broadcasted and incorporated into the soil by a hand hoe at sowing. Triple Super Phosphate was applied into the rows at planting. Two bean seeds coated with *Rhizobium tropici* strain CIAT 899 (10^9 g cellsseed^{-1}) purchased from the Nairobi MICERN, University of Nairobi, Kenya, were planted in each hole and allowed to grow to maturity. The inoculants packets were supplied with gum arabic for sticking as many cells as possible onto the seeds. Bean variety Lyamungu 90 used in this study was supplied by the breeder of the Selian Agricultural Research Institute, Arusha, Tanzania.

2.3 Plant Harvest and Analysis

Twenty plants were sampled 45 days after planting Di Ammonium Phosphate (DAP) from the two inner rows (1 m^2) in each plot for the above-ground biomass assessment. Bean yields from this study are reported elsewhere by [1]. The above ground shoots were cut with a knife at about 1 cm above the soil surface. Plant samples were dried to constant weight at 70°C in an oven for 48 h and ground into fine powder for the analysis of P by dry ashing method [35]. Phosphorus in the digest was measured by the molybdenum blue method as described by [36]. Calcium concentrations were determined by atomic absorption spectrophotometer as described by [37]. The measured concentrations of nutrients were multiplied by plant dry matter to obtain the above ground biomass amounts of the mineral. At harvest, soil adhering to the roots was collected from around 10 bean plants from each plot and analysed for pH, P and calcium as described above.

2.4 Statistical Analysis

Dry matter yield, P and Ca concentration and amounts in the tissues were analyzed using one-way analysis of variance (ANOVA). These computations were done with the software program STATISTICA [38]. The Fisher least significance difference (LSD) was used to compare treatment means at $P \leq 0.05$.

3. RESULTS AND DISCUSSION

3.1 Soil Analysis

Resultsof soil analysis are shown in Table 1 and reported elsewhere by [2]. Generally, P was low at all the sites with reference to optimum level of 11 mg P kg^{-1} soil as proposed by [39] for bean production. The exchangeable Ca ranged from 3.39 - 5.59 cmol kg^{-1} (Table 1). The proposed optimum level of Ca for the majority of crops is 5.0 cmol kg^{-1} [40] Four out of the six sites contained Ca levels lower than the proposed optimum levels and hence should receive some form of amelioration.

Table 1. Selected chemical properties of soils collected from the Western Usambara mountains in the Lushoto District of the Tanga Region, Tanzania

Site	Chemical properties of soils*		
	pH H_2O	Bray 1 P	Ca
		mg kg^{-1}	cmol kg^{-1}
Magamba	4.9	4.20	3.39
Ubiri	5.8	3.16	3.99
Ngulwii	5.5	2.80	5.59
Soni	5.9	1.68	5.59
Mbuzii	5.9	2.80	4.79
Mkuzi	5.2	4.20	4.79
Average	5.5	3.14	4.59

**Source: Ndakidemi and Semoka (2006)*

3.2 Dry Matter Yield

There was a small variation in dry matter yield across sites (Table 2) suggesting that to a greater extent, the six farmers' fields were fairly uniform. The dry matter (DM) yield of bean responded strongly (*P*≤0.001) to all amendments used in this study (Table 3) indicating that P was among the limiting nutrients in the study area. Dry matter yields also correlated significantly with their shoot amounts P (Table 3; r = 0.97, *P*=.05) and Ca (r = 0.86, *P*=.05) suggesting that the dry matter was related to their amounts. Moreover, there was significant correlation between the amendment treatments and dry matter (r = 0.83, *P*=.05) indicating insufficient P and probably Ca in soils used in the study (Table 1). The dry matter increased by more than twofold by adding Triple Super Phosphate alone or Tughutu combined with Minjingu phosphate rock as compared with the control treatment. Addition of Tughutu or Minjingu phosphate rock alone increased the dry matter by more than 50% as compared to the control treatment. However, combining Tughutu and Triple super phosphate gave the best results by increasing the dry matter more than threefold as compared with the control. In general, Minjingu phosphate rock or Tughutu supplied alone produced comparable dry matter yield, whereas there was no significant dry matter yield difference between Triple Super Phosphate or Tughutu combined with Minjingu phosphate rock (Table 3). The observed variations in dry matter are partly explained by the chemical composition of the materials used in this study [28,23]. Yield from Minjingu phosphate rock or Tughutu treatment were generally lower than those of Triple Super Phosphate owing to low P contents in these materials [28,23]. Generally there was a positive effect on dry matter yield by combining Minjingu phosphate rock or Triple Super Phosphate with Tughutu. This work is consistent with the work done by [34,15,29] that reported yield increases in maize by combining *Tithonia* or *Tephrosia vogelii* with Triple Super Phosphate or Minjingu phosphate rock.

3.3 Phosphorus and Calcium Amount in Shoots

Significant variation on P and Ca amounts in shoots were observed (*P*≤0.001) in all plots that were supplied with the amendments (Table 3). The amount of P and Ca in this study almost paralleled the dry matter yield (Table 3). This suggests that P and Ca were among the major limiting elements for bean growth in the Western Usambara Mountains (Table 3; [2,3]). Combining Tughutu and Triple Super Phosphate resulted in significantly higher P amount compared with all other treatments tested and was followed by Tughutu combined with Minjingu phosphate rock (Table 3). The good response of Triple Super Phosphate as compared with Minjingu phosphate rock could be due to the higher and faster dissolution rate of Triple Super Phosphate than Minjingu phosphate rock that improved their concentration in the soil (Table 4), in shoots (data not shown) and made them available for plant uptake (Table 3). Similar results have also been reported by [24,33] in maize.

Table 2. Estimates of micro-site variations on dry matter yield of common bean in WUM, northern Tanzania

Site	Dry matter yield** g plant^{-1}
Magamba	17.95
Ubiri	18.24
Ngulwii	17.55
Soni	19.17
Mbuzii	16.95
Mkuzi	20.94
Average	**18.47**

***Dry matter was determined by taking the average yield across all treatments from each site.*

Calcium amount in shoots almost followed the trend of P, but combining Tughutu with Minjingu phosphate rock or Triple Super Phosphate produced the best results that were not different (Table 2). A comparative study on the properties of Tughutu and other organic sources from Western Usambara Mountains revealed that Tughutu was superior to most of them in N, P and K content [17] Furthermore, mineralization patterns of Tughutu were faster and higher for N, P and K as compared with those of Tithonia and other useful shrubs. Therefore, high qualities of this plant render it a good source of nutrient for bean growers in Western Usambara Mountains.

In this study, combining organic material with Triple Super Phosphate or Minjingu phosphate rock promoted the uptake of P and Ca in bean. This was also reflected in the dry matter yield (Table 2). Research evidence suggests that Ca plays a crucial role in plant growth and development. This is responsible for structural rigidity of the cell wall, controlling the cell membrane structures and functions, and in many different signal transduction processes [41], which ultimately may contribute significantly in regulating plant growth and development as observed in this study (Table 2). Results from this study showed that the amount of P and dry matter yield in beans was significantly enhanced with the addition of Tughutu, Minjingu phosphate rock and the combination of Tuguthu with Minjingu phosphate rock or Triple Super Phosphate (Table 2 and 3). Phosphorus plays a key role in a plant's energy transfer mechanism (high energy phosphate), an essential intermediary in the metabolism of carbohydrate, protein and phospholipid transformations in plants and final plant growth [6]. Taken together, these results suggest that small-scale farmers in Western Usambara Mountains have the potential to benefit from the biomass transfer technology combined with a cheap inorganic resource such as Minjingu phosphate rock in improving their crop production.

3.4 Soil pH, Residual P and Ca at Harvest

The treatments supplied significantly (*P*<.05) changed the soil pH, P and Ca concentration in the soil solution at harvest (Table 4). Compared with control, Triple Super Phosphate supplied alone significantly decreased the soil pH more than with all other treatments. [42,43] also reported significant pH decreases with Triple Super Phosphate supply. However, the addition of Tughutu, Minjingu phosphate rock and the combination of Tuguthu with Minjingu phosphate rock or Triple Super Phosphate increased the soil pH as compared with Triple Super Phosphate and the control treatment (Table 4). The increase in soil pH owing to Minjingu phosphate rock can be owing to reasonably higher Ca content in this material [23]. Minjingu phosphate rock in this context provided a liming effect to the soil and hence raised its pH. Similar increases in soil pH with Minjingu phosphate rock applications and use of organic amendments have been reported by [16,15,30,31,34].

The effect of Tughutu, Minjingu phosphate rock, Triple Super Phosphate and/or their combination on residual P in the soil at harvest is shown in Table 4. Their application in the soil significantly (*P*=.05) increased the residual P in the soil. In this study, the use of Tuguthu combined with Triple Super Phosphate or Minjingu phosphate rock or Triple Super Phosphate applied alone elevated the residual P above the optimum level of 11 mg P kg^{-1} soil for bean production [39]. Addition of Tuguthu alone doubled the residual P in the soil as compared with control, but the level was still low. The observed small increase in soil P with Tughutu application was probably from the decay and the release into the soil of the organically bound P held in this material. These results suggest that Tughutu supplied alone has lower P input in the soil. Addition of Minjingu phosphate rock alone was not sufficient to raise the residual P value to the proposed optimum level (Table 4). It is possible that soil conditions were not favourable for Minjingu phosphate rock solubility and release of enough P into the soil in the first year. Amorphous rock phosphate could be weathered and released for plant growth over time [44,45]. Combining Minjingu phosphate rock with Tughutu released P above the proposed optimum level of 11 mg P kg^{-1} soil for bean production (Table 4). Studies have shown that organic acids released during the decomposition of organic materials improved the availability of soluble P from rock phosphates [6,14-16,30,31]. These findings suggest that repeated addition of inorganic phosphorus applied alone or in combination with Tughutu could build soil P reserves to reasonable levels and sustain crop productivity in Western Usambara Mountains.

The addition of Tughutu, Minjingu phosphate rock, Triple Super Phosphate and/or their combination influenced the residual exchangeable Ca in the soil (Table 4). The proposed optimum level of exchangeable Ca in the soil is 5.0 cmol kg^{-1} [40]. Except Triple Super Phosphate and control, other treatments increased the exchangeable Ca above the proposed optimum levels in the following order: Tuguthu + Minjingu phosphate rock>Minjingu phosphate rock>Tuguthu + Triple Super Phosphate>Tughutu>Triple Super Phosphate> control (Table 4). All treatments involving Minjingu phosphate rock were superior in increasing residual soil Ca as compared with others. Similar observations in which the addition of Minjingu phosphate rock in soils increased the residual Ca as compared with Triple Super Phosphate have been reported by [32]. Minjingu phosphate rock has a reasonably higher Ca content than Triple Super Phosphate [23] and Tughutu [17].

Table 3. Effects of Tughutu application, Minjingu phosphate rock or triple super phosphate supply on dry matter yield (DMY), P and Ca amount in shoots of *Phaseolus vulgaris* L. measured at 45 days after planting

Treatments	Dry matter yield	P	Ca	P	Ca
	g.plant^{-1}	mg.plant^{-1}	mg.plant^{-1}	kg.ha^{-1}	kg.ha^{-1}
P_0 +T_0 (Control)	9.68±0.26d	12.31±0.80d	116.81±4.02d	2.46±0.16d	23.36±0.80d
T_0 + MPR	15.58±0.66c	26.66±2.12c	302.38±23.34bc	5.33±0.42c	60.48±4.67bc
T_0 + TSP	19.88±0.69b	38.86±2.46b	326.34±21.21b	7.77±0.49b	65.27±4.24b
T	15.27±0.81c	24.06±1.88c	216.34±18.97c	4.81±0.38c	43.27±3.79c
T+ MPR	22.03±1.13b	45.07±3.75b	557.51±61.05a	9.01±0.75b	111.50±12.21a
T+ TSP	28.35±1.92a	66.80±6.86a	529.80±41.23a	13.36±1.37a	105.92±8.25a
F - Statistics	37.84***	28.97***	26.48***	28.97***	26.48***

**** Significant at $P\leq 0.001$. a) P_0 = zero level of phosphorous; T_0 = zero level of Tughutu; Minjingu phosphate rock 26 kg P ha-1 = 26 kg P ha^{-1} of Minjingu phosphate rock; Triple Super Phosphate 26 kg P ha^{-1} = 26 kg P ha^{-1} of Triple Super Phosphate; T2.5 t ha^{-1} = 2.5 t of Tughutu ha^{-1} b) Mean values within a column followed by different letter(s) differ significantly at P=.05 according to Fishers least significance difference*

Table 4. Effects of Tughutu application, Minjingu phosphate rock or Triple Super Phosphate supply on pH, residual P and Ca in the soil collected from rhizosphere of *Phaseolus vulgaris* L. plants at harvest

Treatments	pH H_2O	P	Ca
		mg.kg^{-1}	cmol.kg^{-1}
P_0 + T_0 (Control)	5.32±0.16bc	3.28±0.41d	4.52±0.40b
T_0 + MPR	5.86±0.18a	10.59±0.47b	5.99±0.45a
T_0 +TSP	5.23±0.16c	14.76±0.80a	4.72±0.41b
T	5.79±0.20ab	6.93±0.51c	5.01±0.41ab
T+ MPR	5.98±0.20a	14.61±1.23a	6.14±0.41a
T+ TSP	5.71±0.17abc	16.79±1.06a	5.05±0.37ab
F - Statistics	2.92*	41.77*	2.68*

** Significant at P=.05. a) P_0 = zero level of phosphorous; T_0 = zero level of Tughutu; Minjingu phosphate rock 26 kg P ha^{-1} = 26 kg P ha^{-1} of Minjingu phosphate rock; Triple Super Phosphate 26 kg P ha^{-1} = 26 kg P ha^{-1} of Triple Super Phosphate; T2.5 t.ha^{-1} = 2.5 t of Tughutu ha^{-1} b) Mean values within a column followed by different letter(s) differ significantly at P□.05 according to Fishers least significance difference*

4. CONCLUSION

The inherently low soil fertility status in most parts of the Western Usambara Mountains makes sustaining agricultural production difficult. This is the first work to evaluate Tughutualone and/or in combination with phosphate rock or Triple super phosphate on their influence on growth, amount of phosphorous and calcium content in bean shoots. The application of Tughutu, Minjingu Phosphate Rock or triple super phosphate and their combination showed synergistic effects in plant growth, amount of phosphorous and calcium and improvement in selected chemical soil properties measured at the end of the crop season. In conclusion, the locally available shrub (Tughutu) and Minjingu Phosphate Rock can constitute a very valuable and viable supplement to the industrial fertilizer sources in the Western Usambara Mountains. Future research could also focus on the relative cost (collecting, purchasing, supply of the products, transport and farm labour) of applying Tughutu and Minjingu Phosphate Rock in relation to that of triple super phosphate. There would appear to be no negative effects of Tughutu and Minjingu Phosphate Rock application on these soils or the bean crop.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Ndakidemi PA. Agronomic and economic potential of tughutu (*Vernonia subligera* O.Hoffn) and minjingu phosphate rock as alternative P sources for bean growers. Pedosphere. 2007;17(6);732-738.
2. Ndakidemi PA, Semoka JMR. Soil fertility survey in western Usambara Mountains, northern Tanzania. Pedosphere. 2006;16; 237-244.
3. Ndakidemi PA, Semoka JMR. Soil fertility constraints to bean production in Lushoto District and their amelioration by application of lime, phosphorous and potassium. In Msumali GP, Mabagala RB (eds.). Bean Research. Proceedings of 12th Bean Research Workshop, Sokoine University of Agriculture, Morogoro, Tanzania. 1993;8:32-50.
4. Vance CP. Symbiotic nitrogen fixation and phosphorus acquisition. Plant nutrition in a World of Declining Renewable Resources. Plant Physiol. 2001;127:390-377.
5. Tang C, Hinsinger P, Drevon JJ, Jaillard B. Phosphorus deficiency impairs early nodule functioning and enhances proton release in roots of *Medicago truncatula* L. Ann. Bot. 2001;88:131-138.
6. Vance CP, Uhde-Stone C, Allan DL. Phosphorus acquisition and use: critical adaptations by plants for securing a nonrenewable resource. New Phytol. 2003;157:423-447.
7. Greenwood EAN, Hallsworth EG. Studies on the nutrition of forage legumes. II. Some interactions of Ca, P, Cu and Mo on the growth and chemical composition of *Trifolium subterraneum* L. Plant Soil. 1960;12:97-127.
8. Banath CL, Greenwood EAN, Loneragan JF. Effects of calcium deficiency on symbiotic nitrogen fixation. Plant Physiol. 1966;41;760-763.
9. Lowter WL, Loneragan JF. Calcium and nodulation in subterranean clover (*Trifolium subterraneum* L.). Plant Physiol. 1968;43:1362-1366. on P availability. Soil Biol. Biochem. 2003;35:207-216.
10. Muns DN. Nodulation of *Medicago sativa* in solution culture. V. Calcium and pH requirements during infection. Plant Soil. 1970;32:90-102.
11. Blevins DG, Barnett NM, Bottino PJ. The effects of calcium and the ionophore A23187 on nodulation, nitrogen fixation and growth of soybeans. Physiol. Plant. 1977;41:235-238.
12. Streeter JG. Effect of elevated calcium concentration in infected cells of soybean (*Glycine max* L. Merr.) nodules on nitrogenase activity and N input to the plant. J. Exp. Bot. 1998;49:997-1003.
13. Lyamchai CJ, Lyiom SD, Ndondi RV, Owenya MZ, Ndakidemi PA. Massawe NF. Participatory rural appraisal for Kwalei Catchment, Lushoto District. Selian Agricultural Research Institute, Arusha, Tanzania. 1998;71.
14. Ikerra TWD, Mnkeni PNS, Singh BR. Effects of added compost and farmyard manure on P release from minjingu phosphate rock and its uptake by maize. Norw. J. Agr. Sci. 1994;8:13-23.
15. Ikerra ST. Use of minjingu phosphate rock combined with different organic inputs in improving phosphorus availability and maize yields on a Chromic Acrisol in Morogoro, Tanzania, Ph.D Thesis. Sokoine University of Agriculture, Morogoro, Tanzania. 2004;262.
16. Savini I. The effect of organic and inorganic amendments on phosphorous release and availability from two phosphate rocks and triple super phosphate in phosphorous fixing soils, MSc Thesis. University of Nairobi, Kenya. 2000;104.
17. Wickama JM, Mowo JG. Using local resources to improve soil fertility in Tanzania. Managing Africa's Soils Working Paper International Institute for Environment and Development (IIED). London. 2001;21:24.
18. Kwabiah AB, Palm CA, Stoskopf NC, Voroney RP. Response of soil microbial biomass dynamics to quality of plant materials with emphasis. 2003;35(2):207–216.
19. George TS, Gregory PJ, Wood M, Read D. Buresh RJ. Phosphatase activity and

organic acids in the rhizosphere of potential agroforestry. 2002;34(10):1487–1494.

20. Kwabiah AB., Stoskopf NC, Palm CA, VOoroney RP. Soil availability as affected by the chemical composition of plant materials: Implications for P-limiting agriculture in tropical Africa. Agr. Ecosyst. Environ. 2003;100:53-61.
21. Kwabiah AB, Stoskopf NC, Palm CA, Voroney RP, Rao MR, Gacheru E. Phosphorus availability and maize response to organic and inorganic fertilizer inputs in a short-term study in western Kenya. Agr. Ecosyst. Environ. 2003;95:49-59.
22. Weil RR. Soil and Plant Influences on Crop Response to Two African Phosphate Rocks. Agron. J. 2000;92:1167-1175.
23. Szilas C. The Tanzanian Minjingu phosphate rock – possibilities and limitations for direct application. PhD Thesis, Royal Veterinary and Agricultural University, Copenhagen; 2002. Available:http://www.igv.kvl.dk/-casz
24. Msolla MM. Agronomic evaluation of maize performance using hard and soft Minjingu phosphate rocks and in mixtures with triple phosphate on selected Tanzanian soils.
25. Mnkeni PNS, Semoka JMR, Buganga BBS. Agronomic effectiveness of Minjingu phosphate rock as a source of phosphorus for maize in some soils of Morogoro District, Tanzania. Zimbabwe J. Agric. Res. 1991;30:27-37.
26. Semoka JMR, Mnkeni PNS, Ringo HD. Effectiveness of Tanzanian phosphate rocks of igneous and sedimentary origin as sources of phosphorus for maize. Zimbabwe J. Agric. Res. 1992;30:127-136.
27. Haque I, Lupwayi NZ, Ssali H. Agronomic effectiveness of unacidulated and partially acidulated Minjingu rock phosphate on *Stylosanthes guianensis*. Trop. Grasslands. 1999;33:159-164.
28. Mowo JG. Effectiveness of phosphate rock on Ferralsols in Tanzania and the influence of within field variability, Ph.D Thesis. Wageningen Agricultural University, The Netherlands. 2000;64.
29. Mkangwa CZ. Influence of Minjingu Phosphte rock application on *Tephrosia vogelii* fallow productivity and subsequent maize response on Ferralsol in Morogoro, Tanzania. PhD Thesis, Sokoine University of Agriculture, Morogoro, Tanzania. 2004;227.
30. Savini I, Smithson P, Karanja N. Effects of added biomass, soil pH and calcium on the solubility of Minjingu phosphate rock in a Kenyan Oxisol. Arch. Agron. Soil Sci. 2006;52:19-36.
31. Savini I, Smithson PC, Karanja NK, Yamasaki H. Influence of *Tithonia diversifolia* and triple superphosphate on dissolution and effectiveness of phosphate rock in acidic soil. J. Plant Nutr. Soil Sci. 2006b;169;593-604.
32. Szilas C, Semoka JMR, Borggaard OK. Can local Minjingu phosphate rock replace superphosphate on acid soils in Tanzania? Nutr. Cycl. Agroecosys. 2006;77:257-268.
33. Msolla MM, Semoka JMR, Szilas C, Borggaard OK. Crop (Maize) response to direct application of local phosphate rock on selected acid soils of Tanzania. Comm. Soil Sci. Plant Anal. 2007;38:93-106.
34. Osunde AO, Zapata F, Sangiga N. Agronomic evaluation of rock Phosphate as a phosphorus sources for *Leucaena leucocephala* grown on an altisol. In Proceedings of the African Association of Biological Nitrogen Fixation (AABNF) held at the International Institute of Tropical Agriculture (IITA), Ibadan Nigeria, 24-28 September, 1990: 1992.
35. Chapman HD, Pratt PF. Methods of Analysis for Soils, Plants and
36. Murphy J, Riley JP. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta. 1962;27:31-36.
37. Hesse PR. A text book of soil chemistry analysis. John Murray Ltd. London. 1971;120-121and 309.
38. STATISTICA. StatSoft, Inc. 2300 East 14th Street, Tulsa, OK 74104, USA; 2008.
39. Schwatz HF, Corralles MAP. Nutritional disorders in beans. In Schwatz HF, Corrales MAP (eds.). Bean Production Problems in the Tropics. CIAT, Cali, Columbia. 1989;57-604.
40. Marx ES, Hart J, Steven RG. Soil test interpretation guide. Oregon State University extension services. Oregon State University, Corvallis. 1996;7.
41. Helper PK, Calcium: A central regulator of plant growth and development. Plant Cell. 2005;17:2142-2155.
42. Robinson JBD. The influence of fertilizer and manure on the pH reaction of a coffee

soil. E. Afr. Agric. and For. J. 1956;22:76-80.

43. Huffman EO. Reaction of phosphate in soils: Recent research by TVA. Proceeding 71. The Fertilizer Society, London; 1962.

44. Chieh SH, Menon RG. Factors affecting the agronomic effectiveness of phosphate rock for direct application. Fert. Res. 1995;41:227-234.

45. Smalbarger SA. Singh U, Chien SH, Henao J, Wilkens PW. Development and validation of a phosphate rock decision support system. Agron. J. 2006;98:471-483.

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