

**THE FORTIFICATION OF COMPOST WITH
PHOSPHATE ROCK.**

(A field Experiment).

BY

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DEDICATION.

My special dedication goes to Mum, Uncle Felix and Sister Christine. They have been very supportive throughout my studies. I will always recognize them for better for worse. I thank God for this wonderful gift of giving me these people. Further, I pay my sincere homage to the late grand-mum (Atalia). She was always for me in every circumstance. Her soul should rest in eternal piece. Last but not the least; I thank my fiancée A.Banda for the encouragement that she gave me during the research.

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ABSTRACT

Zambia is well vested with many natural resources that have not been expected. One of such resource is the Chilembwe phosphate rock (PR) found in eastern province. The particular rock is of ingenious origin, hence having a very low solubility rate. Direct application of phosphate rock on fields of annual crops has been attempted but yields have not improved significantly. Therefore, only perennial crops can benefit from this material over a long period of time. Nevertheless, the production of chemical fertilizers such as Triple Super Phosphate involves the reaction of phosphate rock with orthophosphoric acid. This particular acid is very expensive, thus increasing the costs of fertilizers. The low soil fertility coupled with high costs of fertilizers has resulted into low crop yields in most developing countries. For this reason, poverty levels have exacerbated such that attaining the millennium development goals by the year 2015 is a mere phallus. Cheaper methods of solubilizing this valuable material need to be invented. The fortification of compost with phosphate rock is one of the promising ways of making phosphorus available for plant uptake. The process relies on the presence of organic acids that are secreted microorganisms during decomposition of organic matter. The research on fortification of compost with phosphate rock was carried out at the University of Zambia, 'field station' from 01-08-05 to 23-12-05. Five compost heaps were made. The rates of phosphate rock added to each compost heap were 0.00kg, 2.41kg, 4.82kg, 9.61kg and 14.47kg that corresponded to 0, 20, 40, 80 and 120kg P₂O₅ per hectare respectively. Incubation of composts lasted for two months, followed by application and planting of green beans. Phospho-Compost and soil samples were tested for available phosphorus in the laboratory. Also plant tissue analysis for phosphorus was done. The biomass and weight of pods per plant were measured on dry basis. It was discovered that the 40kg/ha level of phosphate rock produced the highest crop yield as compared to other levels.

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P in a bioactive soil was remarkably enhanced such as a phenomenon inspires the application of a similar principle on the bio-activation of relatively non-reactive PR. The fact that certain soil microbes are capable of dissolving relatively insoluble phosphatic compounds (Asea, 1988; Bojinova, 1997) has opened the possibility for inducing microbial solubilization of phosphate rock. Many investigators believed that the phenomenon was closely related with the ability of the microbes to produce organic acids (Goenadi, 1995).

1.2 Forms of available phosphorus.

Phosphorus is the macronutrient that plants absorb either as H_2PO_4^- the principle form, or smaller amounts of the secondary orthophosphate ion, HPO_4^{2-} . At pH 7.22 there are approximately equal amounts of those available species. Below this pH, H_2PO_4^- is the main form while HPO_4^{2-} becomes more important at pH values above 7.22 (Tisdale, 1985)

According to Donahue (1983), P is most available at pH 6.5 for mineral soils and at pH 5.5 for organic soils. The other form available is PO_4^{3-} at very high values.

1.3 The role of phosphorus (P) in crops.

Phosphorus is one of the major nutrients, the other three being nitrogen, potassium and sulphur in the Zambian situation. These are needed in large quantities to sustain high crop yields. The primary role of P is to store energy produced by photosynthesis for use in growth and development and reproductive processes. Phosphorus is an essential element and a component of certain enzymes and proteins, Adenosine Triphosphate (ATP) and other compounds. ATP is involved in various energy transfer reactions. Adequate P encourages vigorous root and shoot growth and promotes early maturity. These effects often increase efficient use of water and potential grain yield. When there is a deficiency of P, plants get stunted and grain development is also affected. The development of a purple colour is symptomatic of a severe deficiency.

1.4 Problem statement

Zambian soils are of low fertility because they are poor in phosphorus, nitrogen and Cation Exchange Capacity (C.E.C). Furthermore there is inadequate supply of cheap and acceptable compost manure for organic production of high value horticultural crops. This is because organic manures are low in phosphorus and other nutrients. On the other hand, inorganic phosphatic fertilizers are expensive and not acceptable for farming.

1.5 Hypothesis

The composting of organic matter with PR will **not** increase the agronomic effectiveness of compost for crop production.

1.6 Objectives

Evaluation of the agronomic effectiveness of phospho-compost for the production of high value horticultural crops (Green beans).

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 PHOSPHATE ROCK.

According to the International Fertilizer Development Center report (I.F.D.C, 1978), PRs have in the last few years received attention as sources of sources of phosphorus for plants especially in the developing countries. The term phosphate rock (PR) describes any naturally occurring geological material that is an important raw material for phosphate fertilizer. The term comprises both unprocessed phosphate ore as well as the concentrated phosphate products (Notholt and Highley, 1986). The formula for pure PR is $[Ca_{10} (PO_4)_6 (X)_2]$ where X is F^- , OH^- or Cl^- . The mineral are called apatites with the most commonly occurring being fluoroapatite (F^-). Carbonate fluoroapatite (francolite) is the primary apatite mineral occurring in most phosphate rocks. The phosphate ore have varying mineralogical, textural and chemical characteristics depending on the origin of the rock and the natural processes it has been subjected to the francolite forms a continuous series with end members that contain no carbonate substitution. Substitution of the series governs most of the physical and chemical properties of the francolites and this also controls the reactivity of PR.

According to Van Straaten (2002), there are five major types of phosphate rock resources that are being mined in the world:

- Sedimentary/marine phosphate deposits
- Igneous phosphate deposits.
- Metamorphic deposits.
- Biogenic deposits (bird and bat guano accumulations)
- Phosphate deposits as a result of weathering.

Sedimentary/marine phosphate rocks produce about 80-90% of the total world production of PR. The igneous and weathered deposits account for about 10-20% and only 1-2% are from biogenic resources (Van Kauwenbergh, 2001). The most suitable phosphate rocks for direct application are those classified as 'reactive', because of the chemical

composition that allows for rapid dissolution in the soil. PR of biogenic, marine and metamorphic deposits is relatively reactive where as that of igneous origin is not. There is however, a gradual depletion of high-grade PR sources taking place all over the world. The PR from igneous rock is not very reactive but can be upgraded to high-grade concentrates of up to 36-40% P_2O_5 and this upgrading process is very expensive. The igneous deposit contain apatites of the fluoroapatite $[Ca_{10}(PO_4)_6OH_2]$ type.. The pure apatites from igneous deposits contain about 42% P_2O_5 and are not suitable for direct application. Due to their un-reactivity, for example the igneous layers of Missouri are sources which are less soluble because of their crystalline structure. The sedimentary layers rich in calcium as those of Arkansas are also of worse sources of phosphorus because calcium reduces the solubility of phosphorus (Howeler and Woodruff 1968). The Fluorine is regarded as an element which lowers the reactivity of phosphate rock while the carbonates non-related to calcium are regarded as being able to increase its reactivity. Caro and Hill (1956), estimate that the best test of the agronomic value of rock phosphates is their solubility in the citric acid and their content dependent carbonate. These two tests present the best collection with the outputs.

2.1.1 Physical characteristics.

The physical characteristics of rock phosphates have less importance than their chemical composition as for the availability of phosphorus. They have all the same an impact on this one. The principal physical characteristics used are compactness, porosity, the smoothness of crushing and active surface. As a general rule, reactivity of phosphate of rock, therefore its availability increases when its density decreases and that its active or specific surface increases. Active surface tends to increase according to the data of Caro and Hill (1956), although the results are very variable of a type of phosphate to the other. However, Kramer (1962) concluded from his research that the smoothness of the particles has little importance up to a certain point. It is considered that it is not necessary and economically difficult to justify, obtaining particles finer than those which pass a sieve of 149 microns. Similarly, Canner and Adams (1926) did not obtain significant phosphate from rock finer than 50 microns.

Baranov and Sirotnin (1964) noted that it is not by crushing a phosphate of rock of poor quality more finely than one can improve the availability of phosphorus than it contains. On the other hand it is possible to improve the availability of a poor phosphate rock by crushing it finely and by perforating it or by mixing it with manure before application. It should be noted finally that the law on manures of Canada stipulates that the phosphate rock to be sold like such must be crushed so that 80% of the product passes in a sieve of 149 microns.

2.1.2 Factors Affecting the Relative Agronomic Effectiveness of PR.

The relative effectiveness of PR as a fertilizer is expressed as its ability to supply P for the desired levels of crop production.

(i) Reactivity of phosphate rocks

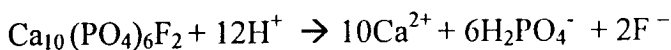
The chemical and mineralogical properties of untreated PR are the key factors in determining the reactivity and agronomic effectiveness of a given PR. The degree of isomorphous substitution in the apatite structure by carbonates determines the chemical reactivity of the phosphate rock. Sedimentary PR has a high reactivity as compared to those of igneous rock and metamorphic origin.

(ii) Soil factors affecting PR dissolution.

There are specific soil properties that influence the dissolution of apatite minerals in the phosphate rocks and thus the agronomic effectiveness. These factors influence the solubility of the PR for direct application.

- Soil pH or soil reaction;

Soil pH is one of the most important factors affecting P availability. Generally the effectiveness of phosphate rocks greatly depends on soil pH. PR dissolution is higher under acidic conditions than alkaline ones (Chien 2001). The effect of pH on dissolution or PR is shown by the following equation



(iii) Cation exchange capacity (C.E.C)

The C.E.C of the soil is closely related to the soil texture and it affects the calcium status of the soil. Sandy soils with a low CEC do not provide a calcium sink for the calcium ions released from the PR, so the rate of PR dissolution is decreased. This results in a reduction in the agronomic effectiveness of the PR (Kanobo and Gilkes, 1988)

(iv) Sorption capacity

The dissolution of the PR, increases with P sorption capacity (Symth and Sanchez, 1982). Soils that have a high capacity of fixing P like Oxisols and Ultisols enhance the dissolution of the PR by reducing the P concentration in the immediate surrounding of the PR (Syers and Mackay, 1986)

(v) Crop Factors

Crop species have been found to have different responses to applied PR due to several factors. Some of these factors are length of growing season, calcium absorbing or releasing capacity and acidification of the rhizosphere by organic acids.

• Length of growing season

It has been found that perennial crops tend to benefit more from the application of PR than short term or annual crops (Chien, Sale and Hammond, 1990). Research carried out in Malaysia has shown that plantation tree crops like rubber, cocoa and oil palm trees promote the dissolution of the PR due to their high root density.

• Calcium absorbing capacity of plants

Plants have been known to improve PR dissolution by removing calcium and phosphorus from the soil solution surrounding the PR particles (Drack and Stekel, 1955). According to the solubility product principle for PR dissolution, the P concentration of P solution increases as the calcium concentration decreases. The concentration of P in solution should be greatest in the presence of plants that absorb the most calcium such as the Leguminous (*Phaseolus vulgaris*) and cruciferes (*Brassica oleracea*) compared to graminaceous ones (*Zea mays*).

- **Acidification of the rhizosphere by organic acids.**

This account for the differences plants species have in utilizing PR. The organic acids produced by plants have different abilities in their mobilizing capacity of P from PR. As an example, the roots of pigeon pea release piscidic acid that complex iron to enhance the availability of iron bound phosphorus. P deficient rape seed plants acidify part of their rhizosphere by exuding malic and citric acids, thus accessing the poorly soluble PR sources (Vand Der Mass and Van Diest, 1983).

(vi) Management Factors

Management practices like method of planting timing of application of PR and lime application can influence the effectiveness of PR or water soluble P fertilizers (Chien and Menon 1995). The placement of PR in soils influences the rate of P release of PR . It has been shown through various studies that broadcasting and incorporating the PR in the soil increases the effectiveness of PR as compared to banding because there is more contact of the PR with the soil. Timing of the application of PR is important for its effectiveness. It has been demonstrated that the effectiveness of low soluble PR was enhanced when applied early to acid soils (Cabala-Rosand and Wild, 1982). Early application before planting allows some time for the dissolution to start.

(vii) Organic Matter Content

Organic matter is one of the major factors that affect the agronomic effectiveness of PR and has several functions. Organic matter especially cattle manure affects the solubilization of PR as it acts as a sink for calcium ions. The removal of calcium ions from the solution by the manure, results in the further dissolution of the PR, hence promoting the forward reaction.

2.2 Phosphate rock in Zambia

Four PR deposits have been found in Zambia.

- Chilembwe deposits (1.6 million tones, 12 % P_2O_5); Mineral exploration (MINEX) Department of the ZIMCO in 1978 discovered Chilembwe deposit in Petauke, Eastern province, located 460 km east of Lusaka.
- Sugar loaf of Mumbwa North deposits (0.25 million tones, 5% P_2O_5) Central Province, known as early as 1958
- Nkombwa Hill deposit (500 million tones, 4% P_2O_5) southeast of Isoka Northern Province.
- Kaluwe deposit (200 million tones 2.5% P_2O_5) in Rufunsa valley.

The chemical composition of phosphate rock from the deposits influences their value as sources of phosphorus for agricultural purposes. Their physical strength is also important as it affects particle size reduction or weatherability and hence processing costs. Phosphate rock will only be of value in acidic soils which solubilize it and make it available to plants; otherwise they are of low reactivity to make P available for immediate crop benefit. Phosphate rock from Chilembwe, which has 1.5% citrate soluble P_2O_5 and is of igneous origin (Ssali 1991) was used in this research.

2.3 phospho-compost .

Treating PRs with organic materials and composting them is a promising technique for enhancing the solubility and the subsequent availability to plants of phosphorus (P) from PRs. The technology is particularly attractive where:

- Moderate to reactive PRs are available but unsuitable for the production of fully acidulated fertilizers such single or Triple Super Phosphate.
- Organic manures are applied routinely to maintain the organic fraction of soils and supplement their nutrient requirement (as in most tropical countries).
- Organic farming is practiced, which excludes, the use of chemically processed fertilizers, and

- City and farm by-products need to be disposed of in an environmentally friendly manner. The PR-composted products are usually referred to as phospho-compost.

2.3.1 Principles of phospho-Composting

Phospho-compositing is based on sound scientific principles. During the decomposition of organic materials, intense microbial activity occurs. This results in numerous types of bacteria and fungi, which produce a large number of organic acids and humic substances. Some of the most commonly produced organic acids are: citric, malic, fumaric, succinic, tartaric, oxaloacetic, propionic, lacticoxalic, 2-ketogluconic and butyric acids.(Bangar, Yadav and Mishra, 1985).

The term humic substances are a generic name given to a large number of amorphous, colloidal organic polymers formed during the decomposition of organic matter. Humic substances are of high molecular weight and generally more stable than organic acids. Humic substances can be divided into three main fractions based on their solubility in acid and/or alkaline. The fraction that is soluble in acid and alkaline is called **fulvic acid**, that is soluble in alkali but precipitated in acid is **humic acid**, and that is insoluble in acid and alkali is **humic**.

The enhancement of P released from PRs seems to be a function of the acidification of PR by organic acids and more importantly their chelating ability on calcium (Ca), iron (Fe) and aluminium (Al) (Pohlman and MacColl, 1986).

The greater ability of organic acids compared with mineral acids of comparable strength, to release P from PR and the direct evidence of their chelating ability have been documented (Johnson 1954a). Another important factor in the release of P from PR is the participation of the OH groups in the organic acids. For example, it has been shown that citric acid with three carboxyl (COOH) groups and OH group was able to dissolve more P from PR than cis-aconitic acid with three carboxyl groups but without the OH group. Fulvic acid is the most reactive of the humic substance in adsorbing significant amount of Ca^{2+} and releasing H^+ ions, thereby enhancing PR dissolution. Humic acids may form complexes with P and Ca, and create a sink for further dissolution of PR (Otti, 1990).

The application of humic substances to soil also makes more P available to plants by competing for, and by forming a protective coating over, soil phosphate-sorption sites. An additional phosphate that accrues from the application of phosphor-compost is the movement of dissolved P to a greater soil depth, which provides a larger soil volume for P uptake by plants.

2.3.2 Practical considerations of Phospho-Composting

Organic manures is a broad term that comprises: manures prepared from cattle dung excreta of other animals, crop residues, rural and urban composts and other animal wastes. The concentration of nutrients in organic materials is variable. Although most of these materials contain significant amount of nitrogen (N), they contain little P. The effectiveness of the composts in solubilizing PR varies with the kind and composition of waste material and with the rate of decomposition. It is the function of the magnitude of production of organic acids and chelating substances in the compost, which in turn result from the metabolic activities of micro-organisms including bacteria fungi and actinomycetes. Reports indicate that plant materials such as chopped leaves, crop residues (example, cereal straw) and lawn clippings composted with animal wastes are favoured because they produce more organic acids and humic substances. Composting PR with poultry manure may not be preferred option because poultry manure contains large amount of calcium carbonates and other basic compounds that hinder PR dissolution (Mahimai raja 1995).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location

The experiment was carried out at the University of Zambia, 'Field Station under School of Agriculture Sciences, between 01-08-05 and 23-12-05. Five compost heaps were made at the field station and the test crop; green beans (carioca 15) was grown on the field.

3.2 Composting

Cheap and readily available dry grass, which was cut from the lawns, and fresh kraal manure were the organic materials used to make composts. The ratio of grass to manure on dry weight basis was, (4.95kg of grass to 2.50kg of kraal manure), per every compost heap. The dry grass and kraal manure were the sources of Carbon and Nitrogen respectively for microorganisms during decomposition. The total weight of dry organic matter per every un-decomposed compost heap was 40.00kg.

However, one compost heap was a control while the other four were fortified with varying levels of ground phosphate rock. Further, when making the composts, all materials were piled into alternate layers until the 1mx1mx1m compost heaps were complete. The layers of dry grass were softened by sprinkling water on them. When all the compost heaps were made to completion, they were covered with black polythene plastics to achieve effective incubation and decomposition. The compost heaps were turned every after two weeks to enhance aerobic respiration by microorganisms. The incubation period took 60 days, from 01-08-05 to 30-09-05.

3.3 Phosphate rock source and application rates.

The school of mines supplied phosphate rock from chilembwe PR deposits. It is of igneous origin, with the citrate solubility rates of 1.5% of PR added to each 40kg organic

matter compost, P₂ O₅ (Ssali, 1991) and particle size of 0.425mm. the rates were 0.000kg, 2.41kg, 4.83kg, 9.66kg and 14.47kg.

3.4 Experiment/Planting of Green beans.

The experiment consisted of 2 factors being; 2 levels of organic matter (OM), factor A and 5 levels of PR, factor B. On dry weight basis, the application rate of organic matter was 6.0kg per 3m by 2m plot, which is equivalent to 10 tons per hectare. The number of treatments was ten, as shown in table 1.

Treatments	Level(OM)	OM(kg/ha)	Level(PR)	PR(kg/ha)	Equivalent P ₂ O ₅ (kg/ha)
1	1	0.0	1	0.00	0
2	1	0.0	2	0.81	20
3	1	0.0	3	1.61	40
4	1	0.0	4	3.22	80
5	1	0.0	5	4.83	120
6	2	6.0	1	0.00	0
7	2	6.0	2	1.81	20
8	2	6.0	3	1.61	40
9	2	6.0	4	3.22	80
10	2	6.0	5	4.83	120

Table 1: Experimental set up.

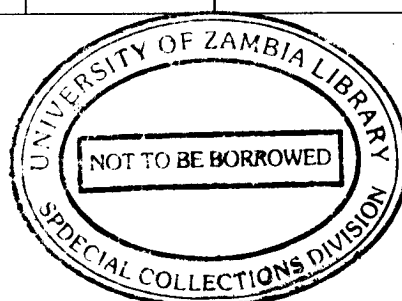




fig. 1: General overview of the field



fig. 2: Treatment No. 1 (Control)



fig. 3: Treatment No. 10



fig. 4: Treatment No. 8

In the field, the experiment followed a randomized complete block design (RCBD) of 3 replications. After incubation, phospho-compost was incorporated in the plots before sowing beans. The same applied for direct application of PR. Beans was sown on 01.10.05 and each plot had 4 rows of plants. The inter row and intra row spacing was 50cm and 20cm respectively.

3.5 Crop Management.

Three seeds of beans were sown per station and later thinned leaving one plant. The maximum plant population was 60 plants per plot. Irrigation was done regularly because the rate of evapo-transpiration was very high. Weeding was done every after 2 weeks by hoes. No chemical fertilizers, herbicides, growth regulators and pesticides were used for crop production.

3.6 Phospho-Compost, soil and plant analysis.

Phospho-compost and soil samples were taken to the laboratory for determination of available phosphorous, using Bray 1 method, For plant analysis, leaves and pods were sampled per plant, then oven dried at 65⁰C for three days. The dry plant samples were ground and later digested using nitric acid and perchloric acid. Samples filtrates were collected and colour was developed for spectrophotometer reading of phosphorus contents.

3.7 Data Collection

Data was collected on biomass and total pod weight per plant on dry basis. The crops were harvested 83 days after sowing, by cutting stems just above the soil surface. The plants were oven dried at 65⁰C for three days as well.

Analysis of variance (ANOVA) was done using MSTAT C statistical package. Treatment means were separated using the Duncan's Multiple Range Test. The means were then used to construct graphs.

CHAPTER FOUR.

4.0 RESULTS AND DISCUSSION

4.1 The Laboratory Analysis of Available Phosphorus

Level of P (kg/ha).	Particle size (mm).	Available P (mg/l).
0	0.425	46.25
20	0.425	41.75
40	0.425	68.83
80	0.425	40.31
120	0.425	57.34

Table 2: Phospho-Compost analysis.

Soil sample had 19.39mg/l available Phosphorus.

From the table above, Phosho-Compost that had 40kg/ha Level of P tested the highest amount of available Phosphorus (68.83mg/l). This is an indication that the particular compost had optimal environmental conditions for microbial decomposition compared to the others. The higher the level of microbial activity the more organic acids are released and higher the rate of dissolution of Phosphate rock.

4.2 Plant Tissue Analysis of Phosphorus.

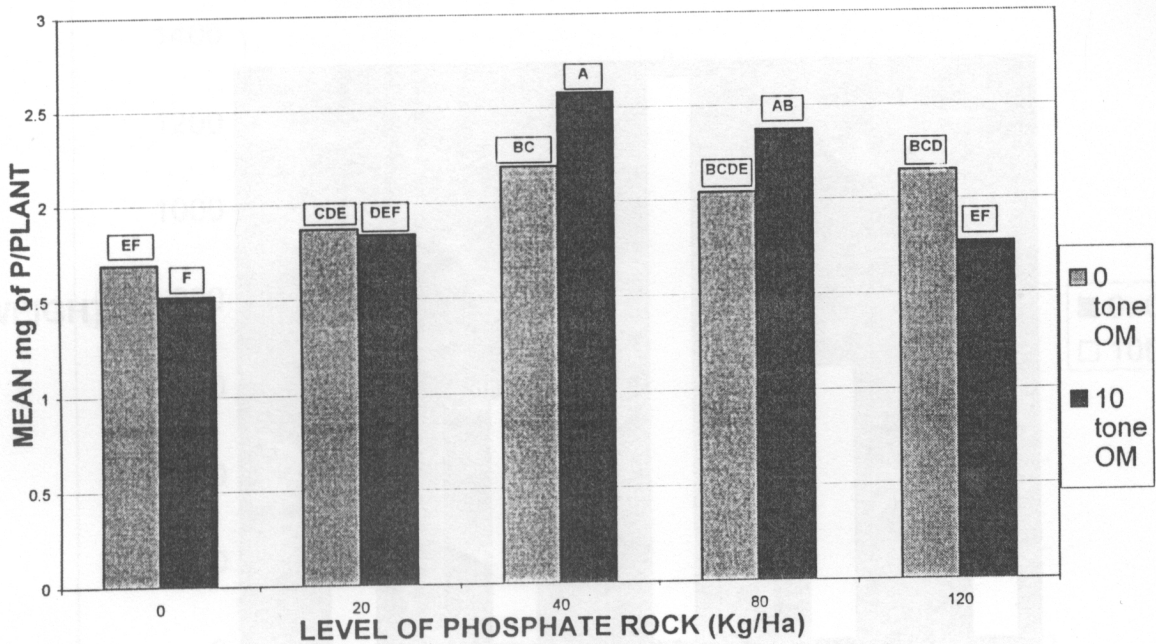


Figure 5: Plant analysis.

The amount of phosphorus in plants which were supplied with phospho-compost increased up to 2.58 mg/plant, equivalent to 40kg/ha level of PR and later there was a decline. The same applies for plants that were supplied with PR without organic matter, but in this case the highest amount of plant P at 40kg/ha level of PR was 2.19 mg/l. From this it can be deduced that fortifying compost with PR makes phosphorus more available as compared to direct field application of slow solubilizing PR.

4.3 Yield of dry Pods

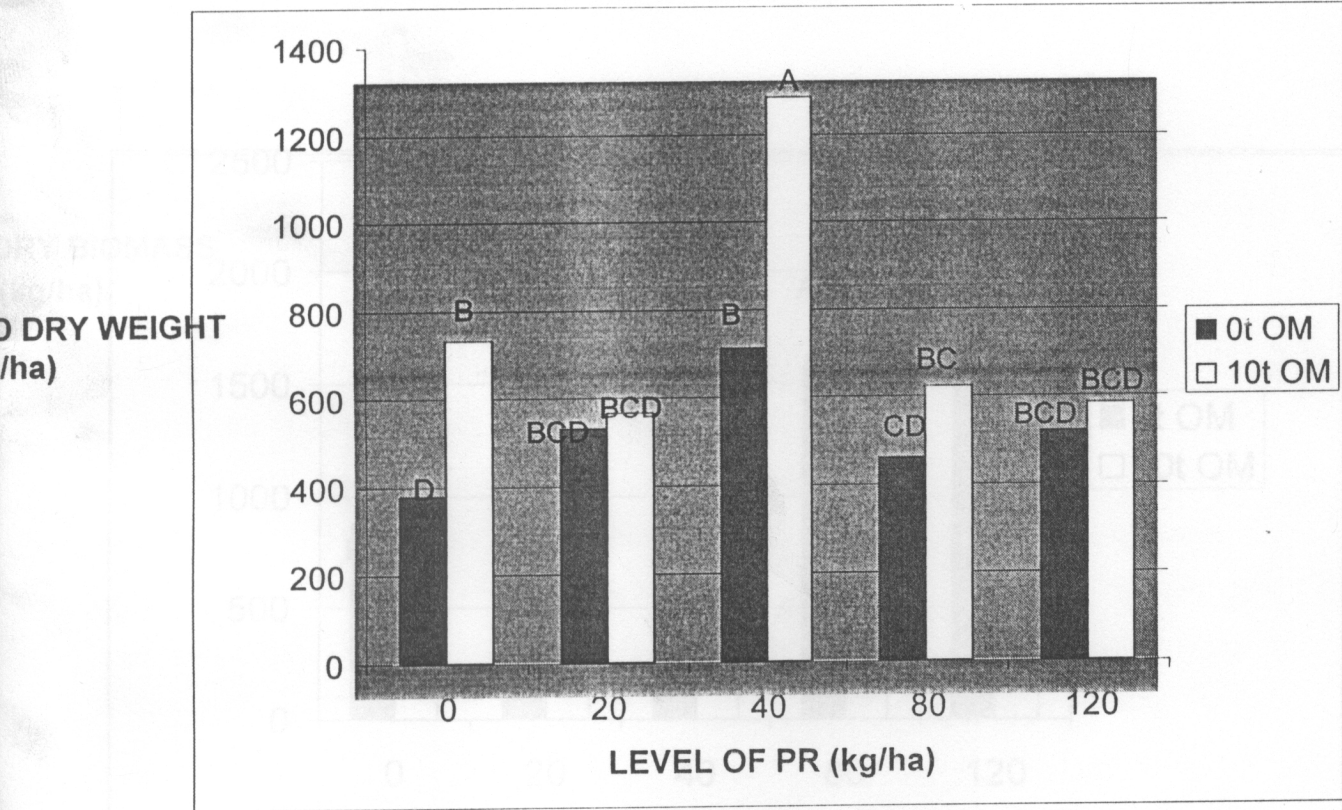


Figure 6: Dry pod yield.

The application of phospho-compost on green beans fields increases pod yield up to the maximum of 1300 kg/ha at PR level of 40 kg/ha and later yields reduces drastically. Furthermore, direct field application of PR without organic matter followed the same trends but, the only difference was that phospho-compost increases pod yield by 85.71% at 40kg/ha level of PR if compared to direct applied phosphate rock.

4.4 Yield of Dry Biomass.

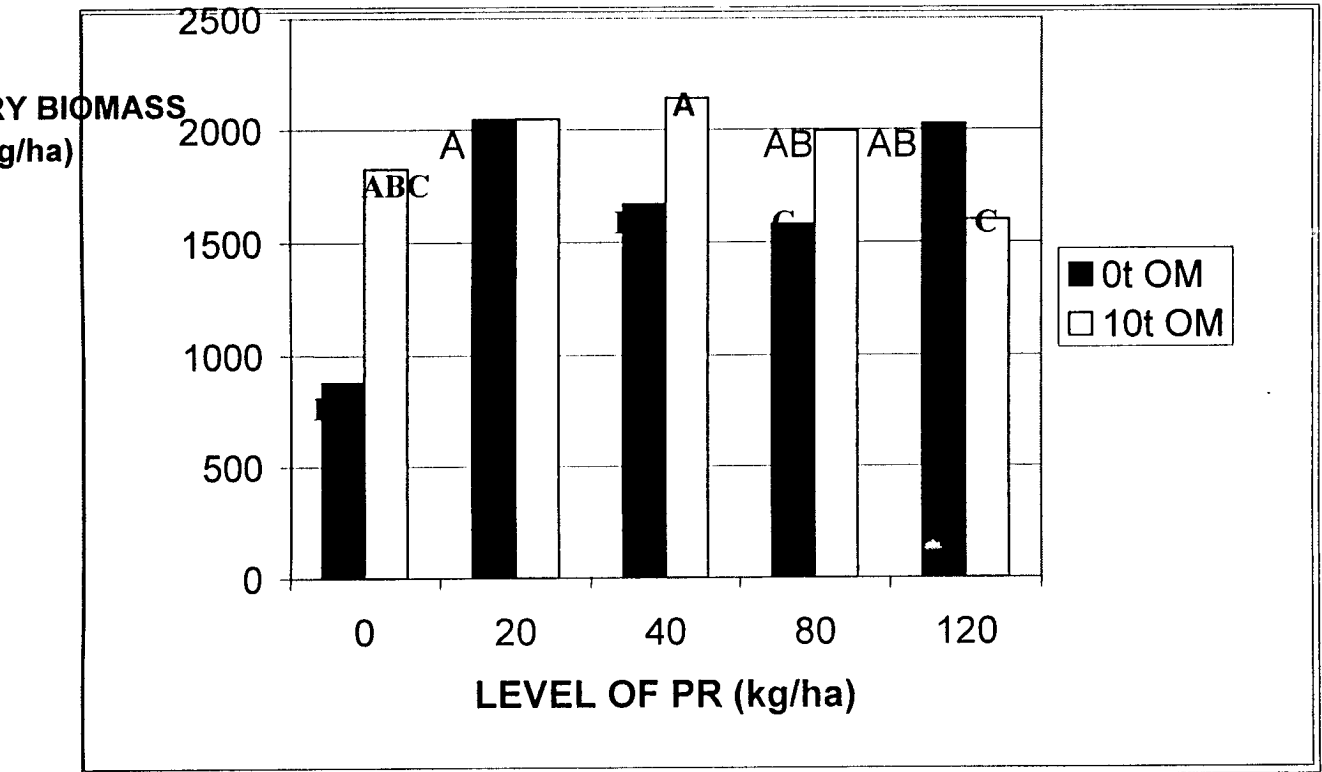


Figure 7; Dry biomass.

The phospho-compost significantly increases crop biomass yield from 0kg/ha to 20kg/ha PR levels and later the increase is insignificant at 40kg/ha PR level. However, biomass yield reduces insignificantly from 40kg/ha to 80kg/ha and later the reduction was significant. On the other hand application of PR alone increases the crop biomass yield from 0kg/ha to 20kg/ha PR levels but later the yield reduced significantly and were maintained low at the subsequent higher PR levels. Generally, phospho-compost maintains higher and stable biomass yields compared to when PR is applied alone in green beans fields.

CHAPTER FIVE.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion.

The decomposition of organic matter in the compost heap was found to solubilize PR. This was reflected by the significant increase of crop biomass and pod yield compared to direct field application of PR alone. The results for plant tissue analysis suggest that composting chilembwe PR with organic matter has the potential to increase the amount of available phosphorus from PR. This could be observed well because there was a direct relationship between crop yield and the amount of phosphorus in the crops. Generally, the optimum level of phosphate rock was found to be 40kg P₂O₅ per hectare. Furthermore, the yield response of crops to different levels of phosphate rock under the fortified and unfortified conditions showed same trends although phospho-compost gave out higher crop yields. Therefore, the fortification of compost with phosphate rock does improve the agronomic effectiveness of the compost for crop production. As such the null hypothesis had been rejected. It also appeared that beans was able to solubilize the phosphate rock because crop yields the amount of phosphorus in plants increased above that of the control experiments.

5.2 Recommendations.

Green beans seemed to have a positive effect of solubilizing phosphate rock because higher crop yield was obtained at 40kg P₂O₅/ha level of phosphate rock compared to the 0kg P₂O₅/ha level. However, there is no enough evidence that this is true. Therefore, the research needs to be repeated for further verification of the results. If this is the case, farmers of beans could be encouraged to apply ground PR directly on their fields because the crop has high affinity for calcium and phosphorus present in PR.

The research was conducted on slightly acid soil with pH 5.74. Chances are high that soil acids took part in solubilizing the phosphate rock. For this reason, the research should also be repeated on soils with a slight higher pH than 5.74.

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7.0 APPENDICES.

7.1 Appendix A: Analysis of Variance.

1. Plant analysis for phosphorus.

ANALYSIS OF VARIANCE TABLE

K	Degrees of	Sum of	Mean	F		
Value	Source	Freedom	Squares	Square	Value	Prob.
1	Replication	2	0.079	0.040	1.1975	-
2	Factor A	1	0.006	0.006	0.1698	0.0130**
4	Factor B	4	2.204	0.551	16.6940	0.0010**
6	AB	4	0.648	0.162	4.9077	0.0075**
-7	Error	18	0.594	0.033		
Total		29	3.530			

Coefficient of Variation: 9.07%

2. Dry Pod Yield.

ANALYSIS OF VARIANCE TABLE

K	Degrees of	Sum of	Mean	F		
Value	Source	Freedom	Squares	Square	Value	Prob.
1	Replication	2	321.722	160.861	6.7546	-
2	Factor A	1	673.443	673.443	28.2779	0.0050**
4	Factor B	4	1544.567	386.142	16.2141	0.0010**
6	AB	4	486.731	121.683	5.1095	0.0063**
-7	Error	18	428.673	23.815		
Total		29	3455.136			

Coefficient of Variation: 19.11%

3 Dry Biomass Yield.

ANALYSIS OF VARIANCE TABLE

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
1	Replication	2	798.283	399.142	6.6831	-
2	Factor A	1	933.380	933.380	15.6282	0.0009 **
4	Factor B	4	2599.476	649.869	10.8812	0.0001 **
6	AB	4	2658.502	664.625	11.1283	0.0001 **
-7	Error	18	1075.031	59.724		
Total		29	8064.672			

Coefficient of Variation: 10.84%

Key: - Not Significant.

** Very Significant at $P < 0.05$.

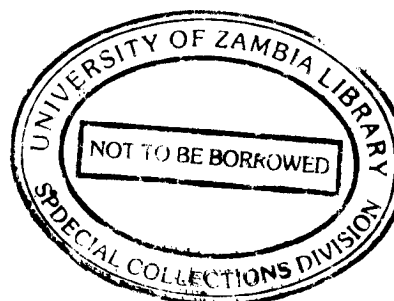
7.2 Appendix B: Means.

1 Plant Analysis for Phosphorus.

Treatments	PR Level (kg/ha)	Means
1	0	1.693 EF
2	20	1.870 CDE
3	40	2.193 BC
4	80	2.037 BCDE
5	120	2.153 BCD
6	0	1.520 F
7	20	1.840 DEF
8	40	2.577 A
9	80	2.373 AB
10	120	1.773 EF

2 Dry Pod Yield

Treatments	PR Level (kg/ha)	Means	
1	0	15.133	D
2	20	21.181	BCD
3	40	28.432	B
4	80	18.441	CD
5	120	20.775	BCD
6	0	29.282	B
7	20	22.562	BCD
8	40	51.320	A
9	80	24.835	BC
10	120	23.343	BCD



3 Dry Biomass Yield.

Treatments	PR Level (kg/ha)	Means	
1	0	35.091	D
2	20	81.755	A
3	40	66.729	BC
4	80	63.108	C
5	120	81.026	AB
6	0	73.026	ABC
7	20	81.881	A
8	40	85.612	A
9	80	79.754	AB
10	120	64.044	C