EFFECT OF *GLIRICIDIA SEPIUM* GREEN MANURE PLACEMENT ON SOLUBILITY OF MINJINGU ROCK PHOSPHATE, GROWTH AND YIELD OF MAIZE AT SUA FARM, MOROGORO, TANZANIA

BY

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ABSTRACT

This study was carried out at Sokoine University of Agriculture (SUA) Farm, Morogoro, Tanzania to assess the effect of *Gliricidia sepium* green manure (GM) placement method on solubility of Minjingu rock phosphate (MRP), growth and yield of maize. The study involved pot and field factorial experiments with treatments arranged in a complete randomized block design in three replications. For the pot experiment, the experimental factors were *G. sepium*. GM placement method (5 t ha^{-1}) at three levels (i.e. No GM, Incorporation and Mulching) and P- fertilizer application rates at seven levels (i.e. 0, 12.5, 25, 50, 100, 150 mg P kg soil^{-1} as MRP and 50 mg P as TSP). Air dried soil (2 kg) was filled in each of the 63 pots representing the 21 treatment combinations. The various treatments were then incubated at 70% field capacity (FC) at ambient temperature for three months. Within this period soil sub samples were collected at two weeks intervals for available phosphorus (AVP) determination in the laboratory. For the field experiment, the experimental factors remained the same as for the pot experiment except that the P-fertilizer application rates were 0, 10, 20, 40, 80 kg P ha^{-1} as MRP and 30 kg P ha^{-1} as TSP. Soil samples were collected at two weeks intervals for the determination of AVP in the laboratory. Additionally, maize height (m) at tasseling stage was recorded and maize samples were collected for the determination of P and N in the leaf, grain and stover. Grain and stover yields were also determined at maturity. The results indicated that GM placement method significantly improved AVP in both pot and field experiments, with the highest AVP obtained by the incorporation treatment. In most of the sampling dates AVP values for incorporation and mulching treatments were not significantly different in both the pot and field experiments. The AVP increased with increase in MRP application rates for both experiments and for all sampling dates. Except for stover N, GM placement method significantly increased concentration and content of P and N in maize leaf. For the incorporation treatment, the values were leaf concentra- tion (0.2005% P; 2.298% N) and leaf content (5.835 mg P; 66.19 mg N). The corresponding values for the mulching treatment were leaf concentration (0.1908% P; 2.252% N) and leaf content (5.426 mg P; 63.43 mg N). Similarly, P and N uptake were significantly increased by GM placement method. The uptake values for incorporation treatment were as follows: grain (6.22 kg ha^{-1} P; 37.82 kg ha^{-1} N), stover (2.18 kg ha^{-1} P; 10.98kg ha^{-1}). Whereas corresponding values for the mulching treatment were grain (5.40 kg ha^{-1} P; 33.77 kg ha^{-1} N), and stover (1.76 kg ha^{-1} P; 9.59kg ha^{-1}). Total P and N and maize height as affected by GM placement method followed a pattern similar to that of P and N for grain and stover. Maize yield was (2.07 kg ha^{-1} grain; 2.57 kg ha^{-1} stover) for control, (2.60 kg ha^{-1} grain; 3.33 kg ha^{-1} stover) for incorporation and (2.34 kg ha^{-1} grain; 2.98 kg ha^{-1} stover) for mulching. P and N uptake by maize significantly increased with increase in MRP application rate. However, at higher rates (i.e. 40, 80 kg P ha^{-1} as MRP), the increase of maize leaf P and P uptake was not significant. Generally, most of the parameters studied showed a linear and quadratic relationship with MRP application rates. Furthermore, the interactions between GM placement method and MRP application rates for most of the parameters studied were not significant.

Based on the results of this study, it was concluded that incorporation and mulching of GM has the potential to improve solubility as well as growth and yield of maize. However, adoption of the practice may be limited because of the labour required in cutting, transporting and incorporating the GM into the soil. Getting a source that will provide sufficient amount of GM to cater for the needs of most of small holder farmers at the appropriate time may also be a problem. Furthermore, GM in this study was used as a source of N for maize and this is merely transferring nutrients within the farm and not actually redressing the nutrient depletion in the soil, therefore it may not be sustainable in the long run.

DECLARATION

I Anthony Anderson Kimaro, do hereby declare to the Senate of Sokoine University of Agriculture, that this dissertation is a result of my own original work and it has never been submitted for a degree award in any other University.

Signature ....

Date ....

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This work is dedicated to GOD the ALMIGHTY, the creator and giver of life, wisdoom and knowledge to every living. To my beloved parents, Mr. Anderson Msami and Mrs. Mary Msami, through whom my education was channeled. To Deborah for physical, spiritual and moral support.

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ABBREVIATIONS

ANOVA	Analysis of variance
asl	Above sea level
Al	Aluminium
AVP	Available phosphorus
BNF	Biological nitrogen fixation
C	Carbon
Ca	Calcium
Ca^{2+}	Calcium ion
Conc.	Concentration
Cont.	Content
DMY	Dry matter yield
Dr	Doctor
E	East
e.g	For example
et al.	And others
etc.	And many more
FC	Field capacity
FYM	Farm yard manure
GLM	General linear model

GM	Green manure
GM Plm	Green manure placement method
$HPHO^{2-}_4$	Secondary orthophosphate ion
$H_2PHO^-_4$	Primary orthophosphate ion
i.e.	That is
ICRAF	International Center for Research in Agroforestry
KCl	Potassium chloride
KRP	Kadjori Rock Phosphate
LPCc	Leaf phosphorus concentration
LPCt	Leaf phosphorus content
LNCc	Leaf nitrogen concentration
LNCt	Leaf nitrogen content
MRP	Minjingu rock phosphate
N	Nitrogen
Na_2CO_3	Sodium carbonate
NCRP	North Carolina rock phosphate
NH_3	Ammonia
NPK	Nitrogen Phosphorus Potassium
OC	Organic Carbon
OH^-	Hydroxyl ion
OM	Organic matter

P	Phosphorus
PARP	Partially acidulated rock phosphate
pH	Negative logarithm of hydrogen ion concentration.
ppm	Parts per million
Prof.	Professor
RCBD	Randomized complete block design
RE	Relative effectiveness
RP	Rock phosphate
RPs	Rock phosphates
RRE	Residual relative effectiveness
S	South
SAS	Statistical Analysis System
SOM	Soil organic matter
SRP	Sechura rock phosphate
SSA	Sub-Saharan Africa
SSP	Single super phosphate
SUA	Sokoine University of Agriculture
SUAFES	Sokoine University of Agriculture Fellowship of Evangelical Students
SURUDE	Foundation for Sustainable Rural Development
TRP	Taiba Rock Phosphate
TSP	Triple super phosphate

WAI	Weeks after incubation
WAP	Weeks after planting

SYMBOLS

%	percentage
µ	Microgram
=	Equal to
>	Greater than
≥	Grater than or equal to
<	Less than
≤	Less than or equal to
cm	Centimeter
ha	Hectare
kg	Kilogram
m	Meter
mg	Milligram
mm	Millimeter
°C	Degree Celcius
°E	Degree East
°S	Degree South
t	Ton

CHAPTER ONE

1. INTRODUCTION

Much of Sub-Saharan Africa (SSA) has experienced a rapid decline in per-capita food production in the last 30 years. The major reason for this is declining soil fertility which is to a large extent caused by soil erosion and nutrient mining (ICRAF, 1997a). Data from nutrient balance studies indicate that an average of 660 kg N, 75 kg P and 450 K kg ha^{-1} has been lost during the last 30 years from about 200 million ha of cultivated land in 37 African countries (Sanchez *et al.*, 1996). The total annual nutrient depletion in SAA is equivalent to 7.9 million tons of NPK per year,which is equivalent to six times the amount of annual fertilizer consumption in the region, excluding South Africa (Sanchez *et al.*, 1996). Maize crop with a moderate grain yield of 4 t ha^{-1} is known to accumulate about 18 kg P ha^{-1} (Palm, 1995), which is mined during harvest.

Phosphorus (P) deficiency in tropical soils has been reported by many research scientists workers (Sanchez, 1976; Singh and Uriyo, 1978; Le Marre, 1991). About 40% of the land surface of the Tropics consist of highly weathered soils such as oxisols and ultisols (Sale and Mokwunye, 1993). The excessive weathering experienced by these soils has reduced the total P levels in the soil and the high content of iron and aluminium oxides and exchangeable aluminium result in high P fixation capacities, leading to low concentration of plant available P in the soil solution (Sanchez, 1976). There are extensive areas in Tanzania including Morogoro (Singh and Uriyo, 1978; Ussiri, 1992), with soils which are deficient in P. In soils of SSA, P deficiency has been identified as one of the major limiting factors for crop production (Sahrawat *et al*, 1995). Furthermore, P is known to be a more limiting nutrient than nitrogen (N) for tropical legumes (Hernandez *et al.*, 1981) and for maize production at SUA Farm, Morogoro (Fasuluku, 1997).

The key soil fertility problems arise from the depletion of P and N (ICRAF, 1996). Phosphorus replenishment strategies are mainly fertilizer-based with biological supplementation while N replenishment strategies are mainly biological, with chemical supplementation (Sanchez *et al.*, 1996). Earlier agroforestry research focused on restoring soil fertility through biological nitrogen fixation (BNF) (ICRAF, 1996). In addition to fixation by legumes, N can be replaced through deep-rooted trees and shrubs that capture nitrates from the subsoil (ICRAF, 1996; Sanchez and Palm, 1996; Sanchez *et al.*, 1996). Agroforestry, however, cannot supply most of the P inputs required by crops. Phosphorus, unlike N, is not biologically fixed from the atmos- phere, and the P content of plant residues and manure is normally insufficient to meet the requirements for sustained crop production (Palm, 1995; Sanchez, 1995). Possibly because trees frequently have a higher N to P ratio, than N to P ratio required by crops (Palm, 1995), therefore the quantities of biomass that are sufficient to supply N to crops are inadequate to supply sufficient P. Although improved fallow and other sequential systems do accumulate P in their biomass and return it to the soil via litter fall and decomposition (Sanchez, 1995), this is merely recycling and does not cons- titute an input from outside the system. This situation is compounded by the physi- ological fact that most of the P accumulated by cereal crops and grain legumes is in the grain and thus removed from the soil at harvest (Sanchez, 1995). In addition, deep capture of P is likely to be negligible because of very low concentration of P in the sub soil (Sanchez, 1995). Moreover, Buresh and Tien (1998) pointed out that a greater capture of subsoil resources by roots would be expected for water and mobile nutrients such as nitrate, than less mobile nutrients such as P. Therefore, P is often a key critical nutrient in agroforestry and other low external input systems. Mineral sources of P must be applied to soils where this mineral is depleted, but commercial fertilizers are beyond the means of most small – scale farmers.

Rock phosphate (RP) has received considerable attention as low-cost P fertilizer in acid soils (Khasawneh and Doll, 1978; Chien and Menon, 1995). Many African countries have ample RP deposits that could be used directly or indirectly as super phosphate to reserve P depletion (Sanchez *et al.*; 1996). Minjingu RP (MRP) mined in Tanzania, Kodjari RP (KRP) mined in Burkina Faso, Taiba RP (TRP) mined in Senegal to are examples of RP deposits available in Africa (Hammond *et al.*, 1986). Use of RP in combination with organic matter (OM) has been reported to improve the solubility of RP and availability of P in the soil (Ikkera, 1986; Yang *et al.*, 1994; Zaharah and Bah, 1997). In agroforestry systems, OM from tree prunings are used either as soil incorpo- rated green manure (GM) or as surface applied mulch (Kang *et al.*, 1981; Mulongoy and Van der Meersch, 1988). It has been reported that tree prunings are more effective as a source of N when incorporated in the soil than when applied as mulch (Mafongoya and Nair, 1996; Kadiata *et al.*, 1997), and this was associated with faster decomposition and mineralization for the incorporation treatments and high losses from volatilization during decomposition for mulching treatments (Kang *et al.*, 1981). Whether these two GM placement options affect the solubility and availability of P from MRP differently has not been studied. This study therefore, was undertaken to determine the extent of growth and yield of maize as effected by MRP application and *G. sepium* GM placement. The specific objectives were to determine:

a) The effect of *Gliricidia sepium* GM placement on MRP solubility.

b) Height growth, grain and stover yield of maize as affected by MRP application and *G. sepium* GM placement.

c) Maize foliar N and P concentration and content as affected by MRP application and *G. sepium* GM placement.

d) Phosphorus and N uptake by maize as affected by MRP application and *G. sepium* GM placement.

The study hypotheses were:

a) Minjingu rock phosphate solubility is not affected by *G. sepium* GM placement, rates of MRP and their interactions.

b) Concentration and content of P and N per maize leaf is not affected by *G. sepium* placement, rates of MRP and their interactions.

c) Maize P and N uptake is not affected by *G.sepium* GM placement, rates of MRP and their interactions.

d) Maize growth and yield is not affected by *G.sepium* GM placement, rates of MRP and their interactions.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Phosphorus status in the soil and plant growth

The phosphorus status in the soil has been reported in Tanzania (Uriyo and Kasseba, 1973). Some of the highlights made are:

- Soils that fix large quantities of P are Oxisols and Ultisols,
- Generally, in most profiles total and available P decline with depth and available P in this case does not seem to be adequate for optimum crop production,
- In acid soils, various constituents sorb most of the applied P and P sorption increases with depth within the profile, due to increased sesquoxides and clay content. Consequently, if surface soil is eroded, the requirement of P for optimum plant growth on most of these soils would increase. Kaaya (1989) observed the same with soils from the SUA farm,
- In mineral soils, 40-60% of the P would be found in each of the organic and inorganic pools with about 1-2% in the microbial form and perhaps 0.01% in the available form which can be taken up by the growing plants. Plants absorb most of their P as primary orthophosphate ($H_2PO_4^-$), dominant in acidic

condition and smaller amount as the secondary orthophosphate (HPO_4^{2-}), dominant in alkaline condition.

2.2 Rock phosphate as a source of phosphorus

Rock phosphates (RPs) differ in their reactivity and agronomic value depending on whether they are igneous, sedimentary or metamorphic in nature (Lehr and Mac Clellan, 1972). Rock phosphates that have low reactivity can be made more reactive through such processes as partial acidulation, thermal alteration and compaction with soluble P fertilizers (Hammond *et al.*, 1986). For some crops and soils, partially acidulated rock phosphate (PARP) and sometimes RP alone are as effective as superphosphate (Budotela, 1995). Ikerra (1986) working with an ultisol, observed that RP had comparable effect when applied at a rate three times the rate of triple superphosphate (TSP). No significant difference in sorghum yield was observed (Verma *et al.*, 1993) between PARP and single superphosphate (SSP). Therefore, it was concluded that PARP and SSP were equally effective in increasing grain yield of sorghum. Rajan and Marwaha (1993) have also made a similar conclusion. Both total P and available P of RP have been observed to increase when RP was heated with an additive mixture (Na_2CO_3 and KCl) at different temperatures and ratios (Rautaray *et al.*, 1994, 1995). Menon *et al.* (1991) reported that RPs that have low reactivity and high contents of sesquioxides are more effective in releasing P when compacted with soluble P fertilizers such as TSP. Furthermore, Kumar *et al.* (1993)

observed that, both relative effectiveness (RE) and residual RE (RRE) of partially acidulated North Carolina RP (NCRP) were greater than non-acidulated NCRP.

Availability of P from the applied RP is largely affected by soil factors (Chien *et al.*, 1980; Kanabo and Gilkes, 1987; Robinson and Syers, 1990; Wright *et al.*, 1992). Five soil factors have been shown to influence RP dissolution. These are: soil pH, exchangeable Ca, extractable P, soil organic matter (SOM) and P adsorption capacity (Hammond *et al.*, 1986). The first three factors are primary, since the other two, that is SOM and P adsorption capacity of the soils, as explained by Khasawneh and Doll, (1978) influence RP dissolution through their effect either on or in combination with soil pH, exchangeable Ca and soil extractable P. Kirk and Nye (1986) also reported that the dissolution of RP depends on the rate of removal of its three principle dissolution products; Ca^{2+}, $H_2PO_4^-$ and OH. This has been supported by Hanafi *et al.*, (1992) who found a significantly improved RP solubility in open leaching systems as opposed to closed systems. Likewise Wendt and Jones (1997) related the response of maize to RP in soils with low P sorption capacities with leaching. It was explained that, since sandy soils have no capacity for absorbing the dissolution products of RP, it is possible that their removal by leaching played a significant role in RP dissolution. Other results (Mnkeni *et al.*, 1991; Kumar *et al.*, 1993; Hughes and Gilkes, 1994) have indicated improved effectiveness of RP in acidic soils which are deficient in P and Ca. In addition, SOM, soil texture and moisture status of the soil have all been shown to affect RP dissolution (Hagin and Harrison, 1993).

2.3 Effect of rock phosphate and green manure on crop growth and yield

2.3.1 Effect of rock phosphate on crop growth and yield

Rock phosphate is a source of both P and Ca needed for crop growth (Mnkeni *et al.*, 1991; Baligar *et al.*, 1997). Working with MRP, Mnkeni *et al.*, (1991) observed a significant maize response in acid P- deficient soils of Morogoro. The response to P was much greater where the soils were also deficient in Ca. This was associated with improved Ca-nutrition following RP application. Similarly, Saggar *et al.* (1993) concluded that RPs are relatively more effective in improving yield in high P sorption soils than low P sorption soils and in low exchangeable Ca soils than the high exchangeable Ca soils. In their study, they also observed that more reactive RPs such as Sechura RP (SRP) and NCRP produced dry matter yield (DMY) between 73% and 93% of the yield obtained with monocalcium phosphate (MCP). Other results (Ikkera, 1986; Budotela, 1995; Kimbi, 1991; Tusekelege, 1997) have also revealed improved crop response following RP application. Applying RP prior to sowing has been reported to reduce DMY as compared to applying RP at sowing. This effect was associated with P fixation by aluminum (Al) as the soil used had high concentration of Al (Purnomo and Black, 1994). Water stress has also been reported to limit crop response to RPs (Bolland, 1994).Therefore, incorporation of NCRP into sub-soil has been reported to improve its effectiveness by 26% as compared to surface application. On the other hand, Purnomo and Black (1994) concluded that for soils with an acidic sub-surface layer and a low exchangeable Al, placement of TSP had little effect on wheat responses. It is important to note that the effect of RP to crops is subject to many factors such as mineralogical characteristics of the rocks, the behavior of phosphate in the soil, crop needs for phosphate and interaction of these factors (Le Mare, 1991).

2.3.2 Effect of green manure on crop growth and yield

Green manure (GM) can be defined as a green or fresh plant material which is incorporated into the soil, usually at a stage when it's N content is highest and allowed to decompose to supply N to a standing or a subsequent crop (Cosico, 1990). Most studies indicate that GM can significantly improve crop growth and yield (Singh *et al.,* 1991; Szott *et al.*, 1991; Fasuluku, 1997; Anthofer *et al.*, 1998). A study on nine agroforestry tree species showed that application of agroforestry tree prunings significantly improved wheat growth and yield in both field and pot experiments with the highest grain yield (2.48 t ha^{-1}) obtained with *Gliricidia* treatments (Anthofer *et al.*, 1998). Similarly, Cadisch *et al.* (1998) reported that additions of prunings of *G. sepi- um* and *Leucaena leucocephala* substantially increased cumulative DMY of maize over three seasons. Fasuluku (1997) also observed increase in maize grain yields (16.3%) when *Sesbania sesban* GM was applied without fertilizer. Similar results have also been reported in other studies (Cosico, 1990; Hsieh and Hsieh, 1990; Szott *et al.*, 1991; Singh *et al.*, 1991; Tilander, 1993). Experiences from Zimbabwe indicate that incorporation of multipurpose tree prunings gave high N recovery and maize yield compared to surface application (Mafongoya and Nair, 1996) possibly because incorporation of prunings into the soil result in faster decomposition (Wilson *et al.*, 1986) whereas mulching result in large losses of N due to NH_3 volatilization (Kang *et al.* 1981). Application of prunings from *Calliandra calothyrsus* to maize at planting resulted in significantly higher N uptake, N recovery and grain yield when compared to application four weeks after planting (Mafongoya *et al.*, 1996a). However, with *L. leucocephala* the time of prunings application did not have any significant effect on N recovery (Mafongoya *et al.*, 1996a). It has also been reported that, split application of prunings during the crop growth cycle has no effect on N recovery when compared to one time application of the prunings at planting (Mafongoya *et al.*, 1996a). In addition, a significant interaction of pruning quality with method and time of prunings application on N recovery by maize and residual effects on subsequent maize crop has been reported by Mafongoya *et al.* (1996b). Green manure of high quality such as *Tithonia diversifolia* prunings is known to give high yield than low quality GM such as *C. calothyrsus* prunings (Dreschsel and Reck, 1997).

Yamoah *et al.*, (1986) and Montagnini *et al.*, (1993) attributed response of crops to green manuring with improved soil physical properties and nutrients, particularly N supply. However, studies indicate that agroforestry cannot supply most of the P required by crops (Szott *et al.*, 1991; Sanchez, 1995) possibly because P, unlike N is not biologically fixed from air, and the P content of plant residues and manure is normally insufficient to meet the requirements for sustained crop production (Palm, 1995). It could also be due to the fact that P from improved fallow and other sequential systems which is released to the soil via litter decomposition is just recycled and does not constitute an input from outside the system (Sanchez, 1995). This situation is compounded by the physiological fact that most of the P accumulated by cereal crops and grain legumes is in the grain and thus removed from the soil at the time of harvesting. The inability of GM to supply adequate P for crop growth has been linked to sequestration of P in the tree biomass (Haggar *et al*, 1991; Matta-Machando and Jordan, 1995). In Peru, *G. sepium* prunings are known to supply only 5 kg P ha^{-1} when compared to 10 kg P ha^{-1} required (Szott *et al.*, 1991). Maize seedlings mulched with litter from trees with agroforestry potentials have been observed to absorb additional P for growth from the soil (Montagnini *et al.*, 1993). Leguminous mulches applied at a rate of 4t ha^{-1} provided 8 to 12 kg P ha^{-1}, about half of the P requirement of a maize grain crop of 4tha^{-1}, which accumulate 18 kg Pha^{-1} (Palm, 1995). Therefore, inorganic sources of P must be applied to agroforestry systems in soils depleted of this element.

2.3.3 Interaction effects of rock phosphate and green manure on crop growth and yield

Application of MRP in conjunction with farm yard manure (FYM) has been reported to significantly increase grain and DMY of maize as compared to treatments receiving FYM and MRP alone (Ikkera, 1986). This effect was attributed to the effect of FYM in increasing availability of P from MRP (Ikkera, 1986). Increased availability of P from RP applied to rice with green manuring has also been reported in some studies (Singh *et al.*, 1991; Sukthumrong *et al.*, 1987; Cosico, 1990, Zaharah and Bah, 1997). On station research in Western Kenya has shown that maize yields increased 5 times (from 0.8 to 4.5 t ha^{-1}) with RP and *T. diversifolia* (ICRAF, 1997b). Zaharah and Bah (1997) reported a non-significant increase in P uptake for most of RPs treatments and a decline for Algeria RP and TSP treatments. This effect was attributed to immobilization of P by GM (Singh and Jones 1976). The C: P ratios of organic residues added to soil has been reported to be important in determining the effect of organic residues on P sorption (Iyamuremye and Dick, 1996). The C: P rations greater than 130 result in P immobilization by organic manure (Singh and Jones 1976).

2.4 Green manure and rock phosphate solubility

The importance of plant biomass in P availability in soils and RP solubility has usually been liked to enhancement of the dissolution of sparingly soluble P sources leading to an increase in the available P content of the soil (Hammond *et al.*, 1986; Nye and Kirk, 1986; Flash *et al.*, 1987; Sale and Mokwunye, 1993). Secondly, greater availability of P has been attributed to the reduction in P sorption of the soil (Singh and Jones, 1976; Nziguheba *et al.*, 1998). The third contribution is the actual addition of P from decomposing plant biomass (Szott *et al.*, 1991; Palm, 1995; Sanchez, 1995). Finally, plant biomass enhances microbial activities in the soil, thereby influencing mineralization of more recalcitrant fractions of P (Nziguheba, *et al.*, 1998).

Plant biomass is widely known to increase solubility of RP (Ikkera, 1986, Yang *et al.*, 1994; Zaharah and Bah, 1997). Furthermore, Yang *et al.*, (1994) reported that the effect of FYM on the solubility of RP is mainly due to organic substances from decomposition rather than organic compounds in the FYM juice. Zaharah and Bah (1997) reported that GMs generally increased the solubility of the less reactive RPs and depressed that of the more reactive ones. This was believed to be through nutrient supply and release of P and indirectly by decreasing or increasing P fixing capacity. The extent of the influence was observed to be dependent on GM quality, especially the C: P ratio. Upon hydrolysis organic matter may supply some functional groups or anions such as citrate or oxalate that have significant chelation capacity, lowering the activity of polyvalent cations such as Ca, Fe and Al that form insoluble salts with P and thus liberating phosphates from the basic phosphates of these elements at very low pH values (Hammond *et al.*, 1986; Singh *et al.*, 1991).

Organic anions capable of forming stable complexes with Al and Fe in solution and mineral surfaces (Kafkafi *et al.*, 1988) reduce phosphate sorption in the solution. According to Ikkera (1986) and Nziguheba *et al.* (1998), the decomposition of organic matter produce organic anions which may compete for adsorption sites thereby reducing P sorption capacity in the soil. An adsorption study indicated that in Ca-montmorillonite, oxalic acid masked some sites available for phosphate adsorption, thus leaving more P in the solution and a greater competition was observed at lower pH values, indicating enhanced competition between oxalic acid and P as pH was decreasing (Kafkafi *et al.*, 1988). Similarly, Bhatti *et al.*, (1998) reported a significant decrease in phosphate sorption, by as much as 30% due to presence of oxalate and SOM. The study also indicated that oxalate caused desorption of P through ligand exchange of oxalate for phosphate and the presence of OM increased the amount of phosphate desorbed by oxalate. They therefore, concluded that oxalate can significantly increase the solution concentration of phosphate by reducing phosphate sorption, releasing phosphate into solution from sorbed and insoluble pools and complexing Al in solution thereby reducing phosphate reprecipitation. Yang *et al.*, (1994) concluded that the combination of organic manure with mineral phosphate fertilizers could significantly enhance the solubility and mobility of P in the soil due to their effect on P sorption and desorption. Ikkera (1986) and Singh *et al.* (1991) have reported increased availability of P from RP due to OM application. Changes in soil pH due to green manuring can also influence solubility of RP (Singh *et al.*, 1991). Furthermore, OM is known to form complexes with Al, thereby decreasing its concentration in the soil (Von Uexkull, 1984). Le-Mare (1991) also reported that RP tend to be more effective in acidic soils containing high levels of OM.

Application of RP to acidic soil considerably enhance the microbial activity (He-Zl *et al.*, 1997). According to Nziguheba *et al.*, (1998), the increase in microbial biomass may be associated with increased biological activity and mineralization of more recalcitrant fraction of P. It has generally been concluded that acids produced during decomposition of organic materials and compost together with carbonic acid in the soil resulting from metabolic wastes of plant roots, microorganisms and microbial decomposition process in soil help in dissolution of RP (Alexander, 1977). It appears that the effect of OM on RP mineralization is likely to vary with method of placement. Ikkera (1986) studied the effect of incorporating compost and FYM and observed greater release of P when RP was combined with compost or FYM than when it was applied alone. Similar results have been reported by Nziguheba *et al.*, (1998) who incorporated OM from *T. diversifolia* with TSP at 15 cm depth. Another study indicated that incorporation of OM was better than mulching in terms of N recovery and maize yield (Mafongoya and Nair, 1996) and also result in fast decomposition of OM (Wilson *et al.*, 1986). In contrast, Cosico (1990) reported that the effect of GM was the same whether applied as mulch or mixed in the furrow between maize plants. Furthermore, Wendt and Jones (1997) indicated that broadcasting Malawi Tundulu RP gave greater yields than did banding. Another study on the response of wheat to NCRP indicated that the responses for broadcast, band and mix application were 20, 9 and 44% respectively (Purnomo and Black, 1994).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Study site description

The study site is located at Sokoine University of Agriculture (SUA) Farm (6^0 50' 24.7"S; 37^0 38' 59.8"E; 526m asl), Morogoro, Tanzania. The area experiences sub-humid tropical climate with a bimodal rainfall pattern characterized by two rainfall peaks in a year with a definite dry season separating the short rains (October to December) and long rains (March to May). The long term mean annual rainfall is 870mm, total annual evapotranspiration is about 1307mm and the mean annual temperature is 24°C (Fasuluku, 1997). The 1999 long rains rainfall data presented in Table1.

Table 1: Monthly total rainfall during the 1999 growing season at SUA, Morogoro, Tanzania.

Month	March	April	May	June
Rain fall (mm)	29.0	186.2	200.7	95.3

Source: Morogoro Meteorological Station (SUA).

The soils are classified as Acrisols (FAO, 1988) and are deep and well drained, predominantly clay loam with very low organic carbon (OC) and P contents and very low total N contents (Table 2). The overall soil fertility is low.

Table 2: Selected soil properties of the study site at the SUA Farm, Morogoro, Tanzania.

	Soil depth (cm)			
	0-10	10-20	20-30	30-50
Total N (%)	0.11* (0.00)	0.100 (0.00)	0.092 (0.00)	0.080 (0.00)
Total P (ppm)	395 (7.64)	358 (5.93)	335 (2.90)	312 (6.36)
Available P (ppm)	1.392 (0.06)	1.386 (0.32)	0.754 (0.27)	0.603 (0.21)
OC (%)	0.91 (0.02)	0.83 (0.01)	0.63 (0.02)	0.42 (0.10)
Exchangeable acidity (c mol (+) kg^{-1} soil)	1.78 (0.03)	2.22 (0.09)	2.58 (0.10)	2.25 (0.06)
Exchangeable hydrogen (c mol (+) kg^{-1} soil)	0.95 (0.03)	0.65 (0.06)	0.68 (0.03)	0.42 (0.07)
Exchangeable Al (c mol (+) kg^{-1} soil)	0.83 (0.09)	1.57 (0.03)	1.90 (0.06)	1.83 (0.03)
pH	4.26 (0.05)	3.91 (0.18)	3.75 (0.18)	3.86 (0.03)
Electrical conductivity (μScm^{-1})	49.17 (0.49)	49.47 (2.11)	48.73 (3.62)	75.70 (4.45)
Sand (%)	37.07 (0.88)	34.73 (1.45)	32.73 (0.88)	29.40 (0.58)
Coarse silt (%)	4.0 (0.58)	3.67 (1.20)	2.00 (1.0)	3.30 (0.33)
Fine silt (%)	7.20 (0.58)	6.50 (0.88)	6.40 (0.42)	9.10 (0.94)
Clay (%)	51.70 (0.33)	55.10 (1.15)	58.87 (0.29)	58.23 (1.46)
Textural class	Clay loam	Clay loam	Clay loam	Clay loam

*Mean of three replications followed by standard error in parenthesis.

Soil bulk density (1.35 g cm^{-3}) is higher between 10-30 cm soil depth as compared to that of soil above and below this depth (Fasuluku, 1997), because of long term use of farm tractor for ploughing and harrowing (Fasuluku, 1997).

3.2 Experimental design, treatments and management

3.2.1 Pot experiment

This experiment was set up to investigate the effect of *G. sepium* GM placement on P release from MRP under 70% field capacity (FC) moisture content and ambient temperature.

3.2.1.1 Experimental design, treatments and management

A 7 x 3 factorial experiment in a randomized complete block design (RCBD) was used for this experiment. The experimental factors were P fertilizer rates (MRP 6-levels and TSP 1-level) and *G. sepium* GM placement methods (3-levels).

The seven levels of P fertilizer application rates were as follows:

R_1 = 0 mg P kg^{-1} soil

R_2 = 12.5 mg P kg^{-1} soil

R_3 = 25 mg P kg^{-1} soil

R_4 = 50 mg P kg^{-1} soil

R_5 = 100 mg P kg^{-1} soil

R_6 = 159 mg P kg^{-1} soil

R_T = 50 mg P kg^{-1} soil as TSP.

The three levels of GM placement were as follows:

M_0 = No GM

M_1 = Incorporation

M_3 = Mulching.

There were 21 treatment combinations as arranged factorially as follows:

1. M_0R_1
2. M_0R_2
3. M_0R_3
4. M_0R_4
5. M_0R_5
6. M_0R_6
7. M_0R_T
8. M_1R_1
9. M_1R_2
10. M_1R_3
11. M_1R_4
12. M_1R_5
13. M_1R_6
14. M_1R_T
15. M_2R_1
16. M_2R_2
17. M_2R_3
18. M_2R_4
19. M_2R_5
20. M_2R_6
21. M_2R_T

3.2.1.2 Experimental establishment and management

Soil for this experiment was collected from SUA farm at depth of 0-15cm, mixed thoroughly and sub-sampled for routine analysis in the laboratory as described in section 3. 3. 1. Prior to addition of GM and RP, 2 kg of the soil was filled in each of the 63 pots (4 liters) representing the 21-treatment combinations. Thereafter, appropriate rates of RP were added in each pot and mixed thoroughly with the soil. Then *G. sepium* GM at 50 g kg^{-1} soil was thoroughly incorporated into the soil for incorporation treatments whereas for mulching treatments, GM was spread on the surface. The pots were then arranged in a RCBD with three replications and incubated for three months at ambient temperature. Throughout the experimental period, moisture content of the soil was maintained at 70% FC by addition of distilled water. Soil samples for determination of available P (AVP) were collected at 0, 1, 3, 5, 7, 9, 11, and 13 weeks after incubation (WAI). At the end of the incubation period, soil sub-samples were collected from three points in each pot, mixed thoroughly and taken to the laboratory for analysis. *Gliricidia sepium* leaves used in this experiment were collected for N and P determination.

3.2.2 Field experiment

This experiment was conducted to investigate the effect of *G. sepium* GM placement on P release from MRP under field conditions. Maize (*Zea mays* L.) variety Kito was used as a test crop.

3.2.2.1 Experimental design and treatments

A 6 x 3 factorial experiment in a RCBD with three replications was adopted. The experimental factors were P fertilizer rates (MRP 5-levels and TSP 1-level) and *G. sepium* GM placement (3-levels).

The six levels of P fertilizer application were as follows:

R_1 = 0 kg MRP ha^{-1}= 0 kg P ha^{-1}.
R_2 = 71.5 kg MRP ha^{-1} = 10kg P $ha^{-1.}$
R_3 = 143 kg MRP ha^{-1} = 20 kg P $ha^{-1.}$
R_4 = 286 kg MRP ha^{-1} = 40 kg P$ha^{-1.}$
R_5= 572 kg MRP ha^{-1} = 80 kg P $ha^{-1.}$
R_T= 150 kg TSP ha^{-1} = 30 kg P ha^{-1}.

The three levels of *G. sepium* GM placement were the same as for the pot experiment (3.2.1.1). There were 18 treatment combinations arranged factorially as follows:

1. M_0R_1
2. M_0R_2
3. M_0R_3
4. M_0R_4
5. M_0R_5
6. M_0R_T
7. M_1R_1
8. M_1R_2
9. M_1R_3
10. M_1R_4
11. M_1R_5
12. M_1R_T
13. M_2R_1
14. M_2R_2
15. M_2R_3
16. M_2R_4
17. M_2R_5
18. M_2R_T

3.2.2.2 Experimental establishment and management

An area of about 0.3 ha was disc-ploughed and then harrowed. Three blocks each measuring 40 x 20m with 18 plots of 3.6 x 3.6 m were laid out. The distance between blocks was 3 m and between plots was 2 m.

In all plots, MRP and GM were incorporated into the soil manually with a hand hoe to 15 cm depth. For mulching treatments, only MRP was manually incorporated into the soil while GM was evenly spread and left as mulch on the surface. Split application of GM at an equivalent rate of 5 t ha^{-1} was adopted. At planting, 2.5 t ha^{-1} of GM was applied followed by the second application four weeks after maize sowing. In each plot, maize (*Zea mays*) variety Kito was planted at a spacing of 0.9 m between rows and 0.45 m within rows during the first week of March 1999. The plots were clean weeded twice using a hand hoe. *Gliricidia sepium* leaves used as GM were also sampled for N and P analysis.

3.2.2.3 Data collection

Soil for site characterization was collected from SUA Farm at a depth of 0 – 15cm, bulked by blocks, mixed thoroughly and sub-sampled for routine analysis in the laboratory. Soil samples for available P determination were collected at 0, 1, 2, 4, 6, 8, 10, and 12 weeks after planting (WAP). The samples from each plot were collected at 0 – 15 cm depth from three points mixed thoroughly, sub-sampled and stored in the deep freezer prior to the laboratory analysis. At the time of maize tasseling (i.e. four weeks after sowing) height of nine maize plants in the middle three rows were measured. In addition, five early leaves of maize at silking were taken for N and P determination in the laboratory. At maturity, maize were harvested from the two middle rows and partitioned into grain and stover, weighed in the field and sub-sampled for moisture content determination and analysis of N and P in the laboratory.

3.3 Laboratory Procedures

3.3.1 Analysis of soil samples

Soil samples were air dried and sieved to pass thorough a 2 mm sieve. Soil particle analysis was determined by hydrometer method as described by Bouyoucos (1962). Soil OC was determined by Walkley-Black method (Uriyo and Singh, 1974). To deter- mine total N and P, soil samples were digested with hydrogen peroxide and sulphuric acid (Anderson and Ingram, 1993). Total N in the digests was determined by semi-Macro Kjeldahl procedure (Bremner and Mulvaney, 1982) whereas total P was determined colorimetrically by the ascorbic acid method as described by Okalebo and Gathra (1993). Soil AVP was determined by Bray No.1 method (Bray and Kurtz, 1945). Soil pH and electrical conductivity (Ec) were determined in 1: 2.5 soil water suspension using pH-Ec meter (Landon, 1991). Total and exchangeable acidity in the soil were determined as described by Anderson and Ingram (1993). Soil samples for AVP determination from the two experiments were first stored in deep freezers to stop microbial activities. The samples were then analyzed for AVP (Bray and Kurtz, 1945) by sampling dates.

3.3.2 Analysis of plants samples

Sub samples of maize grain, stover, and *G. sepium* leaves were oven dried (70°C) to constant weight. The samples were then ground, digested and analyzed for total N and P as described in the section 3.3.1.

3.4 Data analysis

Some soil physical (i.e. sand, silt, clay and textural class) and chemical (i.e. total N, total P, AVP, OC, exchangeable acidity, exchangeable Al, pH and electrical conductivity) properties were sorted by depths and then means and standard error were calculated using procedure means of SAS (SAS inst. Inc., 1987). Soil AVP data from the two experiments were analyzed as described in section 3.2.3.2.

For all statistical analyses a fixed model was fitted and a type III SS analysis was carried out using GLM procedure of SAS (SAS inst. Inc., 1987).

$Y_{ijk} = \mu + B_i + M_{(i)}j + R_{(i)k} + MR_{(i)jk} + \varepsilon_{ijk}$.

$i = 1, 2, 3$ $j = 1, 2, 3$ $k = 1, 2, 3, 4, 5, 6, 7$ (For pot experiment) and 1,2,3,4,5,6 (For field experiment.

Where: Y_{ijk} = Response variable to be analyzed.

μ = Overall mean/ Grand mean of the treatment populations.

B_i = Effect of the ith block.

$M_{(i)j}$ = Main effect of the jth placement method within the ith block.

$R_{(i)k}$ = Main effect of the kth MRP application rates within the ith block.

$MR_{(i)jk}$ = Effect of the interaction of the j placement method within ith block with kth MRP application rate.

ε_{ijk} = Experimental error.

Analysis of variance (ANOVA) was carried out using GLM procedure of SAS on soil AVP, concentration (%) and content (mg $leaf^{-1}$) of maize leaf P and N, maize height (m), P and N (kg ha^{-1}) uptake by grain and stover and total P and N (kg ha^{-1}) uptake by maize crop using plot means. Following the ANOVA, means separation was done by planned contrasts of SAS (SAS Inst. Inc., 1987).

CHAPTER FOUR

4. RESULTS

4.1 Site Characterization

Results of selected soil physical and chemical properties are presented in Table 2 for the field trial and Table 3 for the pot experiment. Generally, the soil is acidic with low P and N content and high exchangeable Al. At the end of the incubation period, exchangeable Al was observed to decrease (Table 4). Phosphorus and N concentration for the *G. sepium* green manure used for the two experiments are presented in Table 5.

4.2 Pot experiment

4.2.1 Available phosphorus

4.2.1.1 Interaction of green manure placement and rates of rock phosphate

Interactive effects of green manure placement and MRP application rates on soil AVP are presented in figure 1 for the whole incubation period and figure 2 for week five

Table 3: Selected initial top soil (0 – 15 cm depth) properties for soil used in the pot experiment.

Total N (%)	0.096* (0.002)
Total P (ppm)	328 (17)
Available P (ppm)	3.07 (0.26)
OC (%)	0.92 (0.02)
Exchangeable acidity (c mol (+) kg^{-1} soil)	0.82 (0.03)
Exchangeable hydrogen (c mol (+) kg^{-1} soil)	0.48 (0.03)
Exchangeable Al (c mol (+) kg^{-1} soil)	0.34 (0.03)
pH	4.49 (0.10)
Electrical conductivity (μ Scm^{-1})	60.37 (0.62)
Sand (%)	36.73 (0.3)
Coarse silt (%)	4.60 (0.60)
Fine silt (%)	9.20 (1.14)
Clay (%)	49.47 (0.67)
Textural class	Clay loam

*Mean of three replications followed by standard error in parenthesis.

Table 4: Selected soil properties for soil used in pot experiment at the end of the experiment.

Total N (%)	0.041 (0.002)
Available P (ppm)	3.07 (0.26)
Exchangeable acidity (c mol (+) kg^{-1} soil soil)	0.18 (0.03)
Exchangeable hydrogen (c mol (+) kg^{-1} soil)	0.15 (0.03)
Exchangeable Al (c mol (+) kg^{-1} soil)	0.00 (0.00)
PH	4.95 (0.026)
Electrical conductivity (μScm^{-1})	215 (2.08)

*Mean of three replications followed by standard error in parenthesis.

Table 5: Nitrogen and phosphorus concentration in *G. sepium* green manure used in the two experiments

	Pot experiment	Field experiment
N (%)	2.61* (0.08)	2.85 (0.12)
P (%)	0.12 (0.01)	0.14 (0.02)

*Mean of three replications followed by standard error in parenthesis.

and seven after incubation. Summary of ANOVA results is presented in appendix 2a. The effects were significant ($P<0.05$) at 1, 3, 5, and 7 week after incubation (WAI), but there were no significant ($P>0.05$) differences for the rest of the sampling period (Appendix 1). Generally, AVP in all GM-MRP combinations increased with increase in incubation time and reached a peak between 4 and 7 WAI (Fig.1) after which it decreased. For TSP rate, soil AVP gradually decreased with increase of incubation time to 7 WAI (Fig.1). At a given rate, GM application gave higher values of AVP than control (Fig.2) and above R_5, incorporation was superior than mulching. For TSP rate, the differences between incorporation, mulching and control with respect to AVP were not significant (Fig.2). The effect of TSP (i.e. R_T) was higher than that of R_4 at week five but comparable at week seven after incubation (Fig. 2).

4.3 Field experiment

4.3.1 Available phosphorus

4.3.1.1 Interaction of green manure placement and rates of rock phosphate

Interaction of green manure placement methods and MRP application rates on soil AVP are presented in figure 3 for the whole incubation period and figure 4 for week

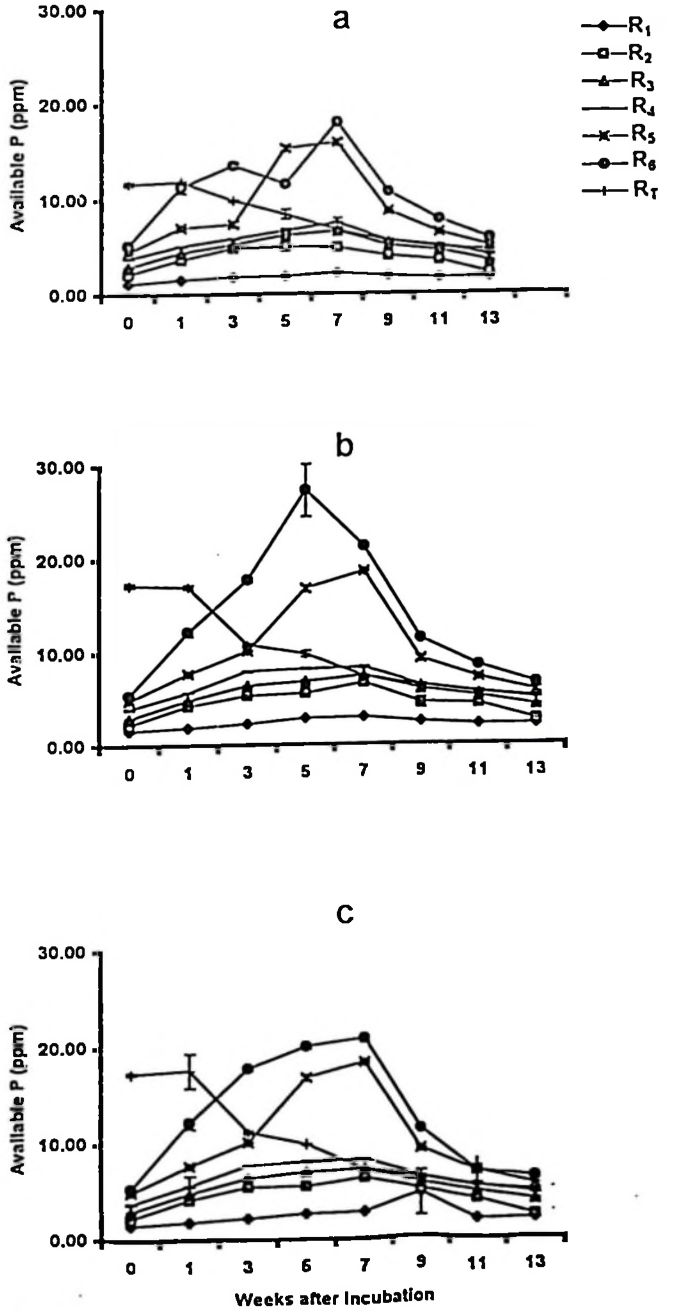

Figure 1: Pot experiment: Interaction of *G. sepium* green manure placement method and rates of Minjingu rock phosphate on available phosphorus.
a = No GM b = Incorporation c = Mulching.
Rates as defined in section 3.2.1.1.

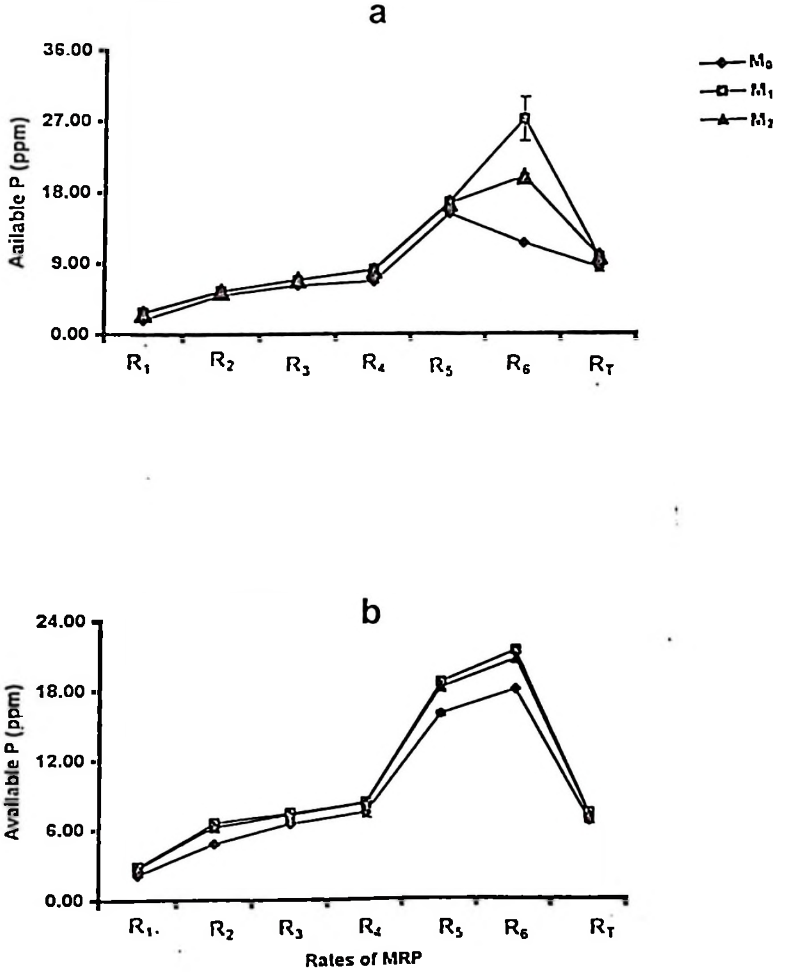

Figure 2: Pot experiment: Interaction of *G. sepium* green manure placement method and rates of Minjingu rock phosphate on available phosphorus at week five (a) and week seven (b) after incubation.
Placement method and rates as defined in Section 3.2.1.1.

four and six after planting. Summary of ANOVA results is presented in appendix 2b. Significant ($P<0.05$) interactions were observed at 2, 4 and 6 weeks after planting (WAI), but there were no significant ($P>0.05$) differences for the rest of the sampling dates (Appendix 2b). Generally, AVP in all GM-MRP combinations increased with increase in time after planting and reached a peak between 3 and 7 WAP (Fig.3) after which it decreased to 8 WAP where it levels off. For TSP rate, soil AVP gradually decreased with time to 8 WAP and remained more or less constant thereafter (Fig.3). At a given rate, GM application gave higher values of AVP than control (Fig.4) and values for incorporation and mulching were similar in both MRP and TSP rates. Combination of GM and MRP at rates $\geq R_4$ improved soil AVP than the control at four and six weeks after planting (Fig.4). The effect of TSP (i.e. R_T) was comparable to that of R_3 and R_4 for MRP at week seven and even less at week four (Fig. 4).

4.3.2 Maize leaf phosphorus and nitrogen

4.3.2.1 Maize leaf phosphorus and nitrogen concentration

Fig. 5a and b show the effect of GM placement methods on maize leaf P and N concentration. The ANOVA results are shown in appendix 2c. Green manure

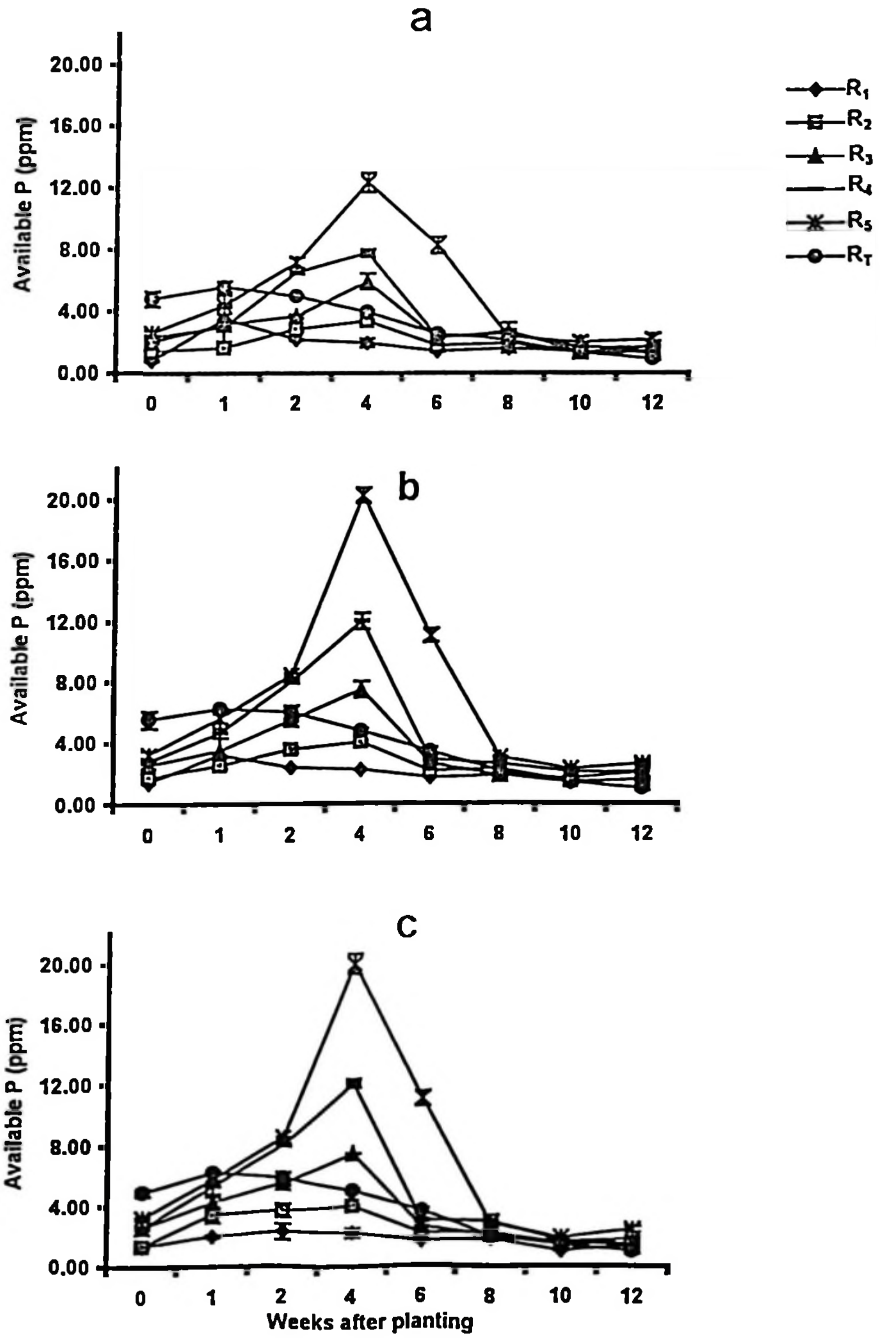

Figure 3: Interaction of *G. sepium* green manure placement method and rates of Minjingu rock phosphate on available phosphorus at SUA Farm, Morogoro, Tanzania. a = No GM, b = Incorporation, c = Mulching. Rates as defined in section 3.2.2.1.

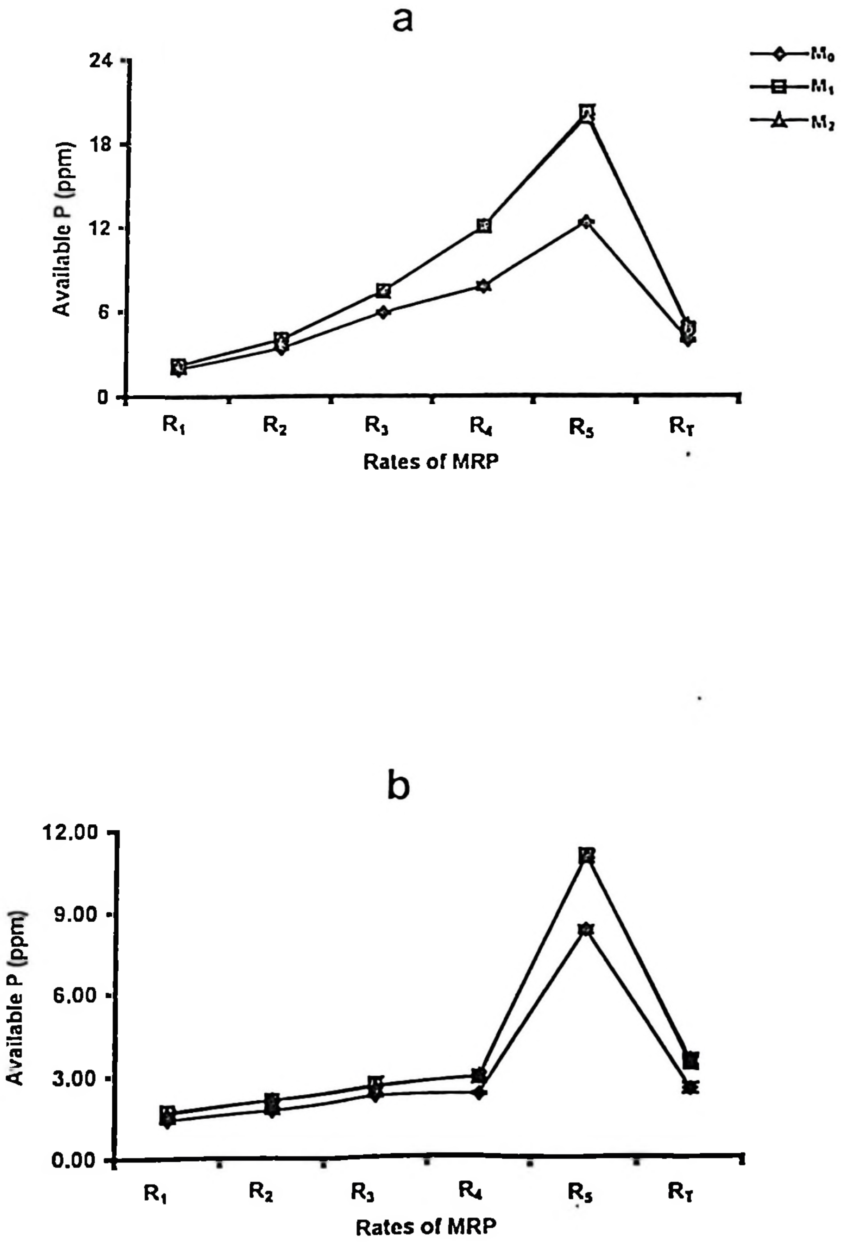

Figure 4: Interaction of *G. sepium* green manure placement method and rates of Minjingu rock phosphate on available phosphorus at week four (a) and week six (b) after planting at SUA Farm, Morogoro, Tanzania. Placement method and rates as defined in section 3.2.2.1.

placement method significantly ($P<0.05$) affected leaf P and N concentration. Leaf P concentration for the control, incorporation and mulching treatments were 0.1807%, 0.2005% and 0.1908% respectively (Appendix 4a). This is equivalent to 11% (incorporation) and 5% (mulching) increase when compared to the control. On the other hand, the mean leaf N concentration for incorporation (2.154%) and mulching (2.298%) were significantly different ($P<0.05$) from the control (2.252%) but not significantly different from each other (Fig. 5b and Appendix 4).

The results of the effects of MRP application rates on maize leaf P and N concentration are presented in Fig. 6a and b respectively. The ANOVA results are shown in appendix 2c. It was observed that MRP application rates resulted in significant ($p<0.05$) differences in leaf P concentration but not for N concentration. The leaf P concentration followed a more or less quadratic trend but leaf N concentration was more or less constant (Fig 6a and b and Appendix 2f). Generally, the effects of TSP (i.e. R_T) and R_4 and R_3 for leaf P concentration were not different (Fig. 6a). Similarly, effects of R_1 and R_2 on leaf P concentration were not significantly different. The effects of the interactions between GM placement and rates of MRP application on maize leaf P and N concentration were not significant although incorporation was superior to the mulching and control treatments.

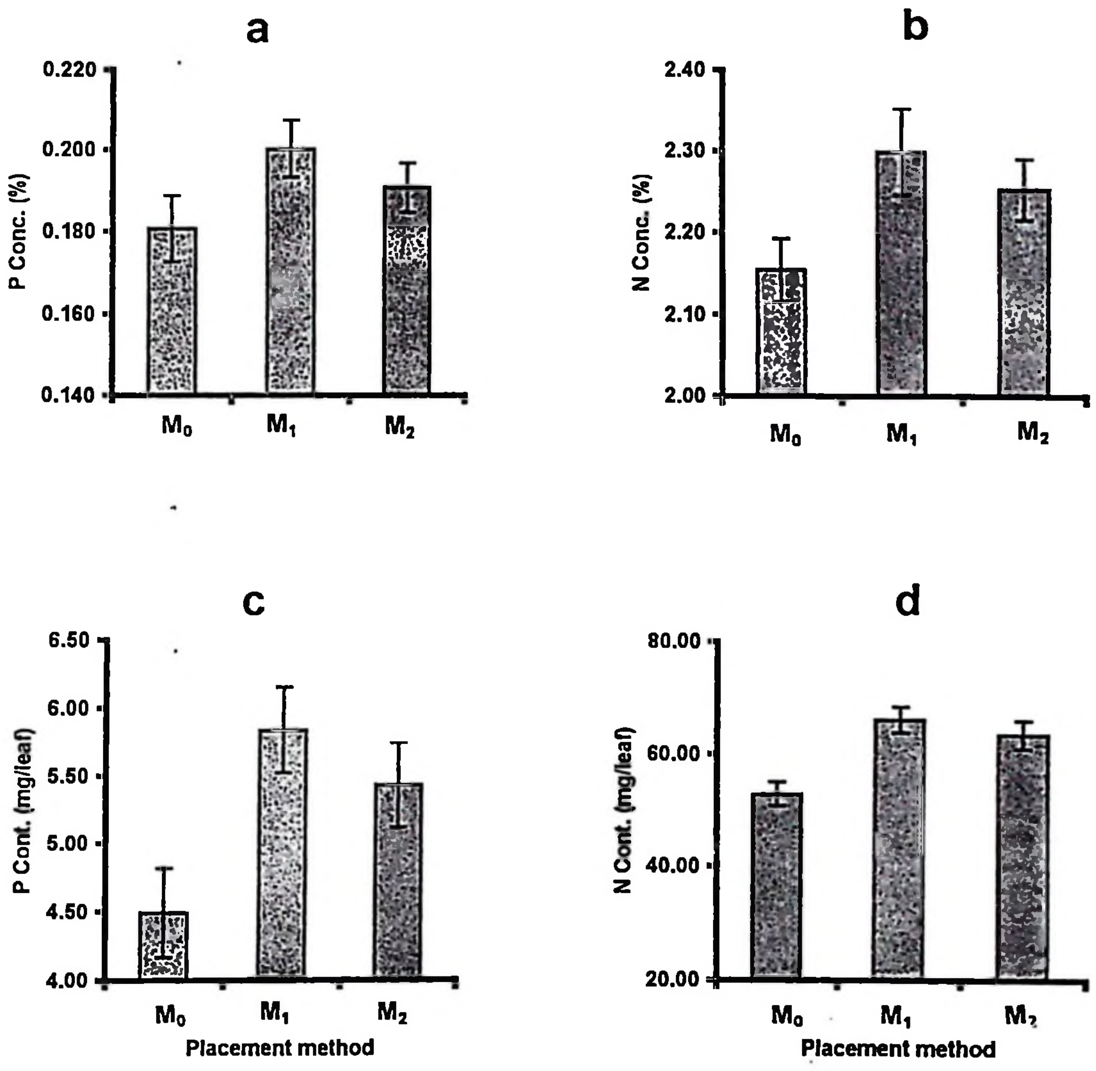

Figure 5: Effect of *G. sepium* green manure placement method on maize leaf P concentration (a), N concentration (b), P content (c) and N content (d) at SUA Farm, Morogoro, Tanzania.
Placement method as defined in section 3.2.2.1.

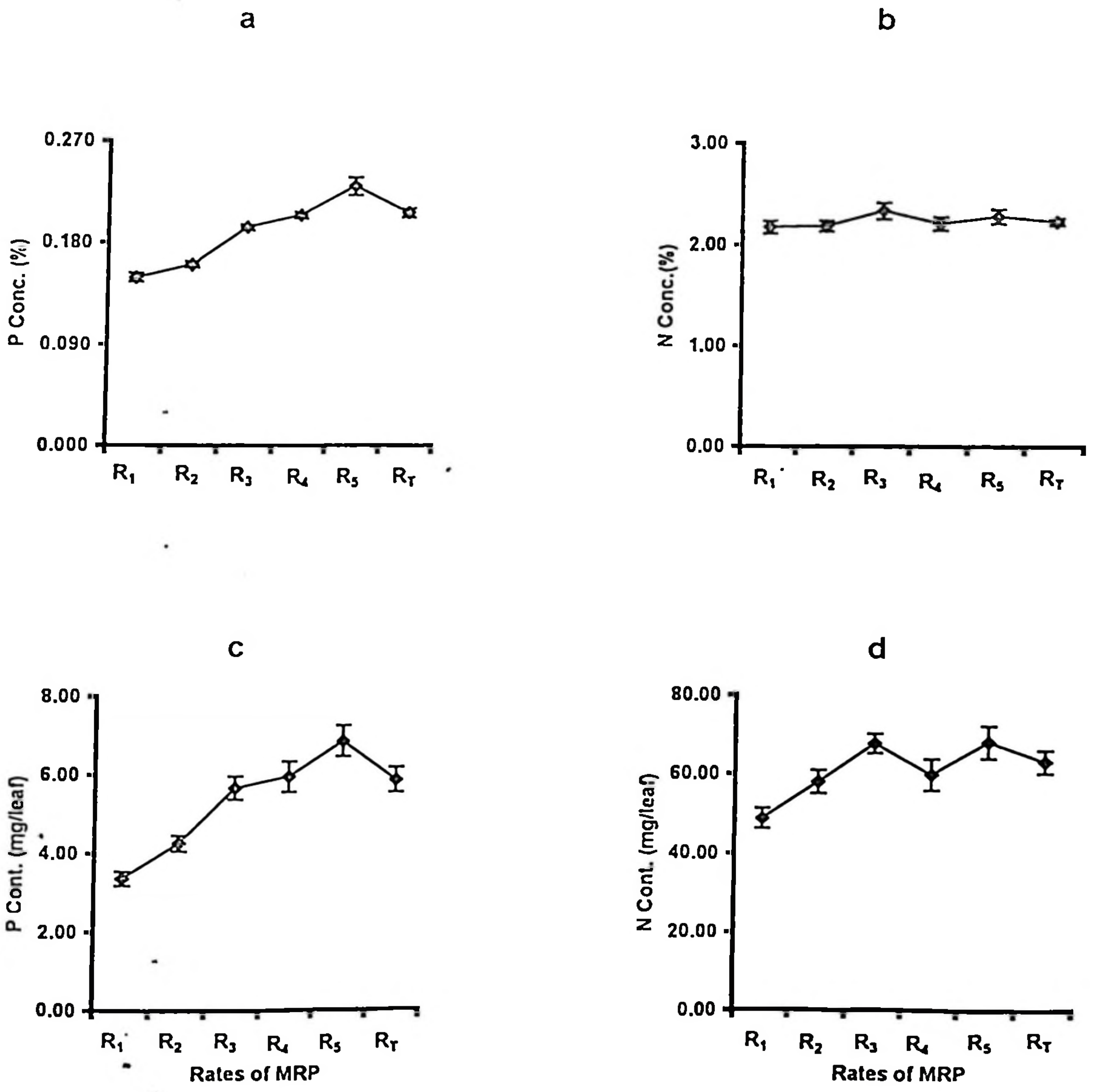

Figure 6: Effect of rates of Minjingu rock phosphate on maize leaf P concentration (a), N concentration (b), P content (c) and N content (d) at SUA Farm, Morogoro, Tanzania.
Rates as defined in section 3.2.2.1.

4.3.2.2 Maize leaf phosphorus and nitrogen content

Green manure application significantly increased maize leaf P and N content (Fig. 5c and d). For both parameters, means of incorporation and mulching treatments were significantly ($P<0.05$) better than the control but not significantly different from each other (Appendix 4). The percentage increase in leaf P content due to GM placement were 30% and 21% for incorporation and mulching treatments respectively. Corresponding increase in leaf N content was 25% and 20% respectively (Appendix 4).

Figures 6c and d present the effects of rates of MRP on maize leaf P and N content respectively. ANOVA results are shown in appendix 2c. Statistical analysis carried out indicated that the effect of MRP application rates on leaf P and N content were significantly different ($P<0.05$) (Fig 6c and d). The increase in leaf P and N content with MRP application rates followed a quadratic trend (Fig. 6c, d and Appendix 2f). Mean differences between rates of application of MRP were also significant. The effect of TSP on leaf P content was comparable to that of R_3 and R_4 for MRP. The interaction effects of GM placement and rates of MRP on leaf P and N content were not significant.

4.3.3 Phosphorus and nitrogen uptake by maize

4.3.3.1 Phosphorus uptake

The effects of *G. sepium* GM placements on grain P, stover P and total P uptake are presented in Fig. 7a, b, and c respectively and Appendix 5. ANOVA results are indicated in appendix 2d. For all parameters, the effects of placement methods were significant ($p<0.05$). Grain P varied significantly ($p<0.05$) between the two placement methods with the highest value (6.22 kg P ha^{-1}) observed in incorporation treatment (Fig.7a and Appendix 5). Stover P (Fig. 7b) and total P uptake by grain and stover (Fig. 7c) followed a pattern similar to that of grain P.

Rates of MRP applied significantly affected grain P (Fig. 8a), stover P (Fig. 8b) and total P uptake (Fig. 8c). P uptake followed a quadratic trend (Appendix 2f). It was observed that for the rates of P greater than R_4 (i.e. > 40 kg P ha^{-1}) P uptake increased at a decreasing rate (Fig.8a, b, and c). However, no significant ($p>0.05$) differences in grain P were observed between 40 and 80 kg P ha^{-1} as MRP and 30 kg P ha^{-1} as TSP. Similarly, the difference in total P uptake between 40 kg P ha^{-1} and 80 kg P ha^{-1} both as MRP was not significant. On the other hand, the difference between stover P was significant in most of MRP application rates (Fig. 8b). The interaction between GM placement methods and rates of MRP on P uptake was not significant (Appendix 2d).

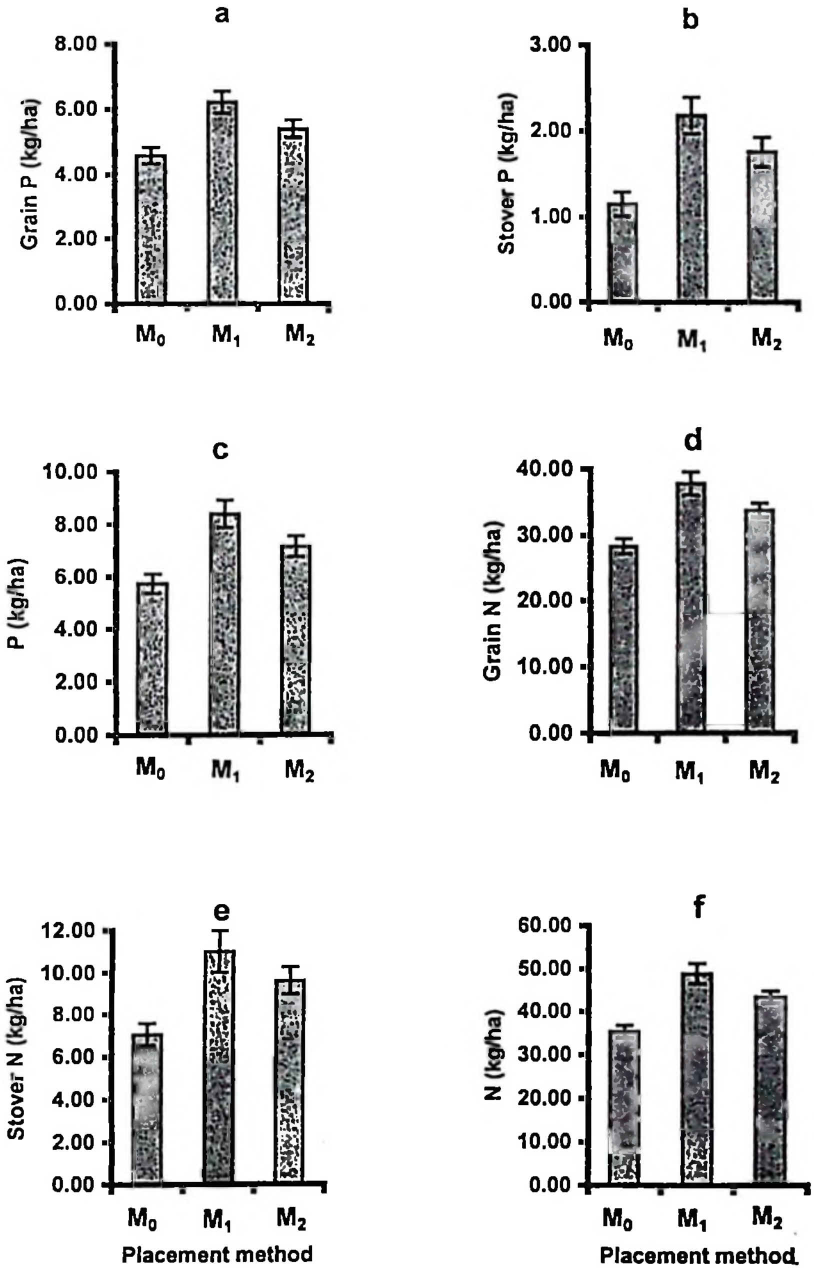

Figure 7: Effect of *G. sepium* green manure placement method on grain P (a), stover P (b), total P (c), grain N (d), stover N (e) and total N (f) uptake at SUA Farm, Morogoro, Tanzania.
Placement method as defined in section 3.2.2.1.

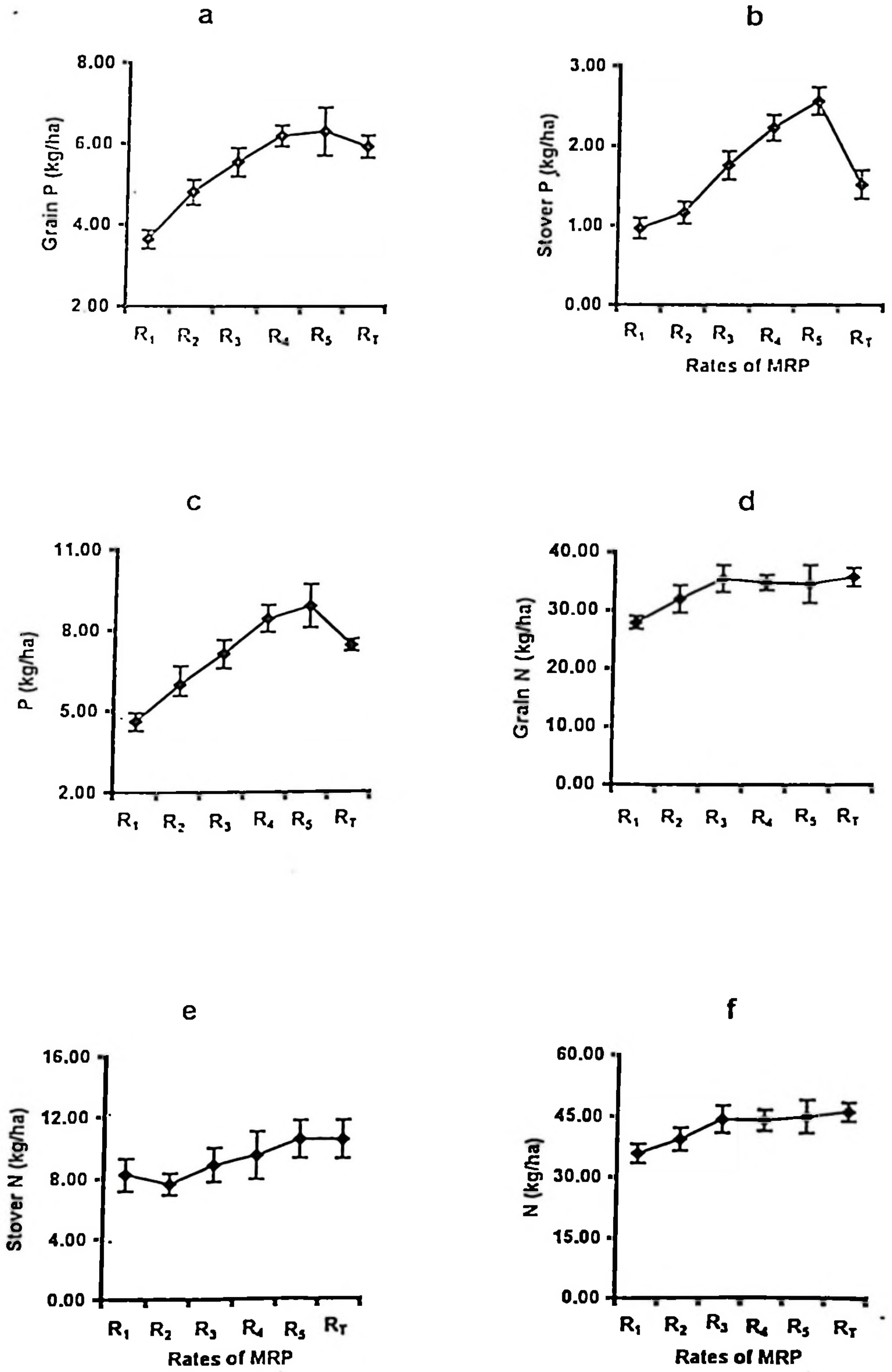

Figure 8: Effect of rate of Minjingu rock phosphate on grain P (a), stover P (b), total P (c), grain N (d), stover N (e) and total N (f) uptake at SUA Farm, Morogoro, Tanzania.
Rates as defined in section 3.2.2.1.

4.3.3.2 Nitrogen uptake

Effects of GM placement method on grain N, stover N and total N uptake are presented in Fig. 7d, e and f respectively and Appendix 5. The effects were significantly different ($P<0.05$) in all parameters with the highest values obtained by incorporation. Grain N for incorporation (37.82kg ha^{-1}) and mulching (33.77kg N ha^{-1}) were statistically higher by 33% and 19% respectively as compared to the control (Appendix 5). For stover N, the incorporation (10.98kg N ha^{-1}) and mulching (9.59kg N ha^{-1}) treatments differed statistically from the control treatment but not from each other (Appendix 5). Likewise total N uptake followed a pattern similar to that of grain N (Fig. 7f).

The effect of rates of MRP application on grain N, stover N and total N are shown in Fig. 8d, e and f respectively. ANOVA results are shown in appendix 2d. Significant differences ($p<0.05$) were observed between the rates for grain N and total N uptake but not for stover N. Except for application of 10 kg P ha^{-1}, grain N between rates of MRP were significantly ($p<0.05$) higher than the control but not from each other (Fig. 8d). The same pattern was observed in total N uptake (Fig. 8f). No significant ($P>0.05$) differences between rates of MRP was observed in stover N. Except for stover N, MRP application rates resulted in significant quadratic relationship with N uptake. The effect of TSP on grain N, stover N and total N uptake was comparable to that of MRP at R_3, R_4, and R_5. Interactions of GM placement and rates of MRP on grain N, stover N and total N uptake were not significant (Appendix 2d).

4.3.4 Maize growth and yield

The effects of GM placement on maize height, grain yield and stover yield are presented in Fig. 9a, b, and c respectively and appendix 6a. Generally, the effects were significantly ($P<0.05$) different for the three parameters (Appendix 2e). In terms of maize height, mulching and incorporation treatments were not significantly different (Appendix 6). The highest mean height (1.37m) was recorded in mulching treatment and the lowest (1.19m) in control treatment (Fig 9a). Unlike maize height, maize grain yield differed significantly ($P<0.05$) between control, incorporation and mulching treatments (Fig. 9b) with the highest yield (2.60 t ha^{-1}) obtained from the incorporation treatment. Stover yield from control plots (2.57 t ha^{-1}) was significantly less than yield from incorporation (3.33 t ha^{-1}) but was not different from mulching treatments (Fig. 9c).

Figure 10 indicates the effect of MRP application rates on maize height growth and yield. The effect of MRP application rates on maize height growth and grain yield were significant ($P<0.05$) but no significant differences were observed in stover yield (Appendix 2e). Generally, maize height increased linearly and curvilinearly with rate of MRP application (Fig. 10a and Appendix 2f). Grain yield from control (1.89 t ha^{-}

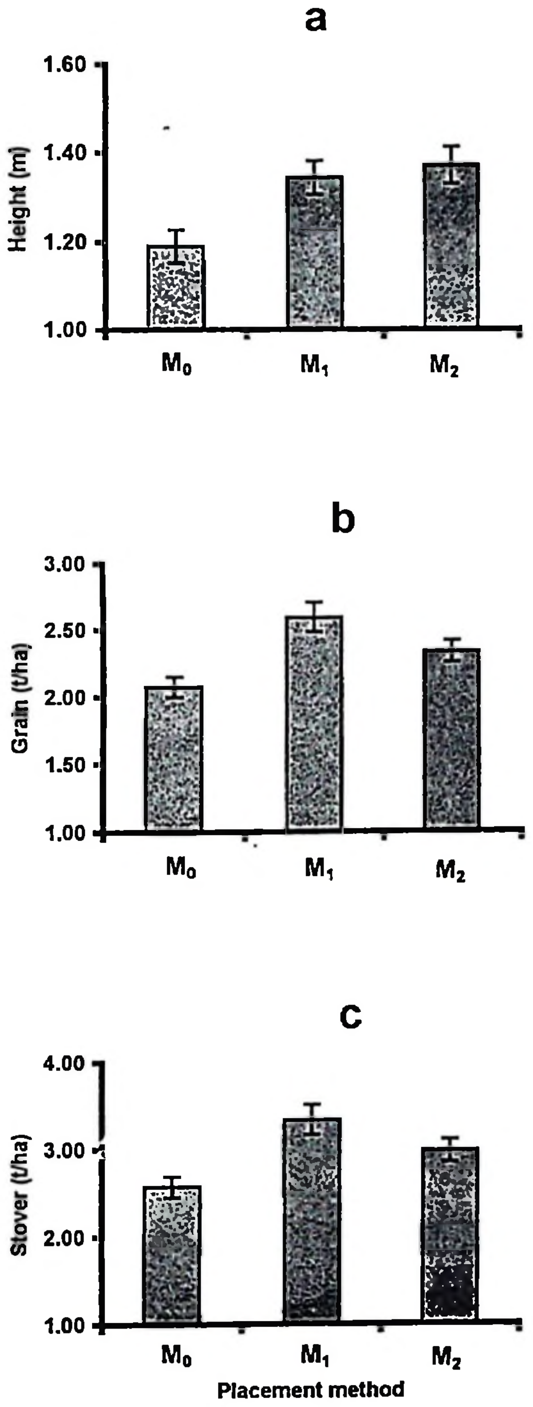

Figure 9: Effect of *G. sepium* green manure placement method on height (a), grain yield (b) and stover yield (c) at SUA Farm, Morogoro, Tanzania. Placement method as defined in section 3.2.2.1.

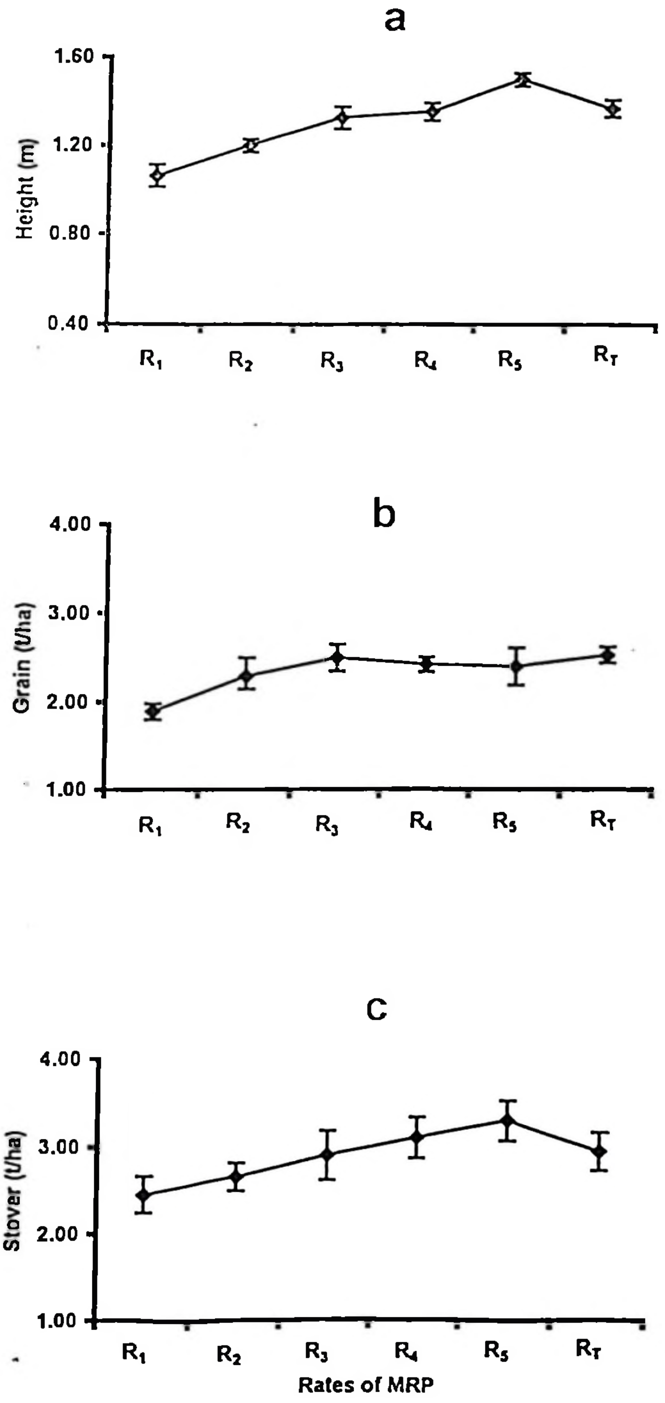

Figure 10: Effect of rate of Minjingu rock phosphate on height (a), grain yield (b) and stover yield (c) at SUA Farm, Morogoro, and Tanzania. Rates as defined in section 3.2.2.1.

^{1}) was significantly less than yields from all other rates (Fig. 10b) where no differences were observed in the other rates. Stover yield for all rates did not differ significantly (Fig. 10c). Grain yield, unlike stover yield, had linear and quadratic relationship with MRP application rates (Appendix 2f). The effect of TSP on maize growth and yield was comparable to those of R_4 and R_3 for MRP. Visual observation in the field revealed that termite attack affected very much maize growth after tusseling stage. The interaction between GM placement and rate of MRP was not significantly different for the three parameters (Appendix 2e).

CHAPTER FIVE

5 DISCUSSION

5.1 Pot experiment

The results of pot experiment indicated that AVP irrespective of the method of placement and rate of MRP application increased with time up to 7 WAI and decreased gradually thereafter (Fig. 1). On the other hand, AVP in TSP treatments (R_T) decreased gradually with the increase in incubation period. Similar results have been reported by other workers (Ikkera, 1986; Mkeni *et al.*, 1992; Utumo, 1995; Tusekelege, 1997; Kitua, 1997). This initial increase in AVP is attributed to solubility of MRP due to low pH and extractable P of the soil used in this study (Table 3). According to Hammond *et al.* (1986) low soil pH, low extractable P and low exchangeable Ca are conditions, which favor the dissolution of RP. Similarly, Nye and Kirk (1986) reported that the dissolution of RP depends on the rate of removal of its three principle dissolution products, Ca^{2+}, $H_2PO^-_4$ and OH^-. Substantial dissolution of RP in acidic soil have also been reported in other studies (Mandal and Khan, 1982; Mkeni *et al.*, 1992; Hanafi *et al.*, 1992). The results obtained in this study compare well with those of Mandal and Khan (1982) who obtained a peak after thirty days. The decrease in AVP at TSP treatment is because TSP is highly soluble and part of solubilized P was fixed by the soil constituents in form not extractable by the Bray 1 extractants (Tusekelege, 1997). Aluminium (Table 4) could be the possible soil constituent that may be associated with this fixation as results show the decrease in exchangeable Al at the end of the experiment. Other studies (Esilaba *et al.*, 1992; Utumo, 1995; Utumo and Sunyoto, 1995; Wong and swift, 1995) have also indicated a decrease in Al following RP application. The increase of AVP with rate of MRP applications is also associated with increased dissolution of MRP and hence release of P in the soil. Other researchers (Utumo and Sunyoto, 1995; Kitua, 1997) have also reported similar results.

Figure 2 indicates that, treatments which received GM, had higher AVP than the control (No GM), with highest values obtained by the incorporation treatments and at rates $\geq R_5$ and incorporation treatment was superior to mulching. This implies that GM alone (Fig. 1b and c) or in combination with MRP (Fig. 2) improved soil AVP when compared to the control. This is attributed to increased dissolution of MRP due to GM application. The possible explanation is that OM upon decomposition produces organic substances such as citrate and oxalate that have significant chelation capacity, lowering the activity of polyvalent cations such as Ca, Fe, and Al that form insoluble salts with P (Hammond *et al.*, 1986; Singh *et al.*, 1991). This in turn provides a driving force for further dissolution of RP (Alexander, 1977). This occurs because as the H^+ concentration increases, the solubility of RP also increases (Kanabo and Gilkes, 1987). Furthermore, application of crop residues is known to increase total number of bacteria in both bulk and rhizosphere soil (Hafner *et al.*, 1993 cited from Marchner *et al.*, 1995). According to Nziguheba *et al.* (1998), the increase of microbial biomass may be associated with increase in biological activity and mineralization of more recalcitrant fractions of P. Various studies (Ikkera, 1986; Yang et al., 1994; Zarah and Bah, 1997; Kitua, 1997) have also indicated increased RP solubility when OM was used in combination with RP. Improved AVP following GM application (Fig. 1 and 2) may be associated with the contribution of P from the decomposing plant biomass (Szott *et al.*, 1991; Sanchez, 1995; Palm 1995). Higher values obtained with incorporation treatment as compared to mulching (Appendix 1) could be associated with faster decomposition of GM (Wilson *et al.*, 1986) and hence more release of P. Additionally, it is possible that incorporation of GM reduce soil P fixing capacity more than its application as mulch. Consequently, more soil P was observed in available form in incorporation than in mulching and control treatments. However, lack of significant differences (Fig. 2) between the two methods of GM application at rates $\leq R_5$ indicate that *G. sepium* GM incorporation does not have any advantage over mulching with respect to soil AVP below this rate.

Trends in AVP seem to follow the decomposition pattern of GM. While *G. sepium* GM is known to decompose faster during the first four weeks after placement (Nduwayezu, 1997; Fasuluku, 1998), rapid increase in AVP was also observed within the same period (Fig. 1).

5.2 Field experiment

5.2.1 Available phosphorus

Trends of AVP under field conditions (Fig. 3 and 4) followed a pattern similar to that of the incubation study. This indicates that the predictions made by the incubation experiment are also applicable under field conditions. However, values of AVP for incubation study were higher than those for the field experiment (Appendices 1 and 3). This can be explained partly by the high rates of MRP used in the incubation experiment, the P uptake by maize crop in the field, the chelation in soil constituents, and uncontrolled moisture content in the field.

The interaction of GM placement method and rate of P fertilizers indicate that GM application significantly improved soil AVP at rates above R_3 (Fig. 4). This is explained by the effect of GM on soil AVP through either of the following ways. Firstly, enhancement of the dissolution of the sparingly soluble P sources (MRP inclusive) leading to an increase in the available P content of the soil (Alexander, 1977; Nye and Kirk, 1986; Hammond *et al.* 1986; Sale and Mokwunye, 1993). Secondly, the reduction in P sorption of the soil (Singh and Jones, 1976; Kafkafi *et al.*, 1988). Thirdly, the enhancement of the microbial activities in the soil thereby influencing the mineralization of more recalcitrant fractions of P (Hafner *et al.*, 1993 cited from Marchner *et al.*, 1995; Nziguheba *et al.*, 1998). Finally, the actual addition of P from the decomposing plant biomass (Szott *et al.*, 1991; Sanchez, 1995; Palm 1995). Lack of significant difference between incorporation and mulching treatments at all rates of application (Fig. 4), indicate that the two methods do not differ with respect to their effect on soil AVP.

Decrease in AVP four WAP (Fig. 3) is attributed to P uptake by maize. This implies that maize plants at this time were in high demand of nutrients. Thus rate of dissolution of RP could not keep pace with the rate of P uptake hence a decrease in AVP in the soil solution. Similarly, it has been observed that a period of high nutrient demand for maize to range between 3 - 8 WAP at Kitete, Morogoro (Nduwayezu, 1997) and 4 - 6 WAP in Central Togo (Lehman *et al.*, 1995). It could also be associated with P fixation by soil constituents.

5.2.2 Maize leaf nutrient concentration and content

The effects of GM placement on maize leaf P and N concentration are presented in figures 5a and b whereas for P and N content are presented in figures 5c and d. The effects were found to be significant ($p<0.05$) in all parameters with highest values obtained by incorporation (Appendix 4a). This is attributed with improved MRP dissolution (5.1) under incorporation than mulching of GM and improved soil nutrients (Yamoah *et al.*, 1986; Montagnini *et al.*, 1993) due to GM application. Thus more P was released into the soil and hence available for uptake by maize plants. Since agroforestry tree prunings have been reported to be a more effective N source when incorporated than when applied as mulch (Kang *et al.*, 1981), then improved leaf N concentration and content due incorporation may be associated with faster decom- position of GM under incorporation than mulching (Wilson *et al.*, 1986).

Except leaf N concentration, the effect of MRP application rates on P and N for the rest of the parameters were significant (Fig. 6 and Appendix 2d). The effect increased with the increase in the rate of application (Fig. 6). Kitua (1997) has also reported increased shoot P and N concentration with increase in rate of RP application for maize plants and White *et al.,* (1999) for rice. On the other hand, it has also been observed that P content in a whole maize plant (Powell and Web, 1974) and maize leaf (Chingonikaya, 1999) increased with rate of applied P. This can be associated with an increase in phosphate uptake, as a result of increased phosphate concentration in the soil solution. This in turn increase the diffusion gradient from the soil to the plant root hairs and hence increased phosphate uptake by maize plant (Ozane, 1980 cited by Kitua, 1997). Similar explanation holds true for N uptake. The curvilinear relationship between MRP application rates and leaf P and N (Appendix 2f) indicate that crop responses have maximum point above which there is a decline.

5.2.3 Phosphorus and Nitrogen uptake by maize

The results of P and N uptake as affected by GM placement are presented in Fig. 7 and appendix 5. In both P and N uptake by maize plants, the effects of GM placement were significant (Fig.7). Incorporation and mulching improved total P uptake by 46.3% and 24.9% respectively and total N uptake by 38.1% and 22.7% respectively as compared to control (Appendix 5). Similarly, Marchner *et al.* (1995) observed increase in total P by incorporation of crop residues than by its application as mulch. This could be explained by more AVP observed in incorporation treatments than in mulching treatments (Appendix 3) and improved soil physical properties and nutrients, particularly N supply following GM application (Yamoah *et al.*, 1986; Montagnini *et al.*, 1993. In western Kenya, Gachengo *et al.*, (1999), found that GM alone or incorpo- ration with TSP significantly increased P and N uptake by maize crop. Rekhi and Bajwa (1993) have also reported similar results.

Phosphorus and N uptake by maize varied with the MRP application rate (Fig. 8). Except stover N, P and N uptake differed significantly between rates of MRP (Appendix 2d). Furthermore, above R_4 grain P, stover P and total P uptake increased at a decreasing rate indicating that a peak has been reached (Fig. 8). This can also be explained by the quadratic relationship observed between P uptake and MRP application rates (Appendix 2f). Similarly, Okalebo (1977) cited by Kitua (1997) observed that the increase of P uptake above 40 kg P ha^{-1} was at a decreasing rate.

These results compare well with those reported by Utumo (1995) who observed that P uptake by corn increased with rate of application for both RP and TSP. Fasuluku (1997) reported similar results. Likewise White *et al.* (1999) observed increase of N and P uptake by grain and straws of rice with increased rate of RP application in both field and pot experiments. Since high root density (Sale and Mokwunye, 1993; Marchner *et al.*, 1995), mobility and influx of P per unit root length (Hafner *et al.*, 1993 cited from Marchner *et al.*, 1995) have been reported to correspond to P uptake; then increased P uptake due to MRP application rates could be associated with improved soil AVP (Appendices 1 and 3). The effect of TSP in most of the parameters assessed was comparable to that of R_3 and R_4 for MRP due to its high solubility. Lack of significant difference in N uptake (Fig. 8) in most of MRP application rates was because of single rate of GM applied.

5.2.4 Maize growth and yield

GM application irrespective of the method of application significantly ($p<0.05$) improved maize growth and yield (Appendix 4a) by 13% (height), 19% (grain), and 22% (stover). These results are consistent with those found by Fasuluku (1997) who observed increase in maize grain yield by 16.3% when *Sesbania sesban* GM was applied without fertilizer. Anthofer *et al.* (1998) also observed that application of agroforestry prunings significantly improved wheat growth in both pot and field experiments with the highest grain yield of 248 gm^{-2} and height (30.3cm) obtained with *Gliricidia* treated wheat. Various studies (Montagnini *et al.*, 1993; Marchner *et *al*., 1995; Cadisch *et al.* 1998), have also reported similar results. This response may be due to nutrient contribution by applied GM (Table 5) because crop response to GM application has been associated with improved soil physical and nutrients, particularly N supply (Yamoah *et al*., 1986; Montagnini *et al.*, 1993).

Figures 9a, b and c show that GM placement methods significantly ($P<0.05$) increased maize growth and yield with the highest values obtained by incorporation. Other workers (Marchner *et al.* 1995; Mafongoya *et al.*, 1996b; Mafongoya and Nair, 1996) have also reported improved crop growth and yield due to GM placement. The results compare well with those found by Tonye *et al.* (1997) who observed that incorporation and mulching of plant residues from a planted fallow of *Cajan cajan* resulted into maize yield of about 3.1 t ha^{-1} and 2.9 t ha^{-1} respectively. On the other hand, a decrease in maize yield (1.4 t ha^{-1}) was found where residues were removed. Contrary to this study Tonye *et al*., (1997) did not find significant differences in yield between incorporation and mulching. Possibly because of the nature of GM and RP used in this study. Yamoah *et al*., (1986) and Montagnini *et al.*, (1993) together associate response of crops to green manuring with improved N supply among other factors. Thus the better results found with incorporation may be due to faster decomposition and mineralization of GM, whereas the lower performance of mulching may be due to high losses from volatilization during decomposition (Kang *et al*., 1981; Wilson *et al.*, 1986). The better performance of maize with incorporation may also be attributed to more soil AVP under incorporation than mulching

(Appendices 1 and 3) due to the effect of GM placement on MRP dissolution. Earlier findings where P is reported to limit crop production in tropical soils (Hernandez *et al.*, 1981; Sahrawat *et al.*, 1995) and at SUA Farm (Fasuluku, 1997) support this idea.

Except for stover yield, MRP application significantly ($p<0.05$) increased maize height growth and grain yield (Fig 10a, b and c). These results agree with those obtained by Mnkeni *et al.* (1991) who observed increase in maize yield with rate of MRP application in Magadu and Mzumbe soils. The results are also similar to those obtained by Utumo and Sunyoto (1995) where each kilogram of RP increased soya bean yield by 1.5 kg. Similarly, Fasuluku (1997) observed that the three levels of TSP fertilizer (0, 20 40 kg P ha^{-1}) significantly improved maize growth and yield at SUA Farm. Other studies (Zaharah and Sharifuddin, 1995; Utumo, 1995; White *et al.*, 1999) have also reported similar results. Improved crop growth and yield following MRP application is associated with its ameliorating effects on soil acidity, increased extractable P and increased exchangeable Ca (Mnkeni *et al.*, 1991; Ikkera, 1986; Utumo and Sunyoto, 1995). This is because the soil used in this experiment had low pH and low extractable P (Table 5). The effect of TSP at 30 kg ha^{-1} was similar to that of 20 kg ha^{-1} and 40 kg ha^{-1} as MRP (Fig. 10). Like wise MRP is known to be equally effective as TSP as a source of P in acidic soils with low extractable P (Mnkeni *et al.*, 1986). However, poor performance of TSP treatment compared to MRP treatments may be due to low rate used in this study. Lack of significant differences between rates of MRP in grain and stover yield (Appendix 2e) could be attributed to termite attack that affected maize growth at a stage between tusseling and maturity. It could also be due to fixation of P by soil constituents. Phosphorus fixation by soils of relatively low pH with very low available P and high clay content (Table 2) have been reported by Sanchez and Palm (1996).

CHAPTER SIX

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study indicated that in both pot and field experiments, GM application enhanced MRP dissolution. Incorporation of GM into the soil slightly improved MRP dissolution than when compared to its application as mulch but the differences between the two methods were not significant. Thus there is a potential for increasing soil AVP when GM is incorporated into the soil or applied as mulch with inorganic P fertilizers. Similarly, soil AVP increased with increase of MRP application rates in both experiments.

Green manure placement method significantly increased concentration and content of P and N in maize leaf. With the exception of leaf P concentration the differences between incorporation and mulching were not significant. With exception of stover N, incorporation of GM into the soil resulted in to a substantial increase of P and N uptake as compared to mulching and control. Maize height and yield were significantly improved by GM placement method. Unlike height, the highest values for yields were obtained from the incorporation treatments. Except for leaf N concentration, MRP application rates significantly improved the content and concentration of P and N in maize leaf. Similarly, P and N uptake, maize height growth and yield increased with increase in MRP application rates up to 40 kg P ha^{-1}. Above 40 kg P ha^{-1} the response increased at a diminishing rate. Generally, most of the parameters studied showed a linear and quadratic relationship with MRP application rates. However, the interactions of GM placement method and MRP application rates were not significant in most of the parameters.

This study demonstrates that solubility of MRP and crop performance in acidic soils can be improved when GM alone or in combination with MRP are incorporated into the soil or applied as mulch. This implies that agroforestry trees that are widely used in improving soil fertility problems contain the form of plant biomass that if managed properly can be used to improve solubility of MRP, crop growth and yield. There are however limitations to the extent and sustainability of the biomass transfer system involved. The amount of GM produced by the agroforestry trees can be insufficient to cater for the need of most of small holder farmers and the labor required in cutting, transporting and incorporating the GM is substantial. Therefore, it may not be economically feasible to most small holders farmers. Furthermore, GM in this study was used as a source of N for maize and this is merely transferring nutrients within the farm and not actually redressing the nutrient depletion in the soil, therefore it may not be sustainable in the long run.

6.2 Recommendations

Based on the results of this study, incorporation and mulching have the potential to improve solubility of MRP, growth and yield of crops. With the current high cost of industrial fertilizers, the use of local RP and GM in agriculture is gaining popularity nowadays. However, as far as GM placement is concerned, further investigations need to be done to make it more feasible to many small farmers. Therefore, the following studies are recommended:

i) Monitoring the residual effect of the two placement methods in the subsequent years in order to assess their performance.

ii) Since GM with C: P ratio greater than 130 are known to increase P immobilization (Singh and Jones, 1976), the screening for suitable agroforestry species to be used with P fertilizers is necessary.

iii) To carry out the economic analysis at the small-scale farmer level as a criterion for selection of the placement method to be adopted.

iv) Where sufficient amount of GM can be produced on farm boundaries, the incorporation of GM as opposed to its application as mulching is recommended. Assuming labour for incorporation is not limiting.

v) The use of GM in combination with inorganic P fertilizers is recommended to combat soil fertility problems in P deficient soils.

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APPENDICES

Appendix 1: Pot experiment: Effect of *G. sepium* green manure placement method and Minjingu rock phosphate application on available phosphorus after laboratory incubation.

GM Plm^y	Rates of MRP	Weeks after incubation							
		0	1	3	5	7	9	11	13
M$_0$	R$_1$	1.11*	1.48	1.76	1.82	2.18	1.83	1.67	1.69
		(0.10)	(0.02)	(0.05)	(0.06)	(0.06)	(0.08)	(0.08)	(0.04)
	R$_2$	2.09	3.64	4.77	4.91	4.82	3.98	3.52	2.11
		(0.08)	(0.06)	(0.06)	(0.06)	(0.08)	(0.09)	(0.11)	(0.04)
	R$_3$	2.86	4.36	5.17	6.14	6.52	5.06	4.47	3.40
		(0.10)	(0.06)	(0.08)	(0.14)	(0.15)	(0.12)	(0.08)	(0.10)
	R$_4$	3.73	5.04	5.80	6.66	7.45	5.60	5.08	4.01
		(0.04)	(0.06)	(0.07)	(0.22)	(0.45)	(0.13)	(0.13)	(0.15)
	R$_5$	4.43	6.98	7.32	15.28	15.90	8.68	6.42	5.01
		(0.04)	(0.11)	(0.25)	(0.26)	(0.29)	(0.06)	(0.08)	(0.12)
	R$_6$	5.15	11.29	13.51	11.52	18.00	10.74	7.80	5.79
		(0.06)	(0.68)	(0.35)	(0.04)	(0.08)	(0.04)	(0.08)	(0.13)
	R$_T$	11.65	11.80	9.82	8.37	6.67	5.50	4.82	4.54
		(0.26)	(0.16)	(0.16)	(0.54)	(0.27)	(0.12)	(0.08)	(0.08)
M$_1$	R$_1$	1.55	1.86	2.27	2.82	2.91	2.39	2.13	2.11
		(0.10)	(0.04)	(0.06)	(0.07)	(0.05)	(0.04)	(0.026)	(0.04)
	R$_2$	2.23	4.20	5.29	5.54	6.60	4.44	4.31	2.61
		(0.08)	(0.12)	(0.09)	(0.18)	(0.02)	(0.18)	(0.20)	(0.13)
	R$_3$	2.91	4.83	6.38	6.82	7.43	5.90	5.13	4.13
		(0.08)	(0.12)	(0.09)	(0.18)	(0.02)	(0.18)	(0.20)	(0.13)
	R$_4$	3.89	5.65	7.95	8.20	8.35	6.42	5.67	4.83
		(0.12)	(0.04)	(0.08)	(0.09)	(0.13)	(0.10)	(0.10)	(0.06)
	R$_5$	4.83	7.73	10.20	16.83	18.67	9.22	7.17	5.74
		(0.12)	(0.13)	(0.10)	(0.33)	(0.11)	(0.20)	(0.11)	(0.21)
	R$_6$	5.34	12.22	17.82	27.30	21.36	11.45	8.45	6.55
		(0.11)	(0.45)	(0.31)	(6.98)	(0.14)	(0.04)	(0.10)	(0.12)
	R$_T$	17.29	17.09	10.90	9.84	7.33	6.32	5.52	5.11
		(0.25)	(0.21)	(0.18)	(0.35)	(0.15)	(0.08)	(0.06)	(0.06)
M$_2$	R$_1$	1.53	1.77	2.15	2.62	2.77	4.49	1.97	1.97
		(0.02)	(0.06)	(0.12)	(0.11)	(0.12)	(2.31)	(0.04)	(0.04)
	R$_2$	2.25	4.13	5.45	5.47	6.31	4.92	4.05	2.34
		(0.04)	(0.08)	(0.21)	(0.13)	(0.10)	(0.04)	(0.02)	(0.02)
	R$_3$	2.96	4.74	6.38	6.94	7.21	5.57	4.82	3.91
		(0.11)	(0.04)	(0.19)	(0.17)	(0.02)	(0.16)	(0.08)	(0.13)
	R$_4$	3.80	5.53	7.70	8.04	8.20	6.23	5.46	4.59
		(0.11)	(0.10)	(0.08)	(0.10)	(0.13)	(0.12)	(0.12)	(0.16)
	R$_5$	4.94	7.62	10.08	16.66	18.13	9.08	6.98	5.58
		(0.10)	(0.04)	(0.08)	(0.22)	(0.14)	(0.09)	(0.15)	(0.02)
	R$_6$	5.39	12.11	17.70	19.96	20.63	11.14	6.93	6.30
		(0.08)	(0.68)	(0.25)	(0.34)	(0.43)	(0.08)	(1.25)	(0.14)
	R$_T$	17.25	17.46	11.13	9.84	7.12	6.07	5.36	4.92
		(0.15)	(1.78)	(0.21)	(0.08)	(0.08)	(0.14)	(0.06)	(0.08)

*Mean of three replications followed by standard error in parenthesis. ^{y}GM placement method.

Appendix 2a: Pot experiment: Probability of Pr >F-ratio for significant differences on the effect of *G. sepium* green manure placement method and Minjingu rock phosphate application on available phosphorus after laboratory incubation.

	Weeks after planting							
SoV	0	1	3	5	7	9	11	13
Block	0.1746	0.9252	0.6030	0.3836	0.6365	0.2381	0.8297	0.0705
Mthd	0.0861	0.0001	0.0001	0.0012	0.0001	0.008	0.0007	0.0001
Rts	0.0201	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Mthd*Rts	0.0001	0.0001	0.0001	0.0025	0.0001	0.5645	0.4862	0.7093

Appendix 2b: Probability of Pr >F-ratio for significant differences on the effect of *G. sepium* green manure placement method and rock phosphate application on available phosphorus at SUA Farm, Morogoro, Tanzania.

	Weeks after planting							
SoV	0	1	2	4	6	8	10	12
Block	0.9366	0.0659	0.3687	0.3895	0.3139	0.2290	0.9351	0.5207
Mthd	0.1951	0.0147	0.0001	0.0001	0.0001	0.8166	0.0639	0.1158
Rts	0.0401	0.0001	0.0001	0.0001	0.0001	0.0022	0.0001	0.0001
Mthd*Rts	0.6333	0.1506	0.0029	0.0001	0.0001	0.4833	0.7946	0.9843

Appendix 2c: Probability of Pr >F-ration for significant differences on the effect of *G. sepium* green manure placement method and Minjingu rock phosphate application on maize leaf phosphorus and nitrogen at SUAFarm, Morogoro, Tanzania.

SoV	LPCc	LNCc	LPCt	LNCt
Block	0.5649	0.0015	0.8303	0.2638
Mthd	0.0001	0.0448	0.0001	0.0001
Rts	0.0001	0.3307	0.0001	0.0002
Mthd*Rts	0.9953	0.9477	0.8152	0.9509

Note:

SoV = Source of variations; Mthd = Green manure placement method; Rts = Rates of MRP applications.

LPCc = leaf P Concentration; LNCc = Leaf N Concentration; LPCt = Leaf P Content; LNCt = Leaf N Content

Appendix 2d: Probability of Pr >F-ratio for significant differences on the effect of *G. sepium* green manure placement method and Minjingu rock phosphate application on maize phosphorus and nitrogen uptake at SUA Farm, Morogoro, Tanzania.

SoV	GrP	StvP	GrN	StvN	TP	TN
Block	0.0248	0.0586	0.0161	0.1031	0.0421	0.0130
Mthd	0.0001	0.0001	0.0001	0.0032	0.0001	0.0001
Rts	0.0001	0.0001	0.0217	0.3490	0.0001	0.0310
Mthd*Rts	0.9511	0.9154	0.9587	0.9456	0.9422	0.9968

Appendix 2e: Probability of Pr >F-ratio for significant differences on the effect of *G. sepium* green manure placement method and Minjingu rock phosphate application on maize growth and yield of maize at SUA Farm, Morogoro, Tanzania.

SoV	Height growth	Maize yield	
		Grain	Stover
Block	0.8994	0.0248	0.1293
Mthd	0.0001	0.0002	0.0037
Rts	0.0001	0.0031	0.4060
Mthd*Rts	0.8335	0.9607	0.9080

Note:

GrP = grain P uptake; GrN= grain N uptake; StvP = Stover P uptake; StvN= Stover N uptake; TP=Total P uptake; TN=Total N. SoV, Mthd, Rts as defined in Appendix 2a

Appendix 2f: Probability of Pr > F-ratio for significant contrasts on the effect of rates of Minjingu rock phosphate on concentration, content, and uptake of P and N, maize height growth and yield at SUA Farm, Morogoro, Tanzania.

Parameters		Pr > F-ration
Maize leaf P concentration	Linear	0.0001
	Quadratic	0.0001
Maize leaf P content	Linear	0.0001
	Quadratic	0.0001
Maize leaf N concentration	Linear	0.1062
	Quadratic	0.1757
Maize leaf N content	Linear	0.0007
	Quadratic	0.0001
Grain P uptake	Linear	0.0001
	Quadratic	0.0001
Grain N uptake	Linear	0.0048
	Quadratic	0.0045
Stover P uptake	Linear	0.0001
	Quadratic	0.0001
Stover N uptake	Linear	0.1578
	Quadratic	0.0919
Total P uptake	Linear	0.0001
	Quadratic	0.0001
Total N uptake	Linear	0.0091
	Quadratic	0.0019
Height	Linear	0.0001
	Quadratic	0.0001
Grain yield	Linear	0.0021
	Quadratic	0.0019
Stover yield	Linear	0.3526
	Quadratic	0.1449

Appendix 3: **Effect of *G. sepium* green manures placement method and Minjningu rock phosphate application on available phosphorus at Sokoine University of Agriculture Farm Morogoro, Tanzania.**

GM	Rates of	Weeks after incubation							
plm^{y}	MRP	0	1	2	4	6	8	10	12
M_0	R_1	0.79	3.48	2.16	1.94	1.40	1.58	1.37	1.41
		(0.04)	(1.58)	(0.06)	(0.28)	(0.08)	(0.28)	(0.15)	(0.21)
	R_2	1.41	1.60	2.83	3.38	1.77	1.93	1.37	1.30
		(0.57)	(0.12)	(0.14)	(0.07)	(0.12)	(0.06)	(0.34)	(0.02)
	R_3	1.99	3.13	3.65	5.93	2.26	2.72	1.34	1.72
		(0.09)	(0.20)	(0.13)	(0.13)	(0.06)	(0.51)	(0.12)	(0.37)
	R_4	2.35	2.96	6.49	7.77	2.33	2.53	1.67	1.72
		(0.10)	(0.89)	(0.10)	(0.28)	(0.04)	(0.30)	(0.14)	(0.32)
	R_5	2.59	4.36	7.12	12.34	8.30	2.35	1.20	2.16
		(0.16)	(0.10)	(0.31)	(0.10)	(0.14)	(0.32)	(0.35)	(0.36)
	R_T	4.79	5.60	4.98	3.96	2.54	2.14	1.30	0.90
		(0.11)	(0.18)	(0.08)	(0.14)	(0.18)	(0.12)	(0.21)	(0.09)
M_1	R_1	1.39	3.24	2.38	2.23	1.73	1.86	1.39	1.58
		(0.14)	(1.16)	(0.10)	(0.24)	(0.12)	(0.29)	(0.17)	(0.35)
	R_2	1.71	2.52	3.56	4.03	2.14	2.30	1.46	1.55
		(0.10)	(0.12)	(0.22)	(0.13)	(0.02)	(0.21)	(0.06)	(0.14)
	R_3	2.50	3.46	5.50	7.49	2.63	1.83	1.67	2.00
		(0.05)	(0.41)	(0.33)	(0.13)	(0.28)	(0.28)	(0.13)	(0.13)
	R_4	2.78	4.66	8.05	12.01	2.91	2.58	2.04	2.11
		(0.14)	(0.32)	(0.13)	(0.11)	(0.18)	(0.48)	(0.04)	(0.46)
	R_5	3.23	5.60	8.48	20.24	11.03	3.03	2.28	2.58
		(0.22)	(0.29)	(0.13)	(0.52)	(0.09)	(0.08)	(0.06)	(0.21)
	R_T	5.52	6.26	6.04	4.78	3.44	2.13	1.39	0.99
		(0.17)	(0.02)	(0.32)	(0.17)	(0.23)	(0.40)	(0.10)	(0.16)
M_2	R_1	1.32	1.96	2.28	2.21	1.61	1.81	1.01	1.30
		(0.08)	(0.10)	(0.04)	(0.31)	(0.11)	(0.14)	(0.14)	(0.04)
	R_2	1.35	3.37	3.68	3.98	2.14	2.23	1.53	1.46
		(0.06)	(0.52)	(0.06)	(0.06)	(0.06)	(0.39)	(0.12)	(0.10)
	R_3	2.57	4.17	5.50	7.42	2.56	2.04	1.48	1.41
		(0.11)	(0.38)	(0.16)	(0.02)	(0.05)	(0.39)	(0.04)	(0.24)
	R_4	2.55	5.23	8.05	12.03	2.96	2.96	1.69	1.76
		(0.07)	(0.44)	(0.10)	(0.30)	(0.12)	(0.39)	(0.08)	(0.18)
	R_5	3.21	5.67	8.52	19.89	10.99	2.82	1.88	2.39
		(0.11)	(0.41)	(0.04)	(0.17)	(0.21)	(0.11)	(0.06)	(0.19)
	R_T	4.88	6.17	5.85	4.99	3.58	2.02	1.39	0.97
		(0.24)	(0.14)	(0.37)	(0.11)	(0.20)	(0.10)	(0.19)	(0.17)

*Mean of three replications followed by standard error in parenthesis. ^{y}GM placement method.

Appendix 4: **Effect of *G. sepium* green manure placement method on maize leaf nitrogen and phosphorus at SUA Farm, Morogoro, Tanzania.**

GM placement method	Concentration (%)		Content (mg leaf^{-1})	
	P	N	P	N
M_0	0.1807c*	2.154b	4.491b	52.836b
	(0.008)	(0.038)	(0.327)	(2.124)
M_1	0.2005a	2.298a	5.835a	66.190a
	(0.007)	(0.053)	(0.313)	(2.279)
M_2	0.1908b	2.252ab	5.426a	63.431a
	(0.006)	(0.037)	(0.312)	(2.566)

*Mean of three replications followed by standard error in parenthesis. Means with the same letter in a given column are not significantly different (P>0.05).

Appendix 5: **Effect of *G. sepium* green manure placement method on maize phosphorus and nitrogen uptake at SUA Farm, Morogoro, Tanzania.**

GM placement method	P uptake (kg ha^{-1})		N uptake (kg ha^{-1})		Total uptake (kg ha^{-1})	
	Grain	Stover	Grain	Stover	P	N
M_0	4.59c*	1.15c	28.30c	7.04b	5.74c	35.34c
	(0.25)	(0.14)	(1.13)	(0.52)	(0.37)	(1.43)
M_1	6.22a	2.18a	37.82a	10.98a	8.40a	48.81a
	(0.34)	(0.21)	(1.72)	(0.99)	(0.52)	(2.34)
M_2	5.40b	1.76b	33.77b	9.59a	7.17b	43.36b
	(0.27)	(0.17)	(1.06)	(0.65)	(0.40)	(1.36)

*Mean of three replications followed by standard error in parenthesis. Means with the same letter in a given column are not significantly different (P>0.05).

Appendix 6: **Effect of *G. sepium* green manure placement method on growth and yield of maize at SUA Farm, Morogoro, Tanzania.**

GM placement Method	Height Growth (m)	Maize yield (t ha^{-1})	
		Grain	Stover
M_0	1.19b*	2.07c	2.57b
	(0.04)	(0.08)	(0.12)
M_1	1.34a	2.60a	3.33a
	(0.04)	(0.11)	(0.18)
M_2	1.37a	2.34b	2.98ab
	(0.04)	(0.08)	(0.13)

*Mean of three replications followed by standard error in parenthesis. Means with the same letter in a given column are not significantly different (P>0.05).