EXPLORING PHOSPHORUS, MUCUNA (*MUCUNA PRURIENS*) AND NITROGEN MANAGEMENT OPTIONS FOR SUSTAINABLE MAIZE PRODUCTION IN A DEPLETED KAOLINITIC SANDY LOAM SOIL OF ZIMBABWE

By

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Declaration

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Abstract

Continuous cropping without replenishing the nutrient component of soils will eventually lead to the depletion of soil nutrients. Small scale farmers in Zimbabwe often do not have the financial means to buy fertilizer and this problem is exacerbated by scarcity of commodities such as fertilizers. The use of herbaceous legumes such as mucuna (*Mucuna pruriens*) can assist to recapitalize soil fertility depletion and improve subsequent maize productivity in sandy loam soils in the small holder farming sector of Zimbabwe. In this study the effect of phosphorus (P) application to a mucuna crop, the effect of mucuna management options and the application of nitrogen (N) to the subsequent maize crop was investigated.

The experiment was carried out during the 2007 to 2009 seasons at the Grasslands Research Station in Marondera in Zimbabwe. The soils are classified as humic ferrolsols and are predominantly of the kaolinitic order with sandy loams of low fertility and are slightly acid ($pH_{CaCl} =$ 5.2). A randomized complete block design was used for the effect of P on mucuna productivity and the effect of P and mucuna management options on the soil properties. The treatments were two P rates (P0 and P40 = 0 kg P ha^{-1} and 40 kg P ha^{-1} respectively) applied to a preceding mucuna crop, four mucuna management options [1) fallow (F) (no mucuna planted = control), 2) mucuna ploughed-in at flowering (MF), 3) all mucuna above ground biomass removed at maturity and only roots were ploughed-in (MAR) and 4) mucuna pods removed and the residues ploughed-in (MPR)]. A split-plot design was used to study the effect of P application to mucuna, mucuna management options and N rates on the growth and yield of the subsequent maize crop. The four N treatments [N0 = 0 kg N ha^{-1}, N40 = 40 kg N ha^{-1}, N80 = 80 kg N ha^{-1} and

N120 = 120 kg N ha^{-1}] were applied to a subsequent maize crop. Growth and development parameters such as biomass production, leaf area index, nutrient content of the foliage and grain yield were determined in the mucuna and maize crops. Soil parameters investigated included nutrient content, pH, bulk density and porosity.

Phosphorus application in these particular soil conditions positively influenced mucuna biomass production and therefore enhanced the role of mucuna as a rotational crop by increased positive effects on the subsequent maize crop. The incorporation of above-ground biomass of mucuna had positive effects on all soil properties investigated. The MF and MPR management options increased the soil organic matter (OM) and reduced bulk density which leads to an improvement in porosity (f) of the soil. Mucuna incorporated at flowering (MF) and P40 treatment combination resulted in the highest mineral N, P, potassium (K), calcium (Ca) and magnesium (Mg) levels.

A significant three-way interaction ($P<0.05$) between mucuna management options, nitrogen rates and time was observed in terms of biomass production and all nutrients in the leaves of the subsequent maize crop. The main findings were that the MF management option had the highest biomass and foliar nutrient accumulation through-out all the treatment combinations. In general the MF management option gave the highest maize yield across all the treatment combinations.

Incorporation of mucuna biomass into the soil prior to planting a maize crop therefore improve soil physical and chemical qualities resulting in improved soil conditions for a subsequent maize crop which in turn lead to higher maize yields. Including a mucuna rotational crop have a similar effect on maize yield than application of 80 kg ha^{-1} of fertilizer N.

Opsomming

Aanhoudende verbouing van gewasse op dieselfde grond sonder om voedingstowwe aan te vul lei uiteindelik tot die agteruitgang van die grond se vrugbaarheid. Kleinboere in Zimbabwe het meestal nie die finansiële vermoëns om bemestingstowwe te koop nie en die probleem word vererger deur die onbekombaarheid van kommoditeite soos bemestingstowwe. Die gebruik van kruidagtige peulplant gewasse soos mucuna (*Mucuna pruriens*) kan bydra om grondverarming teen te werk en om die produksie van ‘n daaropvolgende mielie aanplanting in sandleemgronde in ‘n kleinboerstelsel in Zimbabwe te verhoog. In hierdie studie is die invloed van fosfor (P) toediening aan ‘n mucuna aanplanting, die invloed van bestuursopsies van die mucuna en die toediening van stikstof (N) aan die daaropvolgende mielie aanplanting ondersoek.

Die eksperiment is tydens die 2007 tot 2009 reënseisoen by die Grasslands Research Station in Marondera in Zimbabwe uitgevoer. Die grond word geklassifiseer as humiese ferrolsols en is hoofsaaklik sanderige leemgrond van die kaolinitiese orde met lae vrugbaarheid en is effens suur (pH $_{CaCl\,=}$ 5.2). ’n Volledig ewekansige blokontwerp is gebruik om die invloed van P op die produktiwiteit van mucuna te bepaal asook die invloed van P toediening en mucuna bestuursopsies op grondeienskappe. Die behandelings was twee P vlakke (P0 = 0 kg P ha^{-1} en P40 = 40 kg P ha^{-1}) wat aan ‘n voorafgaande mucuna aanplanting toegedien is, vier mucuna bestuursopsies [1) braak (F) (geen mucuna geplant = kontrole), 2) mucuna ingeploeg met blomtyd (MF), 3) alle bogrondse mucuna biomassa verwyder by rypwording en slegs wortels ingewerk (MAR) en 4) mucuna peule verwyde en die res van die bogrondse material ingeploeg (MPR)] en vier N behandelings [N0 = 0 kg N ha^{-1}, N40 = 40 kg N ha^{-1}, N80 = 80 kg N ha^{-1} en N120 = 120 kg N ha^{-1}] toegedien aan ‘n daaropvolgende mielie aanplanting. Groei en ontwikkeling parameters soos biomassa produksie, blaaroppervlakindeks, nutriëntinhoud van die blare en graanopbrengs is in die mucuna en mielie aanplantings ondersoek. Grondeienskappe soos nutriëntinhoud, pH, bulkdigtheid en porositeit is gemeet.

Fosfaat toediening aan hierdie spesifieke grondtipe het mucuna produksie positief beïnvloed en dus die rol van mucuna as rotasiegewas verbeter deur positiewe reaksies in die daaropvolgende mielie aanplanting. Die inwerk van bogrondse mucuna biomassa het al die fisiese grondeienskappe wat ondersoek is positief beïnvloed. Die MF en MPR bestuursopsies het organiese materiaal inhoud van die grond verhoog en bulkdigtheid verlaag wat lei tot verbeterde grondporeusheid (f). Mucuna wat tydens blomvorming ingewerk is (MF) lei tot die hoogste minerale N, P, kalium (K), kalsium (Ca) en magnesium (Mg) vlakke.

'n Betekenisvolle drie-rigting interaksie ($P < 0.05$) tussen mucuna bestuursopsies, N vlakke en tyd is waargeneem in terme van biomassa produksie en in terme van al die nutriëntvlakke in die mielieblare wat ondersoek is. Die hoofbevindinge was dat die MF bestuursopsie die hoogste biomassa produksie en blaarnutriënt akkumulasie oor alle behandelingskombinasies tot gevolg gehad het. In die algemeen het die MF bestuursopsie die hoogste mielie-opbrengs oor alle behandelingskombinasies tot gevolg gehad.

Die inwerk van mucuna materiaal in die grond voordat mielies geplant word verbeter dus fisiese en chemiese toestande in die grond wat grondtoestande verbeter vir die daaropvolgende miegewas en uiteindelik lei tot hoër mielie-oeste. Die insluiting van mucuna as 'n rotasiegewas het diesefde effek op mielie-opbrengs as die toediening van 80 kg ha^{-1} N bemesting.

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Chapter 1: General Introduction

The small-holder farming regions in Sub Saharan Africa (SSA) are densely populated and are intensively cropped resulting in soil fertility decline, reduction in cereal yield and agricultural sustainability problems (Stoorvogel *et al.,* 1993; Smaling *et al.,* 1997; Govaerts *et al*., 2007). Monoculture cereal production systems have also contributed to serious decline in soil fertility (Fisher *et al.,* 2002). In the past, long term fallows were used to improve soil fertility. However with the current population pressure, the use of long term fallows has become unsustainable (Smaling *et al.,* 1997).

The above problems did not spare Zimbabwe. Currently most small holder farmers do not practice proper fallowing and the fallows are too short to effectively restore soil fertility. Fertilizer use is very low because it is unaffordable. On average farmers in SSA use 8.4 kg ha^{-1} of plant nutrients, far short of what is needed to compensate for the harvested nutrients (Sanchez & Palm, 1996). The current economic problems and critical shortages of fertilizers have led to a shift to other sources of nutrient replenishment such as green manure and crop sequencing.

Most small holder farming areas of Zimbabwe are characterized by fragile soils that are deficient in major nutrients such as nitrogen and phosphorus and are low in organic matter (Tagwira *et al*., 1991; Piha, 1993). They are derived from granites and are thus sandy and inherently infertile (Grant, 1981). The clay mineralogy is predominantly 1:1. This ratio shows poor cation exchange capacity (CEC) and very acidic pH (Nyamapfene, 1991; Hussein, 1997). These soil conditions have a negative impact on the yield of maize.

The perennial droughts that have affected Zimbabwe since 1982 have almost wiped out all the livestock in most communal lands. The depletion in livestock numbers has seen manure production dwindling in most households in Zimbabwe. Low manure levels have resulted in depleted soil nutrition (Tagwira *et al.,* 1991). The current shortages of fertilizers have also hit hard on the nutrient recapitalization in the small holder farming sector. The above scenario has affected the production levels of major crops like maize.

With low manure production levels and scarcity of fertilizers at play there is need to turn to long term organic sources of nutrients. The use of herbaceous legumes such as mucuna (*Mucuna pruriens*) can help to recapitalize nutrient deficiencies in the small holder farming sector of Zimbabwe. Herbaceous legumes help in building up soil fertility through litter fall, which will be returned to the soil during decomposition and fixation of atmospheric nitrogen (Sanchez & Palm, 1996; Rao & Suresh, 1999). Mucuna has the capacity to establish ground cover rapidly, produce a large above ground biomass and accumulate nutrients with consequent beneficial impacts on main crop yield in various environments (Eilita *et al*., 2003).

Unlike inorganic sources of nutrients, organic sources may not release nutrients to coincide with crop demand and uptake (Swift, 1987; Mafongoya & Nair, 1997). Syncronization of the nitrogen (N) supply and demand will lead to increased N-use efficiency by minimizing the opportunity for N loss (Woomer & Swift, 1995; Shoko, *et al*., 2007).

1.1 Rationale of study

Most work done on mucuna focuses on its importance as a source of N. Nitrogen use efficiency is also governed by the dynamics and availability of other factors such as phosphorus (P), organic matter and pH. Therefore there is need to study the dynamics of phosphorus, organic matter, pH, soil physical properties and some trace elements in a mucuna-maize production system on kaolinitic sandy loam soils in Zimbabwe. The study of most sustainable phosphorus, mucuna and nitrogen interaction for maize production will help to close the information gaps and will hopefully provide motivation for a much wider acceptance of mucuna in farming systems in Zimbabwe.

1.2 Main hypotheses

1. The use of P does not affect the productivity of mucuna on a sandy loam soil.
2. There is no effect of P rate, mucuna management option and N rate on maize production.

1.2 Objectives

The main objective of the study was to assess the effect of P, mucuna management options and N on maize production on a kaolinitic sandy loam soil in Zimbabwe. The specific objectives, the integral of which will give answers to the main objective were:

1. To investigate the effects of P on the productivity of mucuna on depleted sandy loam soil in Zimbabwe.
2. To assess the effect of P and mucuna management option on the physical and chemical properties of a depleted sandy loam soil in Zimbabwe.
3. To explore the effect of P, mucuna management option and N on the production of the subsequent maize crop on a depleted sandy loam soil in Zimbabwe.

1.3 Thesis outline

This thesis is written in form of publications and hence each chapter will have its own Materials and Methods section. There are no General Materials and Methods section. Therefore the materials and methods section of the chapters contain duplication because of the format of the thesis.

Chapter 2 reports on the literature study. In Chapter 3 the effect of P on mucuna productivity is described. The sub-hypothesis tested in this Chapter is: "P does not affect productivity of mucuna on a sandy loam soil". In Chapter 4 the effect of P and management options of mucuna on the soil physical properties, pH and organic matter is described. The sub-hypothesis tested in this Chapter is: "P and mucuna management options do not affect physical properties, pH and organic matter of the sandy loam soil in Zimbabwe". Only two P levels were used since the study is focusing on the effect of P or no P on the subsequent maize crop. The effect of P and mucuna management options on the soil chemical properties is documented in Chapter 5. The sub-hypothesis tested is: "P and mucuna management options do not affect soil chemical properties".

Chapter 6 studies the effect of P rate, mucuna management option and N rate on the biomass, leaf area index and foliar nutrient content of the subsequent maize crop on a depleted sandy loam soil. The sub-hypothesis tested is: “P, mucuna management options and N do not influence the biomass, leaf area index and foliar nutrient content of maize on a sandy loam soil”. In Chapter 7 the effect of P rate, mucuna management option and N rate on the yield and yield components of the subsequent maize crop on a depleted sandy loam soil is reported. The sub-hypothesis tested is: “P, mucuna management options and N do not influence the yield and yield components of the subsequent maize crop on a depleted sandy loam soil.” The study’s overall discussions, conclusions and recommendations are made in Chapter 8.

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Chapter 2: Literature study

2.1 Cereal-legume cropping systems

Soil fertility management is now priority in African agricultural development policies. A decline in soil fertility across sub-Saharan Africa is evident and characterised mainly by nutrient mining and soil degradation (Stoorvogel & Smaling, 1990; Van der Pol, 1992; Scoones & Toulmin, 1999; Hilhorst & Muchena, 2000).

The use of legumes in mixed cropping systems is one of the traditional soil-fertility maintenance strategies (Nyambati, 1997). The most common production systems of integrating legumes into cropping systems include the following: simultaneous intercropping, relay intercropping, rotations and improved fallows (Weber, 1996). The use of legumes in cropping systems offers considerable benefits because of their ability to ameliorate soil fertility decline through fixation of atmospheric N and improve the yield of the subsequent crops (Weber, 1996; Giller *et al*., 1997; Shoko, *et al*., 2007).

Two mechanisms have been postulated by which cereal crops benefit from legumes in these multiple cropping systems (Giller *et al*., 1991; Giller *et al*., 1994; Giller & Cadisch, 1995): (1) through immediate transfer in which N travels from the legume directly to the associated crop, and (2) through residual effects in which N fixed by the legumes is available after senescence of legume residues to an associated sequentially cropped non-legume. It is generally believed that the second mechanism is more important. Shoko and Tagwira (2005) also noted that legumes have the potential to improve soil pH and the availability of OM exchangeable bases and some trace elements such as Zn and Cu. According to Ledgard and Giller (1995), nutrient benefits of these systems may accrue more to subsequent crops after root and nodule senescence and decomposition of fallen leaves. However, these grain legumes contribute little or no N to associated cereal crops because a large proportion (60-70%) of the N is removed during grain harvest (Giller *et al*., 1998). The use of forage legumes in many parts of the tropics is limited because they do not contribute directly to the human food supply.

2.2 Replenishing soil fertility

Low soil fertility due to monoculture cereal production systems is recognized as one of the major causes for declining per capita food production in SSA (Sanchez *et al*., 1997). Nutrient balance studies in SSA have shown that on a hectare basis an average of 22 kg N, 2.5 kg P and 15 kg K are lost annually (Sanchez *et al*., 1997). The losses can be as high as 112 kg N, 3 kg P and 70 kg K in the intensely cultivated lands (Stoorvogel *et al*., 1993; Sanchez *et al*., 1997; Van den Bosch *et al*., 1998). These losses are much higher than the estimated inorganic fertilizer use in Africa of 5 to 10 kg (FAO, 1995; Heisey & Mwangi, 1996). This emphasizes the need for soil fertility replenishment in SSA. Sustainable crop production in many soils of sub-Saharan Africa requires high nutrient inputs because the soils are either derived from parent material with low levels of essential nutrients like P and Zn or have been depleted of available P through continuous cropping with insufficient P inputs (Sanchez *et al*., 1997). The Oxisol soils that are widespread in this region have a major chemical constraint of high P fixation (Deckers *et al*., 1994). The low native soil P, high P fixation by soils with high Fe and Al concentration and nutrient depleting effects of long-term cropping without additions of adequate external inputs have contributed to P deficiencies in many tropical soils (Jama *et al*., 1997; Tisdale *et al*., 1999). Phosphorus can be replenished either immediately with high, one-time P application in soils with high P-sorption capacity, or gradually with moderate seasonal applications at rates sufficient to increase P availability in soils with low to moderate P-sorption capacity (Buresh *et al*., 1997). The combination of P and N replenishment may have a synergistic effect.

The elimination of P deficiency can enhance N_2 fixation by legumes (Giller *et al*., 1997; Palm *et al*., 1997). Application of organic materials such as legume residues may increase crop-available P either directly by the process of decomposition and release of P from the biomass or indirectly by the production of organic acids (products of decomposition) that chelate Fe or Al, reducing P fixation (Nziguheba *et al*., 1998). Palm *et al*. (1997) showed that whereas mucuna contains sufficient N in 2 or 3 t of leafy material to match the requirement of a 2-t crop of maize, they cannot meet the P requirements and must be supplemented by inorganic P in areas where P is deficient. Jama *et al*. (1997), working in western Kenya, indicated that it was economically attractive to integrate superphosphates (SP) with *Mucuna pruriens*. Having high N to P ratios, the organic material provides the required N for the crop and the SP meets the additional requirement for P.

Although inorganic fertilizers are the most effective amendments to maintain soil fertility or alleviate nutrient deficiencies, their high cost, inaccessibility and strict recommendations limit their use, particularly by smallholder farmers in SSA (Vlek, 1993; Nandwa & Bekunda, 1998). Continuous use of fertilizer alone cannot sustain crop yield and maintain soil fertility in the long-term because of soil acidification, loss of soil organic matter and soil compaction (Tisdale *et al*., 1999; Shoko *et al*., 2007).

Juo *et al*. (1995a; 1995b) and Kang (1993), working on an Alfisol soil in Nigeria, reported a soil pH decline from 6.2 to 5.1 during 10 yr of maize continuous cropping with the annual application of 160 to 200 kg N ha^{-1}. Several other examples of acidification and the decline of soil organic matter and exchangeable nutrients in sub-Saharan Africa are given in a review by Franzluebbers *et al*. (1998).

2.3 Factors affecting biological nitrogen fixation

The most important factors influencing the quantity of N fixation by rhizobia are soil pH, mineral nutrient status, photosynthetic activity, climate and legume management (Tisdale *et al.*, 1999). Soil acidity can restrict the survival and growth of rhizobia (Tisdale *et al.*, 1999). According to Giller and Wilson (1993) soil acidity affects nodulation and N fixation processes. Soils which are acid contain aluminum, manganese and hydrogen ions which injure rhizobia and legume roots (Tisdale *et al.*, 1999; Chien, 2001; Shoko *et al*., 2007).

A high rate of photosynthetic production is strongly related to increased N fixation by rhizobia (Poppi & Norton 1995; Chien, 2001). Factors that reduce the rate of photosynthesis will reduce N fixation. These factors include reduced light intensity, moisture stress and low temperature (Tisdale *et al*., 1999). Maximum amounts of N are added when legumes are incorporated at flowering (Mpepereki *et al.*, 1999). This is so because there is no N partitioning into the seed. Seed is the biggest N sink in legumes (Shoko & Tagwira, 2005). Giller and Wilson (1993) found that the yields of subsequent crops are higher after green manuring than after dry harvested legumes if the soils has been monocropped for several years.

2.4 Synchrony between mineralized nutrients and their uptake

The efficiency of transferring N from a legume green manure to the succeeding crop depends on synchronizing the N release from the legume residue with the demand of the recipient crop. The plant species and management practices have a great influence on the success of this synchronization, and N mineralization is also affected by moisture, temperature and soil factors such as texture, mineralogy, acidity, biological activity and the presence of other nutrients (Myers *et al.*, 1994). Uptake of N and other nutrients by maize continues until near maturity, but the highest demand for N is at the start of the reproductive stage (R1) when grain filling is initiated to R6 at physiological maturity (Karlen *et al.,* 1988). The fraction of total N added that is taken up by the crop is known as the N recovery value (NIV). The reported NIV values for most organic residues are in the range 10 to 30% by the first crop (Giller & Cadisch, 1995; Mafongoya & Nair, 1997) and between 2 and 10% by the second crop (Mafongoya & Nair, 1997). Factors influencing the synchrony and therefore NIV from organic manures by annual crops include type of species, biomass quality and method and time of application (Mafongoya *et al*., 1997; Tian *et al*., 2000). Giller and Cadisch (1995) reported that approximately 20% of the N from high quality green manure residue is recovered by the first crop.

Incorporation of the legume residue improves N recovery compared to surface placement (Mafongoya & Nair, 1997). This has been attributed to elimination of N losses through ammonia volatilization (Giller and Cadisch, 1995). Van Noordwijk and Purnomosidi (1992) found that N uptake by maize following mucuna was 147 kg ha^{-1} higher than the control crop, while the N content of live biomass incorporated was only 71 kg ha^{-1}. They attributed this to the large amount of litter fall during the growth period, a quantity that exceeded the live biomass measured at the end of the growth period (Van Noordwijk & Purnomosidi, 1992).

2.5 Fallows involving forage legumes

The potential of forage legumes like *Mucuna pruriens* to increase the productivity of crop-livestock systems has received increased attention in recent years because declining soil fertility and scarcity of livestock feeds are major constraints limiting agricultural productivity in these systems (Nnadi & Haque, 1988).

In reviewing the effect of forage legume fallows on subsequent crops in sub-humid West Africa, Scoones and Toulmin (1999) found that maize following *Stylosanthes* had greater grain yields than maize following natural fallows, but the responses varied depending on species of the fallow legume. These positive effects were attributed to improved soil properties such as soil bulk density, soil moisture retention, cation exchange capacity (CEC), organic C and soil N (Mpepereki *et al*., 1999; Tisdale *et al*., 1999).

Studying the rotational effects of forage legumes, Muhr *et al*. (1999) found that even though large amounts of N, P and K (up to 120, 10 and 135 kg ha^{-1}, respectively) were removed as dry season herbage, nutrient accumulation in the remaining biomass increased grain yields of subsequent maize grown on the legume plots. The nutrient export in legume fallow biomass removed in the preceding dry season apparently did not preclude the subsequent yield response of maize, but responses varied depending on the sites' fertility status (Nyambati *et al*., 2002).

Green manure legumes grown in rotation with cereal crops have the capacity to provide high quality organic inputs to meet N demands of subsequent crops (Carsky *et al*., 1999; Tian *et al*., 2000). However Drechsel *et al*. (1996) argue that incorporating these non-food legumes in the farming system requires a sacrifice of land and labour that is normally devoted to crop production.

Reviewing studies on organic matter technologies for integrated nutrient management in smallholder farming systems of southern Africa, Snapp *et al*. (1998) concluded that the use of mucuna as rotational crop with maize has a lower N yield potential as compared to fallow systems. On-farm research in West Africa has shown that integration of these legumes into the farming systems and adoption by farmers could be improved if the legumes have multiple uses (Becker, 1995; Becker & Johnson, 1998; Versteeg *et al.*, 1998a).

2.6 Potential of mucuna as a fallow crop

It is estimated that N fixation ranging from 0 to 250 kg N ha^{-1} can be achieved from herbaceous legumes (Sanginga *et al.*, 1996a; Ibewiro *et al.*, 2000b). The contributions of legume residues to soil improvement and crop production depend largely on the amount of biomass produced, chemical composition and method of application (Sanginga *et al.*, 1996a; Mafongoya & Nair 1997; Palm *et al.*, 1997; Tian *et al.*, 2000; Shoko *et al.*, 2007).

Hairiah and Van Noordwijk (1989) reported that in a growth period of 14 weeks (wk) on an acid soil in Onne, Nigeria, mucuna contributed 110 kg N ha^{-1}. Work done by Mandimba (1995) in Brazzaville, Congo showed that mucuna incorporated at flowering as green manure increased the grain yield of maize up to 56% (to a total of 3.6 t ha^{-1}) compared to a control that did not receive any N fertilizer (2.3 t ha^{-1}). This was comparable to the yields of maize fertilized with 100 kg N ha^{-1} (3.7 t ha^{-1}). Based on survey information, in Honduras, Mausolff & Farber (1995) estimated that use of mucuna as a cover crop combined with a fifth of the recommended inorganic fertilizer increased maize grain yield from 0.7 to 2 t ha^{-1} and reduced cost per hectare by 22%.

Sanginga *et al.* (1996a) reported that when mucuna was fertilized with P in West Africa, it accumulated about 166 kg N to 310 kg N ha^{-1} in 12 wk. Sanginga *et al.* (1996a) also indicated that mucuna derived 70% of its N from atmospheric N, representing 167 kg N ha^{-1} 12 wk^{-1} in the field. Mucuna intercropped in maize obtained a greater proportion of its N (74%) from fixation than did mucuna planted alone (66%), suggesting that competition for soil N influences the proportion of N fixed by mucuna. Maize succeeding a sole crop of mucuna resulted in a maize grain yield equivalent to that obtained with 120 kg N ha^{-1} of inorganic fertilizer (Sanginga *et al.*, 1996b).

In an on-farm study in a derived savanna of West Africa, Versteeg *et al.* (1998a) indicated that when mucuna was used as an annual fallow cover crop, it produced a biomass of 6 to 12 t ha^{-1} and improved subsequent maize grain yields by 70% compared to yields from continuously cropped maize. There was also an increase in the succeeding maize growth parameters (height, leaf area, dry matter production, ear-leaf N concentration) compared to monoculture maize. However an N supplement of 40 kg ha^{-1} had a higher response than any of the monoculture system (Akobundu *et al*. 2000).

Working in a derived savanna of West Africa and sub-humid highlands of East Africa respectively, Carsky *et al*. (1999) and Wortmann *et al*., (2000) evaluated various management options of mucuna to improve fallows and recorded that maize yield was higher where N supplement was applied on mucuna which was ploughed under at flowering than in non-cropped fallows. The use of herbaceous legumes like mucuna as a fallow crop in maize production system showed some promising improvement in concentrations of Ca, Zn, Cu, Fe, B and Mo in the grain and vegetative biomass (Chabi-Olaye *et al*., 2006). Soil pH and exchangeable Ca were not reduced during a 15-year period of continuous mucuna production.Soil organic matter (SOM), infiltration and porosity increased with continuous mucuna use (Chabi-Olaye *et al*., 2006; Wang *et al*., 2006).

2.7 Adaptation characteristics of mucuna

Mucuna tolerates low soil fertility, acidic soils and drought conditions (Hairiah *et al*., 1991; Burle *et al*., 1992; Weber, 1996), properties which indicate its potential for surviving and producing biomass during the drier part of the year. In reviewing the challenges for research and development of legume-based technologies for the African savannas, Weber (1996) concluded that mucuna is among the species adapted to cropping systems in sub-Saharan Africa (Maasdorp & Titterton, 1997).

When used as a cover crop, mucuna has a nematicidal effect (McSorley *et al*., 1994) as well as the ability to smother weeds (Fujii *et al*., 1992; Becker & Johnson, 1998; Versteeg *et al*., 1998a), particularly broad leaved weeds (Hepperly *et al*., 1992). In West Africa, the ability of mucuna to control a local weed, *Imperata cylindrica*, seemed to have a major influence on its adoption (Weber, 1996; Versteeg *et al*., 1998a), indicating that farmer adoption of cover crop/green manure technology may not only be based on agronomic yield, but other factors/uses may also be important (Becker *et al*., 1995).

2.8 Effect of mucuna underground and aboveground biomass on subsequent crop

It is estimated that roots may be the source of 30 to 60% of the C in the soil organic pool (Heal *et al*., 1997). It is estimated that nodulated legume roots contain 15 to 50 kg N ha^{-1} (Unkovich *et al*., 1994; Ibewiro *et al*., 1998). This amount of root N represents < 15% of total plant N (Peoples *et al.*, 1995). On an acid soil, 6-wk-old mucuna had a shallow root system (within 15 cm) and a shoot:root ratio of 6.7:1 (Hairiah *et al*., 1992). Roots contributed only 2 kg N ha^{-1} compared to above-ground biomass that contributed 21 kg N ha^{-1}. Work carried out in Zimbabwe by Muza (1998) reported that mucuna roots contained lower N concentrations (1.38%) compared to above-ground biomass (1.96%). However Tian and Kang (1998) found that roots of mucuna contained higher N concentration (2.62 %) compared to shoots (1.66 %). The lignin concentrations in the roots of mucuna were higher (24.5%) than in the shoot (7.2%) (Tian & Kang, 1998). Conversely the roots contained lower polyphenol concentrations (0.63%) than shoots (3.54 %). The higher lignin concentration in roots suggests that, in combination with shoot stubble, the remaining biomass after removal of the top canopy may be of low quality (Nyambati, 1997). Smyth *et al*. (1991) observed lower yields and N accumulation by maize when mucuna roots were incorporated into the soil compared to whole biomass incorporation and attributed this reduction to the removal of the N in above-ground biomass. Smyth *et al*. (1991) found an increase in maize grain yield of 0.8 t ha^{-1} when mucuna roots were incorporated compared to a zero-N treatment.

Oikeh *et al*. (1998) working in either low or high fertility sites in a moist tropical savanna, showed that independent of the differences in soil fertility, N uptake and N partitioned into grain, stover, and cob were 20% higher after legume-maize rotations than in maize monocrops. Ibewiro *et al*. (1998) studied the N contribution of mucuna, lablab, cogongrass and maize roots, shoots, and whole-plant biomass to succeeding maize. They showed that although N contribution from mucuna roots was only 3 and 4% of the total N, their incorporation resulted in maize grain yield that was 38 % of the yield obtained when whole residue was incorporated. Significant increases in maize yields following mucuna even when mucuna was burned to ease land preparation (Vine, 1953) supports the hypothesis that below-ground parts may contribute significant N to subsequent maize. Despite the availability of data on the contribution of whole-plant biomass incorporation, more information is needed on the contribution of below-ground biomass plus stem-stubble and litter to succeeding maize (Ibewiro *et al*., 2000a).

2.9 Anti-nutritive factors of mucuna

Although mucuna seed has a high protein concentration and its quality is comparable to that of soybean (Ravindran & Ravindran, 1988), it contains a toxic chemical [3, 4-dihydroxyphenyl alanine (Levodopa, or L-Dopa)] (Lorenzetti *et al*., 1998; Siddhuraju & Becker, 2001). L-Dopa can be toxic to humans if consumed at levels above 1.5 g d^{-1} (Lorenzetti *et al*., 1998; Nyambati *et al*., 2002). It has been reported that the oxidation products of L-Dopa conjugate with SH group of proteins (cystein) forming a protein bound 5-S43 cysteinnyldopa cross links, leading to polymerization of proteins (Takasaki & Kawakishi, 1997). A procedure to prepare detoxified mucuna flour is available (Versteeg *et al*., 1998b), but this may demand extra labor. Mucuna seed was extensively used in the southern USA as part of a ration for cows at the beginning of the last century (Tracy & Coe, 1918) and no toxic effects were observed, suggesting that the L-Dopa in mucuna forage may have minimal detrimental effects on ruminant animals. Mucuna contain other anti-nutritional factors such as polyphenols, tannins, trypsin inhibitor activity, cyanogenic glycosides and hemaglutanating activities (Rajaram & Jonardhanan, 1991).

2.10 Integrated nutrient management for the improvement of maize productivity

Integrated Nutrient Management (INM), which seeks to maximize the complementary effects of mineral and organic nutrient sources is emerging as an important approach in improving soil productivity of smallholder farming systems (Smaling *et al*., 1996; Palm *et al*., 1997; Fanzluebbers *et al*., 1998). The INM concept is based on the premise that the decline in soil productivity can be attributed in part to the negative nutrient budgets (the amount of nutrients removed compared to the amount of nutrients being put into the system) in most agricultural production systems in sub-Saharan Africa (Smaling & Braun, 1996). Thus, under maize monoculture production systems recycling of nutrients from organic sources alone may not be sufficient to sustain crop yield. Nutrients exported from the soil through harvested biomass and lost from the soil through various processes such as soil erosion, leaching, and denitrification must be replaced with nutrients from external sources (Cahn *et al.*, 1993; Swift *et al.*, 1994a).

Several long-term experiments conducted in SSA have shown that a combination of inorganic fertilizers and organic manures slowed the decline in soil organic matter after continuous cropping compared to when inorganic fertilizers were used alone or when no inputs were used (Swift *et al.*, 1994b; Kapkiyai *et al.*, 1999). Studies in Zimbabwe on N mineralization from poor quality manures have shown that decomposition of these manures can lead to N immobilization and that N availability can be increased by supplementing with leguminous inorganic sources of N like mucuna (Murwira & Kirchmann, 1993). Akobundu *et al.* (2000) showed that applying a low fertilizer rate (30 kg ha^{-1} N, P, and K) with mucuna residue, significantly increased maize grain yield in a moist savanna of West Africa. In reviewing results on the combined use of organic and inorganic nutrient sources in sub-Saharan Africa, Palm *et al.* (1997) concluded that high and sustained crop yields can be obtained with judicious use of organic residues combined with inorganic fertilizers. They attributed this advantage to enhanced synchrony of nutrient release and demand by the recipient crop, increased nutrient-use efficiency and residual effects of soil organic matter associated with combined nutrient additions compared to inorganic fertilizers applied alone.

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Chapter 3

The effect of P on the productivity of mucuna *(Mucuna pruriens)* on a depleted sandy loam soil in Zimbabwe

Abstract

Positive responses to increased soil phosphorus (P) supply have been noted for several leguminous species including mucuna (*Mucuna pruriens*). The major objective of this research was to investigate the effect of two P levels on the productivity of mucuna on a depleted kaolinitic sandy loam soil in Zimbabwe. Two P treatments [P0 = 0 kg P ha^{-1} and P40 = 40 kg P ha^{-1}] were applied prior to planting a mucuna crop. The following parameters were investigated; biomass, leaf area index (LAI), nodulation data, nitrogen (N) fixed, foliar nutrient dynamics and yield and yield quality. The P40 treatment resulted in significant increases in biomass, leaf area index, nodulation and N fixation compared to the P0 treatment. The foliar N, P and calcium (Ca) content also increased significantly in the P40 treatment compared to the P0 control while magnesium (Mg) and potassium (K) levels were not significantly different. The final pod yield and overall pod quality was also higher in the P40 treatment compared to the P0 treatment. These results imply that P application in these particular soil conditions will positively influence mucuna production and therefore enhance the role of mucuna as a rotational crop by increased positive effects on the subsequent maize phase.

***Keywords**:* mucuna, N fixation, phosphorus, smallholder farmer

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Introduction

Phosphorus (P) is an essential macronutrient for legume growth and function (Ribet & Drevon, 1996). The P requirements of host plants for optimal growth and symbiotic nitrogen fixation processes have been assessed by determination of nodule development and functioning (Sa & Israel, 1991; Israel, 1993). The influence of P on symbiotic nitrogen fixation in mucuna (*Mucuna pruriens*) has received considerable attention, but its role in the process still remains unclear (Hairiah *et al.,* 1995). Robson and O'Hara (1981) concluded that P nutrition increased symbiotic nitrogen fixation in most legumes by stimulating host plant growth rather than by exerting specific effects on rhizobial growth or on nodule formation and function.

Decreased specific-nitrogenase activity in nodules of P deficient legume plants was associated with decreased energy status of host plant cells of nodules (Valverde *et al.,* 2002). These latter observations imply specific involvement of P in symbiotic nitrogen fixation (Israel, 1987; Ribet & Drevon, 1996; Valverde *et al.*, 2002). However, the mechanism to convert inorganic P into different forms of organic P is not known, especially concerning the formation and functioning of symbiotic nodules (Vadez *et al*., 1997).

Nodulation, growth and development and yield of legumes is stimulated by exogenous P supply (Jakobsen, 1985; Sanginga *et al.,* 1996; Gentili & Huss-Danell, 2002). Kolawole and Kang (1997) found that P fertilization increased above-ground biomass, root DM biomass, nodulation and concentrations of nitrogen (N), P, potassium (K), calcium (Ca), magnesium (Mg) and zinc (Zn) of various legumes. The large increase in nodule mass caused by an increase in P levels is due to increased nodule numbers per plant and increased average mass of individual nodules. This enhances N fixation and increases legume biomass and yield (Valverde *et al.*, 2002).

Mucuna is a trailing legume species which can be utilized as a mulch crop, fodder crop or green manure crop (Maasdorp & Titterton, 1997; Muhr *et al.,* 1999). Work done by Hikwa *et al.* (1998) on depleted soils in Zimbabwe reported average mucuna biomass yields of 4.1 t ha^{-1} in a season with P application and 3.3 t ha^{-1} without P application. Work done in West Africa in a sandy soil by Muhr *et al.* (1999) showed that mucuna can produce biomass ranging from 4 to 6 t ha^{-1} in 25 weeks with P supplementation while

Maasdorp and Titterton (1997) who worked in Zimbabwe on a reddish brown clay soil observed mucuna biomass production of 2 – 4 t ha^{-1} in 18 weeks with P supplementation.

The major objective of this study was to assess the effect of P on the productivity of mucuna in a kaolinitic sandy loam soil in Zimbabwe. Mucuna was identified as a suitable rotational crop with maize in this area (Maasdorp & Titterton, 1997) and optimizing mucuna biomass production will most probably have positive effects on fodder production for livestock and subsequent maize production.

Materials and methods

Experimental site

The experiment was carried out at the Grasslands Research Station in Marondera in Zimbabwe. It is situated at approximately 18^{o} 11^{1}S latitude and 31^{o} 30^{1}E longitude at an altitude of 1200 m above sea level. At this site the average annual rainfall is 900 mm per annum (20-year mean), falling predominantly in the hot summer months (November to March). The winters are relatively cool and dry (Table 3.1) (http://www.worldweather.org/130/c00958.htm). The mean US Weather Bureau class A pan evaporation is 1750 mm (Nyakanda, 1997).

The soils are classified as humic Ferrolsols based on the FAO/UNESCO system (FAO UNESCO, 1994) and are equivalent to a Kandiudalfic Eutaudox in the USDA soil taxonomy system (Soil Survey Staff, 1991).The soils are predominantly of the kaolinitic order with loamy sands of low fertility (Hussein, 1997). In general these soils are slightly acid (pH_{CaCl} = 5.2) with organic matter content of 0.33% (Hussein,1997). Soil analyses performed on soil samples taken before the trial started showed a mineral N content of 15 ppm at the time of sampling as well as a P content of 15.8 ppm, K content of 0.15 meq%, Ca content of 0.2 meq% and Mg content of 0.03 meq% (Shoko, unpublished data).

Table 3.1 Rainfall data for the experimental site for 2007 and 2008 (Grasslands Research Station, Marondera, Climatological Section) and long-term climatological data for Marondera (http://www.worldweather.org/130/c00958.htm)

Month	Mean temperature (°C)		Mean total rainfall (mm)			Mean number of rain days
	Daily minimum	Daily maximum	Long term	2007	2008	
Jan	15.3	23.6	193.4	333.1	352.5	14
Feb	13.1	24.5	149.1	48	10	12
Mar	15.8	23.9	90.3	14	74	9
Apr	12.5	22.8	48.7	0	0	5
May	11.9	21.0	10.1	0	0	2
Jun	6.2	18.3	5.4	0	0	1
Jul	5.3	18.4	3.0	0	0	1
Aug	6.3	25.0	3.0	0	0	1
Sep	12.5	25.5	6.8	0	0	1
Oct	13.5	26.0	40.3	85.5	11	5
Nov	14.8	25.9	113.1	157.2	137.4	10
Dec	14.5	24.3	187.7	429.2	282.6	15

Crop establishment

The experimental area was ploughed, disced and planted to *Mucuna pruriens* var. *utilis* in August 2007 (first season crop) and July 2008 (second season crop). Mucuna was planted using an inter-row spacing of 45 cm and intra row spacing of 10 cm. Two phosphorus treatments (40 and 0 kg P ha^{-1}) were applied as pre-planting fertilizer. Weed control was done twice using mechanical methods. Irrigation was applied strategically to supplement rainfall when the mucuna crop started to show signs of moisture stress.

Experimental design and treatments applied

The experimental design was a Randomised Complete Block Design (RCBD) with 2 P treatments [P0 = 0 kg P ha^{-1} and P40 = 40 kg P ha^{-1}] applied prior to planting a mucuna crop. Single Super Phosphate (SSP) was applied as basal fertilizer. The performance of P on mucuna was measured on the following parameters; biomass and LAI (at different stages during the growing season), nodulation, N fixed, foliar nutrient analyses, days to 50% flowering, pod numbers and weight, yield and yield quality. In the case of biomass and LAI the experimental designs were a 2X2 and 2X3 factorial respectively with factors P level and Time (time of sampling). The treatments were replicated 4 times. The plot size was 10 m x 10 m and the nett plot area was 5 m x 5 m. The net plot area was marked at the center of each plot. The rest of the area was used for other destructive measurements such as leaf area and biomass determinations.

Biomass and Leaf Area Index (LAI) determination

Biomass (dry weight) was determined at 4 and 8 weeks after emergence (WAE) and LAI was determined at 4, 6 and 8 WAE. The plants from the net plot were partitioned into leaves and stems. Dry mass was determined by oven drying the components at 80^{o}C to constant weight before weighing. LAI was determined using a Delta-T Leaf Area Meter (Model 2).

Nodulation

Nodulation counts were carried out at flowering. Number of live and dead nodules per plant was recorded. Ten plants for each plot were randomly sampled. The dry weight of the nodules was also determined.

Estimation of nitrogen fixed

The proportion of nitrogen fixed was estimated using the N abundance difference method (Ankomah, 1998). Weeds from the unfertilized plots were used as non-fixing reference crops. The weeds were also sampled at the time of sampling the mucuna plants. Both the mucuna and weed samples were oven dried to constant weight at 60^{0} C and then nitrogen was determined using the Micro- Kjeldahl method (Okalebo *et al.*, 1993). The difference between the N levels in the two plant populations estimate the amount of N fixed. The amount of N fixed was determined at flowering and maturity of mucuna.

Foliar nutrient analyses

From the same plants that were sampled for biomass determination the following nutrients were analysed from the whole plant at flowering and from leaves and pods at maturity: N, P, K, Ca and Mg. The analyses of the mentioned nutrients were done using standard procedures as described by AOAC (1990).

Yield components

Yield determinations were carried out based on the net plot yield. The net plot yield was used to estimate yield (t ha^{-1}). The pod quality parameters measured were fibre and protein using standard analytical methods described by AOAC (1990).

Statistical analyses

Statistical analysis of the data was performed using the STATISTICA software, version 8.02 program (StatSoft, 2004). Analysis of variance (ANOVA) was conducted to determine significance of treatment effects. Means were separated using Bonferroni studentised range for testing least significant differences at the 5% level when ANOVA revealed significant ($P < 0.05$) differences among the treatments.

Results

Biomass accumulation

There was a significant interaction ($P < 0.05$) between P level and time of sampling in both years in terms of biomass of stems and total plants only (Figure 3.1). At 8WAE the stem mass and total biomass produced by plants of the P40 treatment was significantly higher than that of the P0 plants in both years. Total biomass of mucuna almost doubled in the P40 treatment from 4 WAE to 8 WAE. Leaves produced significantly higher biomass yields at both sampling times in both years at P40 compared to P0.

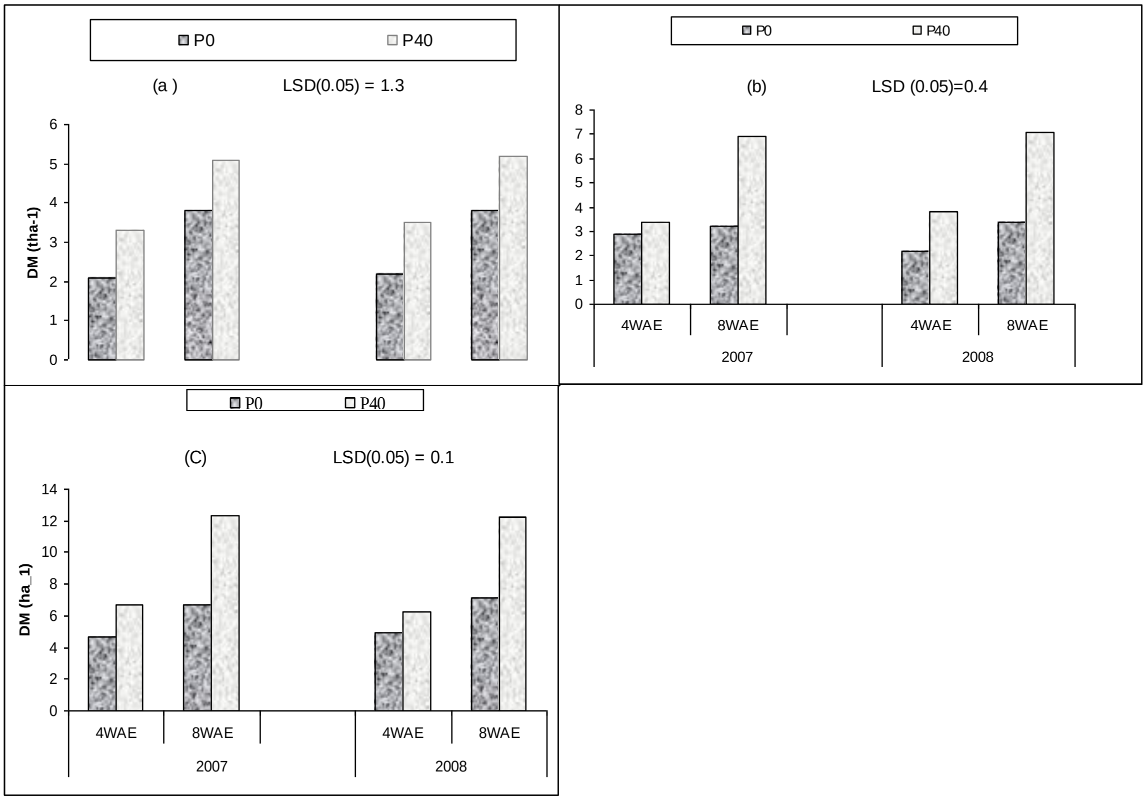

Figure 3.1 Dry matter accumulations by mucuna (a) leaves, (b) stems and (c) whole plant at 4 and 8 WAE under PO & P40 treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied).

Leaf Area Indices (LAI)

Leaf area was measured at 4, 6 and 8 WAE over two seasons to determine the effect of P as illustrated in Figure 3.2. There was significant interaction ($P < 0.05$) between time of sampling and P level in both seasons. The P40 treatment had a significantly ($P < 0.05$) higher LAI at 6 and 8 WAE in 2007 and at 8 WAE in 2008 but not at 4 WAE in any of the seasons. Phosphorus applications can help to increase LAI faster. The results show a LAI of 1.3 and 1.06 for the P40 and P0 treatments respectively at 8 WAE.

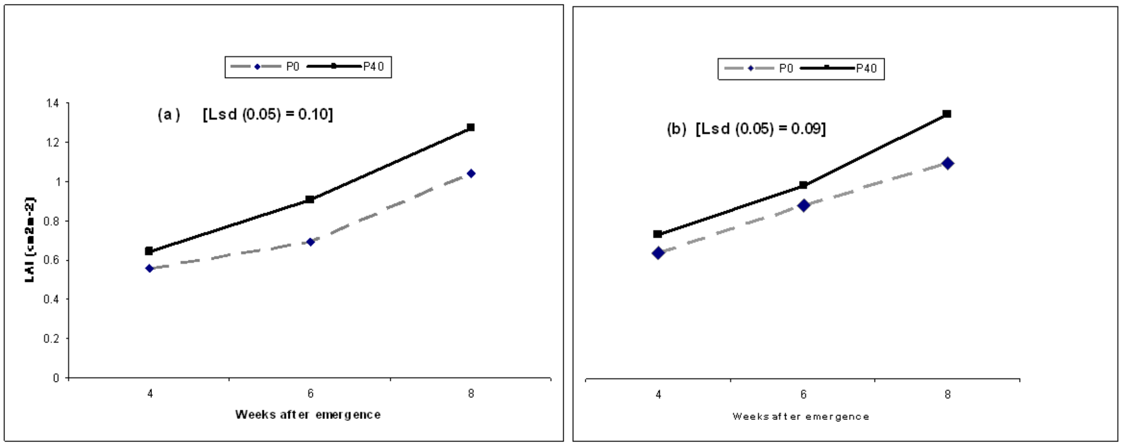

Figure 3.2 LAI for mucuna in (a) 2007 season and (b) 2008 season under P0 & P40 treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied).

Nodulation

The results (Table 3.2) showed that the P40 treatment significantly increased nodulation compared to the P0 treatment. The two seasons means show that the P40 treatment produced 75% (98), 91% (90) and 47%(1.1g) more nodules, live nodules and nodule dry weight than the P0 treatment (56, 47 and 0.75 g respectively).

Table 3.2 Nodule numbers, number of live nodules and nodule dry weight (DW) per plant of mucuna at 2 P levels during the 2007 and 2008 seasons (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied). Means followed by the same unbold letter in a row in a season and those followed by the same bold letter in a row for the 2 seasons means are not significantly different at P = 0.05

	2007 season		**2008 season**		**2 seasons mean**	
P Level	***P0***	***P40***	***P0***	***P40***	***P0***	***P40***
No. of nodules plant^{-1}	55a	97b	58a	100b	56**a**	98**b**
No. of live nodules plant^{-1}	45a	87b	50a	94b	47**a**	90**b**
Nodule DW plant^{-1} (g)	0.67a	1.08b	0.82a	1.12b	0.75**a**	1.1**b**

Estimation of nitrogen fixed

Nitrogen fixed at flowering in the mucuna crop (mean of two years) was 82% more in the P40 treatment (164 kg ha^{-1}) than in the P0 treatment (90 kg ha^{-1}) (Table 3.3). This trend was also evident at maturity. The use of P therefore enhances nitrogen fixation in mucuna as shown in Table 3.3.

Days to 50% flowering

Significant differences ($P < 0.05$) in days to flowering as influenced by P are illustrated in Figure 3.3. Mucuna in the P0 treatment reached 50% flowering about 9 to 10 days earlier than in the P40 treatment in both seasons.

Table 3.3 Estimated N fixed by mucuna during the 2007 and 2008 seasons under P0 & P40 treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied). Means followed by the same unbold letter in a column in a season and those followed by the same bold letter in a column for the 2 seasons means for each sampling time are not significantly different at P = 0.05

	2007 season	**2008 season**	**2 seasons mean**
		N fixed (kg ha^{-1})	
Sampling time			
At flowering:			
P0	89a	91a	90**a**
P40	162b	166b	164**b**
****At maturity:***			
P0	62a	59a	61**a**
P40	92b	90b	91**b**

* At maturity = mucuna biomass - pods

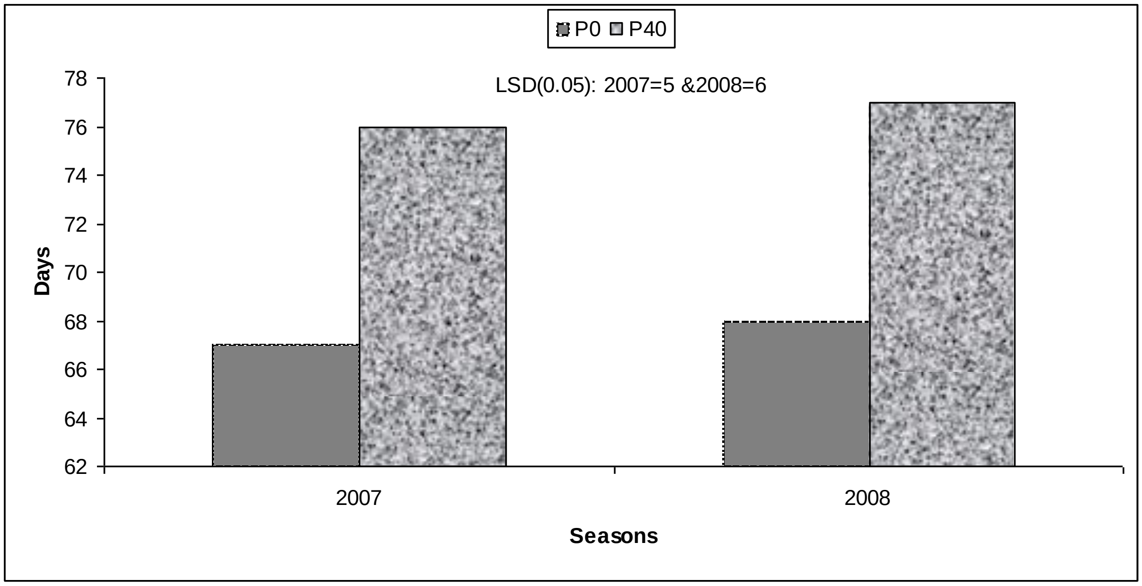

Figure 3.3 Days taken to reach 50 % flowering by mucuna under P0 & P40 treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied.

Foliar nutrient content

Total nutrient content in the foliage of mucuna at flowering and maturity as well as in pods are shown in Table 3.4. Trends were similar in both seasons and the following discussion refers to the mean values for the two seasons. The two P treatments showed significant differences ($P < 0.05$) because the P40 treatment resulted in 23%, 57% and 6%, higher N, P and Ca contents respectively at flowering compared to the P0 treatment. Magnesium and K levels were higher (although not significantly) in the P0 treatment than in the P40 treatment. At maturity mucuna foliage in the P40 treatment had significantly higher (17 %, 31 %, 38 % and 23 %, respectively) N, P, K and Ca contents than in the P0 treatment but the Mg levels did not differ significantly between treatments.

There were significant ($P < 0.05$) differences between treatments with regard to all the nutrients in mature pods (Table 3.4). Pods from the P40 treatment had 24%, 150%, 8%, 100% and 150% higher concentration of N, P, K, Ca and Mg respectively than pods in the P0 treatment.

Yield and yield quality

Significant differences ($P < 0.05$) between P treatments in terms of yield and yield quality is documented in Table 3.5. The final pod yield over two seasons was 34% higher in the P40 treatment (1.8 t ha^{-1}) compared to the P0 treatment (1.3 t ha^{-1}). There were also significant differences ($P < 0.05$) between treatments in terms of pod quality as measured by protein content. The protein content of pods was approximately 50% higher in the P40 treatment than in the P0 treatment in both seasons. The P0 treatment showed a 2% lower fibre content in 2007 but a 4% higher fibre content in 2008 compared to the P40 treatment. The effect of P on fibre content of the pods is therefore inconclusive.

Table 3.4 Nutrient content in foliage of mucuna at flowering and maturity and in mature pods after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied). Means followed by the same letter in a column in a season are not significantly different at P = 0.05

	N	P	K	Ca	Mg
			%		
At flowering:					
2007 season					
P0	5.2a	0.7a	2.5a	4.8a	1.0a
P40	6.6b	1.1b	2.3a	5.2b	0.9a
2008 season					
P0	5.2a	0.7b	2.6a	5.0a	1.0a
P40	6.3b	1.1a	2.4a	5.3b	0.9a
At maturity:					
2007 season					
P0	4.1a	0.8a	0.8a	2.7a	0.4a
P40	4.8b	1.3b	1.1b	3.2b	0.5a
2008 season					
P0	4.1a	0.9a	0.8a	2.6a	0.4a
P40	4.6b	1.3b	1.1b	3.2b	0.3a
In pods:					
2007 season					
P0	4.5a	0.2a	1.1a	0.3a	0.2a
P40	5.6b	0.5b	1.3b	0.6b	0.5b
2008 season					
P0	4.5a	0.3a	1.1a	0.3a	0.2a
P40	5.6b	0.5b	1.5b	0.6b	0.5b

Table 3.5 Pod yield, protein and fibre content of mucuna in P0 and P40 treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied). Means followed by the same unbold letter in a row in a season and those followed by the same bold letter in a row for the 2 seasons mean are not significantly different at P = 0.05.

	2007 season		***2008 season***		***2 seasons mean***		***cv %***
Parameter	***P0***	***P40***	***P0***	***P40***	***P0***	***P40***	
Pod yield(t ha^{-1})	1.3a	1.8b	1.3a	1.8b	1.3**a**	1.8**b**	18
Protein (%)	15a	23b	15a	23b	15**a**	23**b**	18
Fibre (%)	12a	14b	16b	12a	14**b**	13**a**	13

Discussion

This study showed that P application as a basal fertilizer has the potential to increase mucuna biomass under depleted sandy soil conditions. In general legumes show large biomass responses to P fertilizer applications, but Hairiah *et al*. (1995) working in Indonesia found no response of mucuna to P applications on soils with low P content. In contrast, Tian *et al*. (1998), in a pot experiment, found large increases in biomass production of several legumes including mucuna in poor soil amended with P but even larger increases in fertile soil. However in follow-up experiments in the field the results were variable leading to the conclusion that other environmental stress factors influenced the response of legumes to applied P.

The high nodule numbers, dry weights and live nodules in the P40 treatment indicate that P is a requirement for effective symbiotic nitrogen fixation in mucuna. The use of P therefore enhances nitrogen fixation in mucuna which in turn resulted in a higher biomass in the P40 treatments. This finding is fully supported by other researchers such as Vadez *et al*. (1997) and Valverde *et al*. (2002) for other legume crops. Phosphorus is essential in the conversion of ATP to ADP which will provide legumes with energy to fix N (Robson & O'Hara, 1981).

Nitrogen fixation was highest in the P40 treatment at flowering and at maturity. The high N fixation is attributable to the role of P in nodulation (Sanginga *et al.,* 1996; Valverde *et al*., 2003). The P40 treatment delayed flowering by about 10 days. This delay could be attributable to the effect of P on vegetative growth of mucuna at the expense of flowering. This finding is in contrast to the findings of Turk *et al*. (2003) and Keatinge *et al*. (1985) who both found that P application accelerated time to 50% flowering in legume species.

Phosphorus played an important role in nutrient accumulation in mucuna foliage. Most nutrient levels were higher in the P40 treatment than in the P0 treatment. Kolawole and Kang (1997) noted that P is essential in the energy required for the movement of the nutrients up the plant. The incorporation of mucuna at flowering will help to improve not only N status of the soil but other nutrients like P, K, Mg and Ca levels in the soil as well. Higher foliar contents of these nutrients in mucuna that is incorporated should improve the growth and development of the subsequent crop (Tisdale *et al*., 1999; Shoko *et al*., 2008).

Magnesium and Ca have a liming effect. These help to neutralize the hydrogen ions, which are sources of acidity (Tisdale *et al*., 1999). Nitrogen concentration in pods is very high. This implicates that substantially reduced amounts of N will be incorporated into the soil when pods are harvested at maturity before above ground biomass is ploughed in. However, Carsky *et al*. (1999) found that below ground biomass of legume fallow crops also contributed significantly to the yield of a subsequent maize crop.

The higher pod yield in the P40 treatment shows a similar trend to the findings by Sanginga *et al*. (1996) and Gentili and Huss-Danell (2002). The influence of P on luxurious growth of mucuna had a positive effect on protein content. Mean fibre content over two seasons was lower in the P40 treatment than in the P0 treatment but not so pronounced as to make a difference in digestibility of the pods. Given the 50% increase in protein the overall effect of the P40 treatment will be an increase in fodder quality of the pods.

In general, P application improved the biomass production of mucuna, the nutrient content of the plants as well as the quality of the pods. This may lead to a higher amount of better quality fodder if it is to be used as animal fodder. However, in the crop production systems in these parts of Zimbabwe it will most probably be used to enhance soil fertility and to supplement N in a subsequent maize production phase (Hikwa *et al*., 1998). Increased biomass production and improved nutrient content of the mucuna plants may have a more positive effect on the subsequent crop (Sanginga *et al*., 1996; Carsky *et al*., 1999; Muhr *et al*., 1999; Shoko *et al*., 2007). The application of supplementary P to increase aforementioned factors may therefore be a cost-effective way of optimizing maize production in the depleted sandy soils of this region.

Conclusion

The results indicate that P plays a crucial role in mucuna productivity in a depleted sandy soil in Zimbabwe. The small-holder farmers can improve the productivity of their mucuna crop if they apply P and can improve the pod yield as well as the quality of the pods for animal consumption. The improved biomass production and higher nutrient content may have positive effects on a subsequent maize crop by substituting some of the N fertilizer required by the maize and by generally improving the nutrient status and soil organic matter. Further research to determine optimum P application rates for different soils and climatic conditions for mucuna production may be carried out.

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Chapter 4

The effect of P and mucuna *(Mucuna pruriens)* management options on soil organic matter, soil pH and physical properties of a depleted sandy loam soil in Zimbabwe

Abstract

It has been noted that the continuous use of fertilizer alone cannot sustain crop yield and maintain soil fertility. In the long run the soil pH, soil organic matter (SOM), physical properties such as bulk density (Db), particle density (Dp) and porosity (f) will deteriorate. Inclusion of a leguminous crop such as mucuna (*Mucuna pruriens*) in a rotational system may alleviate these problems. The major objective of this research was to investigate the effect of two P levels and four mucuna management options on SOM, pH and physical properties of a depleted kaolinitic sandy soil in Zimbabwe. The 2 P treatments were P0 = 0 kg P ha^{-1} and P40 = 40 kg P ha^{-1} and the 4 mucuna treatments were MF=mucuna incorporated at flowering, MAR= mucuna above ground removed at maturity and only roots incorporated, MPR = above ground biomass except pods incorporated at maturity and F = Fallow (control). The following parameters were investigated; SOM, soil pH, Db, DP and f. The MF and P40 treatment combination increased the SOM, Db, DP and f significantly compared to other treatments. The MF and MPR management options in combination with the P0 treatment resulted in the most acceptable soil pH for maize production. The incorporation of above-ground biomass of mucuna had positive effects on all soil properties investigated.

***Keywords**:* mucuna management, organic matter, soil pH, soil physical properties

Introduction

It has been shown that on the poorly buffered kaolinitic soils found in many areas in the tropics, including sub-Saharan Africa, continuous use of fertilizer alone cannot sustain crop yield and maintain soil fertility, because soil pH, soil organic matter (SOM) and physical properties such as bulk density (Db), particle density (Dp) and porosity (f) will deteriorate in the long run (Juo *et al.*, 1995a; 1995b).

Kang (1993), working on an Alfisol soil in Nigeria, reported a soil pH decline from 6.2 to 5.1 during 10 yr of continuous cropping with maize under inorganic N fertilizer regimes. Several other examples of acidification and the decline of soil organic matter and exchangeable nutrients in sub-Saharan Africa are given in a review by Franzluebbers *et al.* (1998). This means that there is need to find alternative organic sources which will improve soil pH, SOM and soil physical properties. The incorporation of a legume crop at flowering will help to increase N, K and Ca levels in the soil and improve SOM (Shoko *et al.*, 2007).

Shoko *et al.* (2007) noted that monoculture practices in cereal crops increase soil acidity. Acidification increases the amount of heavy metals in the soil (Tisdale *et al.*, 1999; Sullivan, 2003). Hydrous oxide metals such as Fe and Al inhibit the availability of essential bases (Tisdale *et al.*, 1999). This prevents the plant from taking up essential nutrients especially the basic cations. So there is need to use other means to raise the soil pH. Maize monoculture practices call for the excessive use of N fertilizers such as ammonium sulphate, ammonium nitrate, urea, ammonium phosphate and ammonium hydroxide all of which have some acidifying effects on the soil (Tisdale *et al.*, 1999). The use of organic sources of N such as mucuna can help to address problems of acidity.

The contribution of root biomass from legume rotational crops to the nutrient and organic matter of the soil is believed to be important for soil fertility maintenance and carbon sequestration, as the below-ground biomass forms a substantial proportion of the total biomass in an ecosystem (Juo *et al.*, 1995a). It is estimated that roots may be the source of 30 to 60% of the C in the soil organic pool (Heal *et al.*, 1997). Root tissues are continuously sloughed off and replaced, and these sloughed-off tissues, along with senescent and dead roots, constitute a substantial source of organic matter addition to the soil ecosystem.

According to Sanginga *et al*. (1996) and Carsky *et al.* (1999) the influence of mucuna on soil physical properties and SOM depends on soil type, management and environmental conditions. In many cropping systems, soil management to increase SOM, improve soil pH and improve Db for crop production has been approached via the use of crops as green manure and the return of crop residues of rotational legume crops such as mucuna (Becker *et al*., 1995; Snapp *et al*., 1998; Whitbread *et al*., 1999, 2000).

Soil acidity is one of the most important constraints that must be addressed. It does not in itself reduce growth, but it affects the associated chemical environment (Alaban *et al*., 1990). Some nutrients become more soluble at low pH and end up being leached down through the soil profile and into the water supply (Chien, 2001).

Work done by Alaban *et al.* (1990) in the Philippines from 1970 to 1989 showed a significant decrease in organic matter content of the soil from 27 g kg^{-1} to 17 g kg^{-1} due to monoculture production systems of cereal crops. Continuous cereal monoculture cropping and removal of crop residues results in the deterioration of the physical, chemical and biological properties of the soil (Giller *et al*., 1994). Under this monoculture system the soil will have poor cation exchange capacity (CEC), become susceptible to erosion and compaction due to machinery movement and develop poor water holding capacity and infiltration rates. The improvement of soil organic matter through incorporation of legume crops such as mucuna biomass can help to improve the water holding capacity, increase the CEC and improve the availability of nitrogen (N), phosphorous (P) and potassium (K) in the soil.

According to Hussein (1997) and Brady (1974) Db of sandy soils are higher than that of clays. Mucuna biomass if incorporated has the potential to increase SOM. This increase in SOM may improve soil aggregation which will result in an increase in pore spaces and a reduction in Db (Brady, 1974).

The major aim of this study was to determine the effects of P application and mucuna management options on the dynamics of soil pH, SOM and some physical properties of a kaolinitic sandy loam soil in the dry savanna area of Zimbabwe. This is important because mucuna was identified as a potential rotational cropping legume in maize production systems in these areas.

Materials and methods

Experimental site

The experiment was carried out at the Grasslands Research Station in Marondera in Zimbabwe. It is situated at approximately 18^o 11^1 S latitude and 31^o 30^{1}E longitude at an altitude of 1200 m above sea level. At this site the average annual rainfall is 900 mm per annum (20-year mean), falling predominantly in the hot summer months (November to March). The winters are relatively cool and dry (Table 4.1) (http://www.worldweather.org/130/c00958.htm). The mean US Weather Bureau class A pan evaporation is 1750 mm (Nyakanda, 1997).

Table 4.1 Rainfall data for the experimental site for 2007 and 2008 (Grasslands Research Station, Marondera, Climatological Section) and long-term climatological data for Marondera (http://www.worldweather.org/130/c00958.htm)

Month	Mean temperature (°C)		Mean total rainfall (mm)			Mean number of rain days
	Daily minimum	Daily maximum	Long term	2007	2008	
Jan	15.3	23.6	193.4	333.1	352.5	14
Feb	13.1	24.5	149.1	48	10	12
Mar	15.8	23.9	90.3	14	74	9
Apr	12.5	22.8	48.7	0	0	5
May	11.9	21.0	10.1	0	0	2
Jun	6.2	18.3	5.4	0	0	1
Jul	5.3	18.4	3.0	0	0	1
Aug	6.3	25.0	3.0	0	0	1
Sep	12.5	25.5	6.8	0	0	1
Oct	13.5	26.0	40.3	85.5	11	5
Nov	14.8	25.9	113.1	157.2	137.4	10
Dec	14.5	24.3	187.7	429.2	282.6	15

The soils are classified as humic Ferrolsols based on the FAO/UNESCO system (FAO UNESCO, 1994) and are equivalent to a Kandiudalfic Eutaudox in the USDA soil taxonomy system (Soil Survey Staff, 1991). The soils are predominantly of the kaolinitic order with loamy sands of low fertility (Hussein, 1997). In general these soils are slightly acid (pH_{CaCl} = 5.2) with organic matter content of 0.33% (Hussein,1997). Soil analyses performed on soil samples taken before the trial started showed a mineral N content of 15 ppm at the time of sampling as well as a P content of 15.8 ppm, K content of 0.15 meq%, Ca content of 0.2 meq% and Mg content of 0.03 meq% (Shoko *et al*. unpublished data).

Crop establishment

The experimental area was ploughed, disced and planted to *Mucuna pruriens* var. *utilis* in August 2007 (first season crop) and July 2008 (second season crop). Mucuna was planted using an inter row spacing of 45 cm and intra row spacing of 10 cm. Two phosphorus treatments (40 and 0 kg P ha^{-1}) were used as pre-planting fertilizer. Weed control was done twice using mechanical methods. Irrigation was applied strategically to supplement rainfall when the mucuna crop started to show signs of moisture stress.

Experimental design and treatments applied

The experimental design was a split plot with 2 P treatments as main plot factors [P0 = 0 kg P ha^{-1} and P40 = 40 kg P ha^{-1}] applied prior to planting a mucuna crop and 4 mucuna treatment as sub-plot factors [MF = mucuna incorporated at flowering, MAR = mucuna above ground biomass removed at maturity and only roots incorporated, MPR = above ground biomass except pods incorporated at maturity and F = Fallow (control)]. Single Super Phosphate (SSP) was applied as basal fertilizer. The influence of P application and mucuna management options were measured on pH, SOM, Db, particle density (Dp) and porosity (f) of the soils. The treatments were replicated 4 times. The plot size 10mx 10 m. The nett plot area was 25 m^2. The remainder of the plot area was used for other destructive sampling measurements.

Soil sampling

Soils were sampled before planting mucuna in 2007 and were also done 30 days after the incorporation of mucuna in 2007 and 2008. Soil samples were collected at 0-30 cm depth by taking five cores per plot using a 50 mm diameter augur. The five sub samples were thoroughly mixed to obtain one composite sample per plot. Subsequently 500 g of soil were weighed from each composite sample and taken to the laboratory for analyses. The collected soil was analysed for pH, OM, Db, Dp and f.

Determination of SOM

Soil organic matter was determined by the Loss-on-Ignition method (AOAC, 1990). The soil sampled was dried overnight at 80^0C in an oven. Then 5 g of dry soil was weighed and put in a crucible with a known weight. The crucibles were heated in a muffin furnace at 450° C for until constant weight for 24 hrs.. The crucibles were reweighed after heating and the difference in weight was noted to find the amount lost (organic matter).

Determination of Soil pH

This was done using the 0.01M CaCl solution method (Okalebo *et al*., 1993**).**

Determination of Db and Dp

This was done following the protocol outlined by Tagwira (1992).

The following models were used for the determination of the physical properties of the soil:

Bulk density (Db) = Mass of oven dry soil (g)/ Total volume of the soil (cm^3) Eqn 1

Particle Density (Dp) = Mass of soil solids (g) / Volume of the soil (cm^3) Eqn 2

%Porosity (f) = 1-{ Db / Dp} x 100 Eqn 3

Statistical analyses

Statistical analysis of the data was performed using the STATISTICA software, version 8.02 program (StatSoft, 2004). Analysis of variance (ANOVA) was conducted to determine significance of treatment effects. Means were separated using Bonferroni studentised range for testing least significant differences at the 5% level when ANOVA revealed significant ($P < 0.05$) differences among the treatments.

Results

In terms of all the parameters measured the data showed the same trends in both seasons and although the data of both seasons will be shown only the mean data over two seasons will be discussed in the following sections.

SOM

The significant ($P < 0.05$) interaction between P treatments and mucuna management options in terms of SOM accumulation over two seasons is illustrated in Table 4.2. In the P0 treatment the MF treatment accumulated significantly ($P < 0.05$) more SOM than the MPR, F and MAR treatments (0.64, 0.44, 0.26 and 0.26 % respectively). The MPR treatment in turn had significantly higher SOM levels than the MPR and F treatments.

The P40 treatment showed similar trends to the P0 treatment with the exception of the MAR treatment that accumulated significantly ($P < 0.05$) more SOM than the F treatment. Under this P treatment MF had the highest SOM of 0.86 %.

Soil pH

There were significant interactions ($P < 0.05$) between the P treatments and mucuna management options. The P0 treatment showed on average over two seasons significant soil pH increases in all treatments where mucuna was planted compared to the natural fallow treatment whereas in the P40 treatment all the mucuna treatments significantly reduced the pH compared to the natural fallow treatment (Table 4.3). The increase in pH caused by the mucuna treatments in the P0 treatment is however not big enough to influence plant growth significantly. The reduction in soil pH from 5.12 to 4.64 by the MPR treatment in the P40 treatment however, may have detrimental effects on plant growth.

Table 4.2 Percent soil organic matter of the sandy soil under different management options of mucuna during the 2007 and 2008 seasons after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied). MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F= Fallow (control). Figures followed by the same unbold letter in a season and those followed by the same bold letter for the 2 season means are not significantly different at P = 0.05.

	2007 season		**2008 season**		**2 seasons mean**	
Treatment	***P0***	***P40***	***P0***	***P40***	***P0***	***P40***
Before planting mucuna	0.26					
F	0.26a	0.26a	0.26a	0.27a	0.26**a**	0.26**a**
MF	0.63c	0.86e	0.64d	0.90f	0.64**c**	0.88**e**
MAR	0.25a	0.42b	0.27a	0.48c	0.26**a**	0.45**b**
MPR	0.43b	0.77d	0.45b	0.82e	0.44**b**	0.80**d**

Table 4.3 Soil pH (Cacl) levels of the sandy soil under different management options of mucuna during the 2007 and 2008 seasons after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied). MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F= Fallow (control). Figures followed by the same unbold letter in a season and those followed by the same bold letter for the 2 season means are not significantly different at P = 0.05.

	2007 season		**2008 season**		**2 seasons mean**	
Treatment	***P0***	***P40***	***P0***	***P40***	***P0***	***P40***
Before planting mucuna	5.12					
F	5.12c	5.12c	5.13e	5.12d	5.13**d**	5.12**d**
MF	5.31e	5.22d	5.41g	4.92c	5.36**f**	5.07**c**
MAR	5.22d	4.86b	5.23f	4.85b	5.23**e**	4.86**b**
MPR	5.22d	4.60a	5.21e	4.64a	5.22**d**	4.62**a**

Db and Dp

There were significant interactions ($P < 0.05$) between P treatments and mucuna treatments in terms of Db and Dp. At both P levels the mucuna treatments significantly ($P < 0.05$) reduced Db compared to the natural fallow treatment. At both P levels the MAR treatment had the least effect on the Db, although it was still significantly lower than the F treatment (Table 4.4). The same trends were evident for the Dp parameter (Table 4. 5) but Dp values were higher than the Db values due to the organic material in the soil.

Table 4.4 Bulk density (Mgm^{-3}) of the sandy soil under different management options of mucuna during the 2007 and 2008 seasons after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied). MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F= Fallow (control). Figures followed by the same unbold letter in a season and those followed by the same bold letter for the 2 season means are not significantly different at P = 0.05.

	2007 season		**2008 season**		**2 seasons mean**	
Treatment	***P0***	***P40***	***P0***	***P40***	***P0***	***P40***
Before planting mucuna	1.5					
F	1.5d	1.5d	1.5d	1.5c	1.5**d**	1.5**d**
MF	1.3b	1.2a	1.2a	1.3b	1.2**a**	1.3**b**
MAR	1.5d	1.4c	1.4c	1.4c	1.4**c**	1.4**c**
MPR	1.3b	1.2a	1.3b	1.3b	1.3**b**	1.3**b**

% Porosity (f)

The significant ($P < 0.05$) interaction between P treatments and mucuna management options in terms of porosity dynamics over two seasons is illustrated in Table 4.6. The P0 treatment showed significant differences ($P < 0.05$) between all the mucuna management options. The MF management option at P0 treatment improved the porosity of the sandy soils by 6.4%, 13.2 % and 16.8 % compared to the MPR, MAR and F management options respectively (Table 4.6). The 51.4% porosity of the soil in the MF management option indicates that the soil is sufficiently porous.

Table 4.5 Particle density (Mgm^{-3}) of the sandy soil under different management options of mucuna during the 2007 and 2008 seasons after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied). MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F= Fallow (control). Figures followed by the same unbold letter in a season and those followed by the same bold letter for the 2 season means are not significantly different at P = 0.05.

	2007 season		**2008 season**		**2 seasons mean**	
Treatment	***P0***	***P40***	***P0***	***P40***	***P0***	***P40***
Before planting mucuna	2.67					
F	2.67b	2.66b	2.66b	2.64b	2.67**b**	2.65**b**
MF	2.53a	2.52a	2.52a	2.51a	2.52**a**	2.51**a**
MAR	2.66b	2.67b	2.64b	2.66b	2.65**b**	2.66**b**
MPR	2.53a	2.53a	2.51a	2.51a	2.52**a**	2.52**a**

The P40 treatment also showed significant differences (P < 0.05) between the MF, F and MPR treatments. However there were no significant differences (P > 0.05) between the F and MAR treatments in the P40 treatment. The MF management option improved the porosity of the soil by 19.1 % and 3.2% compared to the F and MAR treatments at P40 treatment. At the P40 treatment the MF and MPR management option values of 52.2 % and 50.6 % respectively showed that the soils are sufficiently porous for crop growth.

Table 4.6 Porosity (%)of the sandy soil under different management options of mucuna during the 2007 and 2008 seasons after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied). MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F= Fallow (control). Figures followed by the same unbold letter in a season and those followed by the same bold letter for the 2 season means are not significantly different at P = 0.05.

	2007 season		**2008 season**		**2 seasons mean**	
Treatment	***P0***	***P40***	***P0***	***P40***	***P0***	***P40***
Before planting mucuna	42					
F	42a	43a	43a	43.8a	44**a**	43.4**a**
MF	50.2d	52.4e	52.4d	50.2c	51.4**d**	52.2**d**
MAR	43.8b	43.8b	47b	43.8a	45.4**b**	43.8**a**
MPR	48.6c	53e	48.2b	48.2b	48.3**c**	50.6**d**

Discussion

The MF management option has the potential to increase soil organic matter more than the MAR, MPR and F management options. The MPR management option can improve the SOM content at both P levels. The incorporation of above ground biomass of mucuna as green manure at flowering stage (MF) provided the soil microbes with plant material for decomposition. This decomposition will always add SOM to the soil (Shoko *et al*., 2007). The optimum organic matter content of sandy soils in Zimbabwe is at least 1.5 % (Tagwira, 1992).

Therefore the MF management option at the P0 and P40 treatments and the MPR management option at the P40 treatment will boost the SOM for the subsequent maize crop to the required levels for the small holder farmer on a sandy soil. Work done by Shoko *et al*. (2007) and Wang *et al*. (2009) on other grain legumes such as soyabeans and cowpea support the findings in this study that mucuna has the potential to add more SOM when ploughed in at green manuring stage than after the pods were harvested (removed) at maturity. Higher SOM levels will improve the CEC, fertility, water holding capacity, microbial biomass, porosity and aeration of sandy soils (Kang, 1993). This will increase the final yield of the subsequent maize crop.

Soil pH directly affects the growth and life of plants because it affects the availability of all the plant nutrients. Most of the essential plant nutrients are readily available in between pH 5.2 and 8.8 (Hussein, 1997). Nitrogen, for example has its greatest solubility between pH 5.2 and 6.8. The pH levels of the MF and MPR mucuna management options at P0 treatment are optimal for the availability of N, P, K, Ca, Mg and S (Hussein, 1997). The pH levels will neutralize toxic oxides like Al, Fe and H. The subsequent maize crop can do well and produce high yields on these treatments without any liming at all. However some liming of about 1 300 kg $CaCo_3$ ha^{-1} may be required to raise the pH for the MAR and F management options under P0 treatment if the farmers are to realize good maize yields. The above lime quantity is enough to raise the soil pH with 0.5 units in sandy soils in Zimbabwe (Tagwira, 1992).

However at the P40 treatment the MF, MAR and MPR management options increased soil acidity. Farmers will need to lime the soils. The decrease in pH could be attributed to an increase in carbonic acid and other acids responsible for acidulation of P (Tisdale *et al*., 1999; Chien, 2001). Increased crop growth will result in a higher Ca uptake and the microbial decomposition of SOM added to the soil will also have an acidifying effect.

A Db of soil which is close to 1.2 Mg m^{-3} shows a crumby structured soil that can sustain plant growth and development (Hussein, 1997) and can increase the yield of the subsequent maize crop. The MF and MPR management options have lower Db of 1.2 and 1.3 Mg m^{-3} respectively compared to the F and MAR management options at the P0 treatment and a Db of 1.3 Mg m^{-3} in the P40 treatment. This Db ensures good water holding capacity, aeration and porosity. This can be beneficial to the small holder farmer. The reduced Db can be attributed to the large sums of organic matter which the MF and MPR management options added to the sandy soils.

Soil with a porosity of about 50% is good for crop production. Such a soil is well aerated, well drained and supports microbial activity (Fageria et *al*., 1991). The MF management option ensured that such porosity levels (> 50 %) were achieved in both P treatments. The improved porosity can be attributed to increased SOM as a result of the incorporation of the mucuna biomass at flowering. This management option may help the smallholder farmer to realize good yields from the subsequent maize crop. The MF management option can help to reduce losses of N through denitrification and volatilization due to improved drainage and water holding capacity of the soil. Improved water holding capacity will also help to mitigate against short duration droughts. Results from the F and MAR management option treatments show that the smallholder farmers may need to supplement with kraal manure to improve the porosity of the sandy soil.

Conclusion

The MF management options resulted in the highest SOM, Db, DP and f at the P40 treatment. This shows the potential of mucuna as an ameliorant to soil physical properties when incorporated at flowering stage. However in this management combination it may be necessary to lime the soil to increase its pH to required levels for maize production. At the P0 treatment the MF and MPR management options had the most acceptable soil pH, negating the necessity to apply lime, but this treatment combination resulted in less optimal SOM, Db, Dp and f levels. The response of the maize crop to the better SOM, Db, Dp and f levels at the MF and P40 treatment will determine whether it will be beneficial to add 40 kg of P to the mucuna crop. The cost of the P fertilizers and the subsequent liming may be nullified by the higher yields from and/or lower N requirements of the subsequent maize crop.

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Chapter 5

The effects of P and mucuna *(Mucuna pruriens)* management options on the chemical characterisation of a depleted sandy loam soil in Zimbabwe

Abstract

Low soil fertility due to monoculture crop production systems is recognized as one of the major causes for declining per capita food production in sub-Saharan Africa. The major objective of this research was to investigate the effect of two P levels and four mucuna management options on soil chemical properties on a depleted kaolinitic sandy soil in Zimbabwe. The 2 P treatments were P0 = 0 kg P ha^{-1} and P40 = 40 kg P ha^{-1} and the 4 mucuna treatments were MF=mucuna incorporated at flowering, MAR= mucuna above ground biomass removed at maturity and only roots incorporated, MPR = above ground biomass except pods incorporated at maturity and F = Fallow (control). The following soil nutrients were investigated; Nitrogen, Phosphorus, Potassium, Calcium, Magnesium and Zinc. The MF management option and P40 treatment resulted in the highest N, P, K, Ca and Mg levels. However the P40 and mucuna treatments had significantly lower Zn levels than in the P0 and mucuna treatment combinations.

Keywords*:* exchangeable bases, major nutrients, mucuna, Zn

Introduction

Low soil fertility due to monoculture crop production systems is recognized as one of the major biophysical causes for declining per capita food production in sub-Saharan Africa (Sanchez *et al.,* 1997). Nutrient balance studies in this region have shown that on average 22 kg N, 2.5 kg P, and 15 kg K per hectare are lost annually and losses can be as high as 112 kg N, 3 kg P, and 70 kg K per hectare in the intensively cultivated highlands of Africa (Stoorvogel *et al*., 1993;Van den Bosch *et al*., 1998). These losses are much higher than the estimated inorganic fertilizer use in Africa of 5 to 10 kg per hectare (FAO, 1994; Heisey & Mwangi, 1996). This emphasises the need for soil fertility replenishment through the use of organic sources such as herbaceous legumes like mucuna.

Most smallholder farmers in Zimbabwe practice monoculture crop production systems. Maize is one of the crops which are commonly used in these systems. Monoculture can lead to depletion of inherent soil fertility (Murwira & Kirchmann, 1993). This results in a serious threat to sustainability of maize production in Zimbabwe.

The use of legume crops such mucuna has the potential to improve the chemical and physical characteristics of inherently poor soils such as sands (Palm, 1995). The improvement of the soil structure helps to reduce the adverse effects of soil erosion and decreasing cation exchange capacity (Murwira & Kirchmann, 1993).

Application of organic materials such as herbaceous legumes like mucuna may increase crop-available N, P, K, Ca and Zn either directly by the process of decomposition of the biomass or indirectly by the production of organic acids (products of decomposition) that chelate Fe or Al and thus improving the CEC of the soil (Nziguheba *et al.,* 1998).

Palm (1995) and Jama *et al*. (1997) showed that whereas mucuna contains sufficient N in 2 or 3 t of leafy material to match the requirement of a 2 t crop of maize, it cannot meet the P requirements and must be supplemented by inorganic P in areas where P is deficient. Judicious application of inorganic fertilizers is recognized as an indispensable means of overcoming soil fertility decline and decreasing food production per capita (Mokwunye & Hammond, 1992; Vlek, 1993; Nandwa & Bekunda, 1998).

It is estimated that N fixation ranging from 0 to 250 kg N ha^{-1} with a median of 110 kg N ha^{-1} can be achieved from annual legumes with growth periods of 100 to 150 d (Giller & Wilson, 1991; Sanginga *et al*., 1996; Ibewiro *et al*., 2000). The contributions of legume residues to soil improvement and crop production depend largely on the amount of biomass produced (Sanginga *et al*., 1996), chemical composition (Palm & Sanchez, 1991; Tian *et al*., 1992; Constantinides & Fowness, 1994), and method of application (Mafongoya & Nair, 1997). The decomposition and nutrient release by these residues are also affected by both climatic and edaphic factors, including the biological activity and availability of nutrients in the soil (Myers *et al*., 1994; Mugendi & Nair, 1997).

It is estimated that nodulated legume roots contain from 15 kg to 50 kg N ha^{-1} (Chapman & Myers, 1987; Bergersen *et al.*, 1989; Unkovich *et al*., 1994; Ibewiro *et al.*, 1998; Tian & Kang, 1998). This amount of root N represents a minimum 15% of total plant N (Peoples *et al*., 1995).

The major objective of this study was to assess the role played by mucuna management options on the chemical characterisation of the soil. This is important because mucuna was identified as a potential rotational cropping legume in maize production systems in these areas.

Materials and methods

Experimental site

The experiment was carried out at the Grasslands Research Station in Marondera in Zimbabwe. It is situated at approximately 18^{o} 11^{1}S latitude and 31^{o} 30^{1}E longitude at an altitude of 1200 m above sea level. At this site the average annual rainfall is 900 mm per annum (20-year mean), falling predominantly in the hot summer months (November to March). The winters are relatively cool and dry (Table 5.1) (http://www.worldweather.org/130/c00958.htm). The mean US Weather Bureau class A pan evaporation is 1750 mm (Nyakanda, 1997).

Table 5.1 Rainfall data for the experimental site for 2007 and 2008 (Grasslands Research Station, Marondera, Climatological Section) and long-term climatological data for Marondera (http://www.worldweather.org/130/c00958.htm)

Month	Mean temperature (ºC)		Mean total rainfall (mm)			Mean number of rain days
	Daily minimum	Daily maximum	Long term	2007	2008	
Jan	15.3	23.6	193.4	333.1	352.5	14
Feb	13.1	24.5	149.1	48	10	12
Mar	15.8	23.9	90.3	14	74	9
Apr	12.5	22.8	48.7	0	0	5
May	11.9	21.0	10.1	0	0	2
Jun	6.2	18.3	5.4	0	0	1
Jul	5.3	18.4	3.0	0	0	1
Aug	6.3	25.0	3.0	0	0	1
Sep	12.5	25.5	6.8	0	0	1
Oct	13.5	26.0	40.3	85.5	11	5
Nov	14.8	25.9	113.1	157.2	137.4	10
Dec	14.5	24.3	187.7	429.2	282.6	15

The soils are classified as humic Ferrolsols based on the FAO/UNESCO system (FAO UNESCO, 1994) and are equivalent to a Kandiudalfic Eutaudox in the USDA soil taxonomy system (Soil Survey Staff, 1994). The soils are predominantly of the kaolinitic order with loamy sands of low fertility (Hussein, 1997). In general these soils are slightly acid (pH_{CaCl} = 5.2) with organic matter content of 0.33% (Hussein,1997). Soil analyses performed on soil samples taken before the trial started showed a mineral N content of 15 ppm at the time of sampling as well as a P content of 15.8 ppm, K content of 0.15 meq%, Ca content of 0.2 meq% and Mg content of 0.03 meq% (Shoko, unpublished data).

Crop establishment

The experimental area was ploughed, disced and planted to *Mucuna pruriens* var. *utilis* in August 2007 (first season crop) and July 2008 (second season crop). Mucuna was planted using an inter-row spacing of 45 cm and intra row spacing of 10 cm. Two phosphorus treatments (40 and 0 kg P ha^{-1}) were used as pre-planting fertilizer. Weed control was done twice using mechanical methods. Irrigation was applied strategically to supplement rainfall when the mucuna crop started to show signs of moisture stress.

Experimental design and treatments applied

The experimental design was a split plot with 2 P treatments as main plot factors [P0 = 0 kg P ha^{-1} and P40 = 40 kg P ha^{-1}] applied prior to planting a mucuna crop and 4 mucuna treatments as sub-plot factors [MF=mucuna incorporated at flowering, MAR= mucuna above ground removed at maturity and only roots incorporated, MPR = above ground biomass except pods incorporated at maturity and F = Fallow (control)]. Single Super Phosphate (SSP) was applied as basal fertilizer. The effect of P and mucuna management options was measured on N, P, K, Ca, Mg and Zn content of the soils. The treatments were replicated 4 times.

Soil sampling

Soils were sampled before the planting of mucuna in 2007 and were also done two months after the incorporation of mucuna in 2007 and 2008, shortly before planting of the subsequent maize crop. Soil samples were collected at 0-30 cm depth by taking five cores per plot using a 50 mm diameter augur. The five sub samples were thoroughly mixed to obtain one composite sample per plot. Subsequently 500 g of soil were weighed from each composite sample and taken to the laboratory for analyses. The collected soil was analysed for N, P, K, Ca, Mg and Zn. The analyses were done using the procedures described by AOAC (1990).

Statistical analyses

Statistical analysis of the data was performed using the STATISTICA software, version 8.02 program (StatSoft, 2004). Analysis of variance (ANOVA) was conducted to determine significance of treatment effects. Means were separated using Bonferroni studentised range for testing least significant differences at the 5% level when ANOVA revealed significant ($P < 0.05$) differences among the treatments.

Results

Since the data largely showed the same trends in 2007 and 2008, only the results of the analyses of the mean data over the two seasons will be discussed in the following sections. However the data for the separate seasons is also given in Tables 2 to 6.

Mineral Nitrogen (N)

The significant interactions ($P < 0.05$) between mucuna management options and P treatments on mineral N content of the soil over two seasons are illustrated in Table 5.2. The MF and MPR management options had significantly ($P < 0.05$) higher mineral N contents in the soil as result of the P40 treatment but there were no significant differences in the mineral N content of soil as a result of the P0 and P40 treatments in the F and MAR management options. The MF management option resulted in a 55 % (P0) to 61.9 % (P40) increase in the mineral N content of the soil when compared to the F and MPR management options and 13.4 % (P40) to 15.1% (P0) more N than the MPR management option.

Phosphorus (P)

There were no significant interactions between P and mucuna management options. However there were significant differences ($P < 0.05$) in the phosphorus content (ppm) of the 0-30 cm soil profile between the P0 (18.21 ppm P) and P40 (19.9 ppm P) treatments. The MF management option resulted in the highest P levels in the soil followed by the MPR management option (Table 5.3). There were no significant differences in the P content of the soil between the F and MAR mucuna management options.

Table 5.2 Mineral nitrogen (ppm) of the sandy soil under different management options of mucuna during the 2007 and 2008 seasons after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied). MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F= Fallow (control). Values followed by the same unbold letter in a season and those followed by the same bold letter for the 2 season means are not significantly different at P = 0.05

	2007 season		**2008 season**		**2 seasons mean**	
Treatment	***P0***	***P40***	***P0***	***P40***	***P0***	***P40***
Before planting mucuna	15.03					
F	15a	15a	15.01a	15.01a	15**a**	15**a**
MF	23.25c	24.25c	23.28e	24.32f	23.26**d**	24.29**e**
MAR	15.9a	15a	15.8b	15.01a	15.8**a**	15**a**
MPR	20.25b	21b	17c	21.10d	20.21**b**	21.42**c**

Potassium (K)

Significant interactions (P < 0.05) between mucuna management options and the P treatments on exchangeable K content of the soil over two seasons are shown in Table 5.4. In the case of the MF and MPR management options the P40 treatment resulted in significantly (P < 0.05) higher K levels in the soil but this was not true for the F management option. The MF management option resulted in significantly (P < 0.05) higher K levels compared to the F, MAR and MPR management options regardless of the P treatment. The MF management option in the P0 treatment increased K levels with 620% and 40% compared to the F and MAR management options respectively. A similar trend was observed in the P40 treatment.

Table 5.3 Phosphorus (ppm) of the sandy soil under different management options of mucuna during the 2007 and 2008 seasons after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied). MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F= Fallow (control). Values followed by the same unbold letter in a season and those followed by the same bold letter for the 2 season means are not significantly different at P = 0.05

	2007 season		**2008 season**		**2 seasons mean**		***Mean for mucuna 2 seasons mean***
Treatment	***PO***	***P40***	***P0***	***P40***	P0	P40	
Before planting mucuna	16						
F	17.90b	17.75b	18b	19b	17.95**a**	18.35**a**	*__18.15__a*
MF	20.50c	22.50d	20.15c	23.75f	20.3**b**	23.1**c**	*__21.7__c*
MPR	16.25a	18b	18.9b	18.56b	16.58**a**	17.5**a**	*__17.04__a*
MAR	18b	20c	18b	21d	18**a**	20.5**b**	*__19.25__b*
P treatments (mean)					*__18.21__a*	*__19.9__b*	

Calcium (Ca)

There were significant interactions (P < 0.05) between mucuna management options and P treatments on exchangeable Ca content of the soil over two seasons (Table 5.5). As in the case of N and K, the F and MAR management options had similar Ca contents with the P0 and P40 treatments. The P40 treatment however resulted in significantly (P < 0.05) higher exchangeable Ca content compared to the P0 treatment in the MF and MPR management options. The MF management option increased the exchangeable Ca content with 5% (P40) - 41% (P0) and 1370 % (P0) to 1380 % (P40) but decreased with 65.2% (P0) to 64% (P40) compared to the MPR, F and MAR management options respectively.

Table 5.4 Potassium (meq %) of the sandy soil under different management options of mucuna during the 2007 and 2008 seasons after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied). MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F= Fallow (control). Values followed by the same unbold letter in a season and those followed by the same bold letter for the 2 season means are not significantly different at P = 0.05

	2007 season		**2008 season**		**2 seasons mean**	
Treatment	***P0***	***P40***	***P0***	***P40***	***P0***	***P40***
Before planting mucuna	0.15					
F	0.15a	0.15a	0.15a	0.15a	0.15**a**	0.15**a**
MF	1.09e	1.17f	1.07d	1.15e	1.08**d**	1.16**f**
MAR	0.82b	0.85b	0.80b	0.83b	0.81**b**	0.83**b**
MPR	0.99c	1.04d	1.00c	1.04d	1.00**c**	1.05**d**

Table 5.5 Calcium (meq %) of the sandy soil under different management options of mucuna during the 2007 and 2008 seasons after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied). MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F= Fallow (control). Values followed by the same unbold letter in a season and those followed by the same bold letter for the 2 season means are not significantly different at P = 0.05

	2007 season		**2008 season**		**2 seasons mean**	
Treatment	***P0***	***P40***	***P0***	***P40***	***P0***	***P40***
Before planting mucuna	0.19					
F	0.19a	0.20a	0.20a	0.22a	0.20**a**	0.21**a**
MF	2.94f	3.10g	2.95d	3.12e	2.94**d**	3.11**e**
MAR	1.78b	1.89c	1.82b	1.92b	1.80**b**	1.90**b**
MPR	2.08d	2.96e	2.08c	2.94d	2.08**c**	2.95**d**

Magnesium (Mg)

No significant (P > 0.05) interactions between P treatment and mucuna management options could be observed. The P treatments did not significantly (P > 0.05) influence exchangeable Mg (Table 5.6). However the MF management option resulted in significantly (P < 0.05) higher Mg levels than the F, MAR and MPR management options. The MPR and MAR management options also resulted in a significantly (P < 0.05) higher Mg content than the F management option but there were no significant differences between the MPR and MAR management options. Soils from the MF management option had 60 % and 42.3 % more Mg than the F (control) and MPR management options respectively.

Table 5.6 Magnesium content (meq %) of a sandy soil under different management options of mucuna during the 2007 and 2008 seasons after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied) (MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F= Fallow (control)). Values followed by the same unbold letter in a season and those followed by the same bold letter for the 2 season means are not significantly different at P = 0.05. Values followed by the same italicized letter are not significantly different at P = 0.05

	2007 season		**2008 season**		**2 seasons mean**		***Mucuna management option (2 seasons mean)***
Treatment	***PO***	***P40***	***P0***	***P40***	P0	P40	
Before planting mucuna	0.03						
F	0.03a	0.03a	0.04a	0.03a	0.03**a**	0.04**a**	***0.04****a*
MF	0.27d	0.28d	0.26c	0.29c	0.27**c**	0.28**c**	***0.28****c*
MPR	0.16c	0.16c	0.16b	0.16b	0.16**b**	0.16**b**	***0.16****b*
MAR	0.13b	0.17c	0.14b	0.17b	0.14**b**	0.17**b**	***0.16****b*
P treatments (mean)					***0.15****b*	***0.13****a*	

Zinc (Zn)

Significant interactions (P < 0.05) between mucuna management options and the P treatments on Zn content of the soil over two seasons are shown in Table 5.7. In contrast to the other elements discussed the P0 treatment resulted in significantly (P < 0.05) higher Zn levels where mucuna was planted. No significant differences in Zn levels between the P0 and P40 treatments were noted in the F management option. Again the MF management option resulted in the highest Mg levels followed by the MPR and MAR management options. The two seasons' average in the P0 treatment shows that the MF management option had 43 % and 119.9 % more Zn than the MPR and F management options respectively.

Table 5.7 Zinc content (ppm) of a sandy soil under different management options of mucuna during the 2007 and 2008 seasons after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied) (MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F= Fallow (control)). Values followed by the same unbold letter in a season and those followed by the same bold letter for the 2 season means are not significantly different at P = 0.05

	2007 season		**2008 season**		**2 seasons mean**	
Treatment	***P0***	***P40***	***P0***	***P40***	***P0***	***P40***
Before planting mucuna	4.10					
F	4.13a	4.09a	4.12a	4.10a	4.12**a**	4.10**a**
MF	9.07f	8.79e	9.06e	8.82d	9.06**f**	8.80**e**
MAR	5.06b	4.10a	5.08b	4.12a	5.07**b**	4.11**a**
MPR	6.35d	6.20c	6.32c	6.18c	6.33**d**	6.19**c**

Discussion

Mucuna has the potential to improve soil chemical characteristics for the small holder resource-poor-farmers in Sub Saharan Africa. The results of the study indicated that smallholder farmers can save on N fertilizer if they incorporate a mucuna crop at flowering (MF) compared to the traditional fallow system (F). The fallow (control) management option resulted in a soil N content of 15ppm. Such a soil N level will need about 100 kg N ha^{-1} to allow farmers to harvest about 3-4 t ha^{-1} on sandy textured soils (Tagwira, 1992; Akinnifesi *et al.*, 2006). However the application of the MF management option under the P40 treatment increased N content of the soil to 24.3ppm. Such a soil will need only about 60 kg N ha^{-1} for farmers to realize a yield of 3-4 t ha^{-1} (Pal, 1991; Tagwira, 1992; Akinnifesi *et al.*, 2006). However if farmers remove pods from the mucuna crop and incorporate the rest of the above ground biomass the soil will need about 80 kg N ha^{-1} to realize the same yield. The P0 and MF treatment combination will need a supplement of about 70 kg N ha^{-1}.

The soils in this study, similar to many other soils in sub Saharan Africa, may not sustain satisfactory maize production because of serious P deficiencies (Pal, 1991; Akinnifesi *et al.*, 2006). Similar to the recommendations by Tagwira (1992), Hussein (1997) and Nyakanda (1997) the results of this study showed that P in the soil was inadequate at all P and mucuna management treatment combinations. Phosphorus levels should be > 30 ppm for it to be adequate for a maize crop (Tagwira, 1992). The MAR and MPR management options in the P0 treatment will require a supplementation of 50 kg P ha^{-1} to meet the maize P requirements in Zimbabwe as stipulated by Tagwira (1992). However if farmers use the MF management option they only need to supplement with 40 kg P ha^{-1} to meet the maize P requirements in Zimbabwe. The P40 and MF treatment combination will improve soil P and farmers will need to supplement with about 35 kg P ha^{-1} to meet the maize P requirements in Zimbabwe compared to the MPR and P40 treatment combination which will need about 40 kg ha^{-1}.

The level of exchangeable bases in this study indicated that they have been improved by the mucuna management options. The application of the P40 and the MF treatment combinations may result in farmers needing to supply about 20 kg K ha^{-1} to meet the K requirements for sandy soils. However the application of P40 and other mucuna treatments may require of farmers to supplement with 30 kg K ha^{-1}. The fallow (F) management option will require supplementing with 40 kg K ha^{-1} (Tagwira, 1992; Tisdale *et al.*, 1999). The availability of other exchangeable bases (Ca & Mg) can be enhanced by soil liming with Dolomite or quicklime at 800 kg ha^{-1} to raise the pH of the soil to ensure availability of these nutrients to maize crops. The optimum Ca and Mg requirements for maize production are less than 1.5 and 0.2 (meq %) respectively

(Tisdale *et al.*, 1999). The MF and MPR management options seem to have supplied adequate Ca for the subsequent maize crop. This could be attributed to the incorporation of Ca in the biomass of mucuna at flowering and maturity. For Mg it appears as if the MF management option provided adequate Mg. Since Mg is an essential component of the chlorophyll pyrole (Foy, 1992; Brady & Weil, 1996) this could mean that the mucuna which was incorporated whilst green in the MF management option had sufficient Mg in its foliage to satisfy the Mg requirements of a subsequent maize crop.

The application of mucuna management options under the P40 treatment showed lower Zn content than under the P0 treatment. This could be attributed to a more rigorous rooting system due to P application and hence a more effective removal of Zn from the soil. The acidifying effect of P on soil pH could also contribute to the low available Zn levels (Tisdale *et al.*, 1999). This will lead to the extraction of inherent Zn in the soil (Brady & Weil, 1996; Tisdale, *et.al*. 1999). Maize requires 21 to 70 ppm of Zn in Zimbabwe (Tagwira, 1992). The results of this study indicated that P0 and MF treatment combination will supply about 50 % of the optimum Zn requirements of a maize crop. However about 75 % of Zn requirements needs to be supplemented when using other mucuna management options with either the P0 or P40 treatments.

Conclusion

Phosphorus treatments and mucuna management options showed some great impact on the availability of essential nutrients. Generally mucuna incorporated at flowering (MF) at the P40 treatment will result in a saving on N, P and K fertilizers. However Zn levels are somehow negatively affected by mucuna management options under the P40 treatment. The study also emphasized the need for farmers to supplement with inorganic fertilizers to realize better yields even when mucuna is used as a rotational crop. Mucuna treatments however reduced the inorganic fertilizer requirements.

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Chapter 6

The effect of phosphorus, mucuna management options and nitrogen on the biomass, leaf area index and foliar nutrient content of maize on a depleted sandy loam soil in Zimbabwe

Abstract

Sufficient nutrient levels in leaves of crops have substantial effects on plant growth, development and grain yield, as it is a fundamental constituent of many leaf cell components. In this study; the effect of phosphorus, mucuna management options and nitrogen on the biomass, leaf area index (LAI) and leaf nutrient content of maize on a depleted sandy loam soil in Zimbabwe was investigated. The experimental design was a split- split- plot with two P rates (P0 and P40) applied to the mucuna crop, four mucuna management options [1) fallow (F) (no mucuna planted = control), 2) mucuna ploughed-in at flowering (MF), 3) all mucuna above ground biomass removed at maturity and only roots were ploughed-in (MAR) and 4) mucuna pods removed and the residues ploughed-in (MPR)] and four N treatments [N0 = 0 kg N ha^{-1}, N40 = 40 kg N ha^{-1}, N80 = 80 kg N ha^{-1} and N120 = 120 kg N ha^{-1}] applied to a subsequent maize crop. Data was collected at 5, 6, 7 and 8 weeks after emergence (WAE). Biomass, LAI and foliar nitrogen, phosphorus, potassium, calcium and magnesium in the subsequent maize crop were determined. A significant three-way interaction ($P<0.05$) between mucuna management options, nitrogen rates and time was observed in terms of biomass production and all nutrients in the leaves of the subsequent maize crop. Significant three-way interactions between phosphorus rates, nitrogen rates and time as well as a significant 2-way interaction between phosphorus and time were observed in terms of biomass and nitrogen respectively in the foliage of the subsequent maize crop. However there was no interaction of the four factors for LAI development, but significant differences were noted between times of sampling, nitrogen rates and mucuna management options as independent factors. Significant differences were also noted between the P0 and P40

treatments for phosphorus, potassium, calcium and magnesium levels in the leaves of maize. Generally the MF and MPR management option had significantly higher nutrient contents in the leaves of maize than the F and MAR management options. The F and MAR did not differ significantly in terms of most parameters.

***Keywords**:* biomass, fertilizers, foliar nutrients, leaf area index, maize, mucuna options

Introduction

The declining soil fertility resulting from monoculture crop production systems with little or no fertilizer application, has been cited as the most important constraint threatening food production on smallholder farms in sub-Saharan Africa (Adesina *et al.*, 2000). Previous studies carried out on the use of cover crops showed that inclusion of mucuna (*Mucuna pruriens*) as a fallow crop supplemented with low fertilizer rates, could improve maize growth. Work done by Smyth *et al.* (1991) and Oikeh *et al*. (1998) on mucuna-maize production systems showed that there was lower biomass of maize when mucuna roots were incorporated into the soil compared to whole biomass incorporation and attributed this reduction to the removal of the N in above-ground biomass. These positive effects of mucuna biomass incorporation on maize biomass among other growth parameters were attributed to improved soil properties such as soil bulk density, soil moisture retention, cation exchange capacity (CEC), organic C and soil N (Tisdale *et al*., 1999).

It is well known that nutrient deficiencies in most cultivated crops during the growth season causes nutrient imbalances, leading to reduced yield. Among the essential macronutrients; nitrogen (N) , calcium (Ca) and magnesium (Mg) are described as the most important elements for vegetative growth, flowering and fruit bearing of crops (Mengel & Kirkby, 1987; Shaahan *et al*., 1999). One of the results of N, Ca and Mg deficiency is lack of chlorophyll formation and a low chlorophyll density in plant leaves (Mengel & Kirkby, 1987). Sufficient nutrient level is a fundamental constituent of many leaf cell components, particularly those associated with the photosynthetic apparatus, including carboxylating enzymes and proteins of membranes (Pandey *et al*., 2000). It is important to always monitor the K critical levels in the maize crop because its limiting effect also affects the performance or availability of other basic cations (Brady & Weil, 1996).

Phosphorus is an essential element for root development and its deficiency can render the crop barren as the roots will not be able to absorb sufficient essential nutrients due to a poorly developed rooting system (Tisdale *et al*., 1999). It is also important for energy producing reactions in cells, such as the release of energy when adenosine triphosphate (ATP) is converted to adenosine di-phosphate (ADP) (Brady & Weil, 1996).

The aim of this study was to determine the effects of P application on a preceding mucuna crop, mucuna management options and N fertilizer rates on the biomass, LAI and nutrient content of the leaves of a subsequent maize crop from early vegetative to the flowering stages in a sandy loam soil in Zimbabwe. Mucuna was identified as a suitable rotational crop with maize in this area (Maasdorp & Titterton, 1997) and optimizing mucuna biomass production will most probably have positive effects on the vegetative foliar nutrient content and yield of the subsequent maize crop.

Materials and methods

Experimental site

The experiment was carried out at the Grasslands Research Station in Marondera in Zimbabwe. It is situated at approximately $18^{o}\ 11^{1}$S latitude and $31^{o}\ 30^{1}$E longitude at an altitude of 1200 m above sea level. At this site the average annual rainfall is 900 mm per annum (20-year mean), falling predominantly in the hot summer months (November to March). The winters are relatively cool and dry (Table 1) (http://www.worldweather.org/130/c00958.html). The mean US Weather Bureau class A pan evaporation is 1750 mm (Nyakanda, 1997).

Table 6.1 Rainfall data for the experimental site for 2007 and 2008 (Grasslands Research Station, Marondera, Climatological Section) and long-term climatological data for Marondera (http://www.worldweather.org/130/c00958.htm)

	Mean temperature (ºC)		Mean total rainfall (mm)				
Month	**Daily minimum**	**Daily maximum**	**Long term**	**2007**	**2008**	**2009**	**Mean number of rain days**
Jan	15.3	23.6	193.4	333.1	352.5	366.3	14
Feb	13.1	24.5	149.1	48	10	56.6	12
Mar	15.8	23.9	90.3	14	74	86.5	9
Apr	12.5	22.8	48.7	0	0	12	5
May	11.9	21.0	10.1	0	0	0	2
Jun	6.2	18.3	5.4	0	0		1
Jul	5.3	18.4	3.0	0	0		1
Aug	6.3	25.0	3.0	0	0		1
Sep	12.5	25.5	6.8	0	0		1
Oct	13.5	26.0	40.3	85.5	11		5
Nov	14.8	25.9	113.1	157.2	137.4		10
Dec	14.5	24.3	187.7	429.2	282.6		15

The soils are classified as humic Ferrolsols based on the FAO/UNESCO system (FAO UNESCO, 1994) and are equivalent to a Kandiudalfic Eutaudox in the USDA soil taxonomy system (Soil Survey Staff, 1994). The soils are predominantly of the kaolinitic order with loamy sands of low fertility (Hussein, 1997). In general these soils are slightly acid (pH_{CaCl} = 5.2) with organic matter content of 0.33% (Hussein,1997). Soil analyses performed on soil samples taken before the trial started showed a mineral N content of 15 ppm at the time of sampling as well as a P content of 15.8 ppm, K content of 0.15 meq%, Ca content of 0.2 meq% and Mg content of 0.03 meq% (Shoko, unpublished data).

Crop establishment

The field which was planted to mucuna in both seasons (2007 and 2008) was ploughed, disced and planted to the subsequent maize crop, variety, SC 513 (early maturing). The maize crop was planted on 22 December 2007 (first season crop) and 8 December 2008 (second season crop). An inter-row spacing of 90 cm and intra row spacing of 25 cm was used to achieve a plant population of about 44444 plants ha^{-1}. A seeding rate of 25 kg ha^{-1} was employed. Planting was done by hand. No basal fertilizer was applied to the maize crop. This was done to simulate the resource- poor farmers' practice. The N treatments were split-applied twice at as a top dressing. The first dressing of 40 kg N ha^{-1} was applied at 4 weeks after emergence (WAE) and the balance of each of the treatments was applied at tasseling stage in both seasons. Weed control was done twice using mechanical methods.

Experimental design and treatments applied

The experimental design was a split-split- plot with 2 P treatments applied to the mucuna crop as main plot factors [P0 = 0 kg P ha^{-1} and P40 = 40 kg P ha^{-1} which is 0 and 100% of the recommended rate], four mucuna management options [1) fallow (F) (no mucuna planted = control), 2) mucuna ploughed-in at flowering (MF), 3) all mucuna above ground biomass removed at maturity (MAR) and 4) mucuna pods removed and the residues ploughed-in (MPR)] as sub plot factors and 4 N treatments [N0 = 0 kg N ha^{-1}, N40 = 40 kg N ha^{-1}, N80 = 80 kg N ha^{-1} and N120 = 120 kg N ha^{-1} representing about 0, 33, 66 and 100 % of the recommended rate] applied to the subsequent maize crop as sub-sub-plot factors. The treatments were replicated 4 times. The plot size was 10 m x 10 m.

Biomass and Leaf Area Index (LAI) determination

Biomass (dry weight) and LAI were determined at 5, 6, 7 and 8 weeks after emergence (WAE). From each plot an area of $2m^2$ was sampled per sampling week for total biomass determination. Dry mass was determined by oven drying the components at 80 ^oC to constant weight before weighing. Leaf components from the plants which were sampled for biomass were also used for LAI determination. LAI was determined using a Delta-T Leaf Area Meter (Delta-T area meter MK 2, Cambridge, UK).

Foliar nutrient analyses

From the same plants that were sampled for biomass determination 10 plants were randomly selected. The leafy parts were then removed from the plants for analyses. They were analysed for N, P, K, Ca and Mg. The analyses of the mentioned nutrients were done using standard procedures as described by AOAC (1990).

Statistical analyses

Statistical analysis of the data was performed using the Statistica package (Software, version 8.02). Analysis of variance (ANOVA) was conducted to determine the interaction of factors. Means were separated using Bonferroni adjustment for testing least significant differences at the 5% level when ANOVA revealed significant ($P < 0.05$) differences among the treatments. The treatment factors compared were P rates, mucuna management options, N rates and time.

Results

The combined data for the 2007/08 and 2008/09 seasons are presented because the data for the separate seasons showed similar trends for the parameters measured. The data showed no significant seasonal effects.

Biomass

Although the study looked at 4 factors (P rates, mucuna management options, N rates and time) there was no significant ($P > 0.05$) 4-way interaction. However there were two significant 3-way interactions ($P < 0.05$), namely, mucuna management options x nitrogen rates x time and phosphorus treatments x nitrogen rates x time.

Mucuna management options, nitrogen rates and time interaction

The significant ($P < 0.05$) 3-way interaction of mucuna management options, nitrogen rates and time is illustrated in Table 2. Biomass increased with time of sampling and through out all the 4 sampling times the MF and N120 treatment combination had a significantly ($P < 0.05$) higher biomass followed by the MPR and N120 treatment combinations. However the MF and N0 treatment combination did not differ significantly from the F (control) and N120 treatment combination at all sampling times except at 6 WAE. Invariably, through-out the sampling period the MPR and N120 treatment combination was always second in terms of biomass for the subsequent maize crop to the MF and N120 treatment combination. The F and MAR mucuna management options did not differ significantly from each other at any N rate over all sampling times.

Phosphorus treatments, nitrogen rates and time interaction

A significant interaction ($P < 0.05$) between phosphorus treatment, nitrogen rates and time in terms of the biomass of maize was noted (Table 3). The N120 rate produced significantly ($P < 0.05$) more biomass throughout the sampling times in both the P0 and P40 treatments. In the majority of cases the N rates did not show significant differences between the P treatments. Only at 6 WAE in the N0 treatment and at 8 WAE in the N120 treatment did the P40 treatment produced significantly more biomass than in the corresponding P0 treatments.

Leaf Area Indices (LAI) determination

There were no significant ($P > 0.05$) interactions between the four factors (P rates, mucuna management options, N rates and time) used in this study in terms of LAI. However there were significant ($P < 0.05$) differences between treatments within factors of N rates, mucuna management options and times of sampling. There were no P treatment effects.

Effect of mucuna management options on LAI

The LAI of maize under the MF mucuna management option (2.73) were significantly ($P < 0.05$) higher than the MPR mucuna management option (1.99). Both these management options had significantly higher LAI than the F (1.09) and MAR (1.12) mucuna management options which did not differ significantly from each other. The MF mucuna management option resulted in a 143.8% and 37.7% higher LAI than the F and MPR options respectively. The LAI of maize under the MPR and MF management option is considered sufficient for maximum productivity.

Table 6.2 Combined (2007/08 and 2008/09 seasons) biomass (tha^{-1}) of maize as influenced by mucuna management options, nitrogen rates and time interactions on a sandy loam soil in Zimbabwe (MF = mucuna incorporated at flowering, MAR = mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F = Fallow (control); N0 = 0 kg N ha^{-1}, N40 = 40 kg N ha^{-1}, N80 = 80 kg N ha^{-1}, N120 = 120 kg N ha^{-1}). Values followed by the same letter are not significantly different at P = 0.05

		Maize biomass (t ha^{-1})			
		……………….Weeks after emergence…………..			
Mucuna options	***N (kg ha^{-1})***	***5***	***6***	***7***	***8***
F	0	0.73a	1.36b	1.53c	2.03d
	40	1.23b	1.52c	1.63c	2.31f
	80	1.54c	2.22f	2.11d	2.32f
	120	1.59c	2.31f	2.52g	3.00h
MF	0	1.58c	2.00d	2.59g	2.97h
	40	2.03d	2.45g	2.53g	3.11h
	80	2.11d	3.12h	3.13h	4.00j
	120	2.41f	3.54i	3.94j	5.13L
MPR	0	1.51c	1.78e	2.04d	2.36f
	40	1.83e	2.08d	2.04d	2.43g
	80	1.89e	2.56g	2.45g	3.59i
	120	2.04e	2.98h	3.17h	4.50k
MAR	0	0.88a	1.38c	1.51c	2.13e
	40	1.25b	1.69c	1.64c	2.36f
	80	1.30b	2.25f	2.05e	2.30f
	120	1.62c	2.34f	2.53g	3.06h

Table 6.3 Combined (2007/08 and 2008/09 seasons) biomass (tha^{-1}) accumulation of maize as influenced by phosphorus, nitrogen rates and time interactions on a sandy loam soil in Zimbabwe after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1}) applied to the mucuna crop and four N rates (N0 = 0 kg N ha^{-1}, N40 = 40 kg N ha^{-1} , N80 = 80 kg N ha^{-1} , N120 = 120 kg N ha^{-1}) applied to the maize crop. WAE is weeks after emergence. Values followed by the same letter is not significantly different at P = 0.05

	…………………………			*Maize biomass ((t ha^{-1})*………………………				
	P0				**P40**			
N (kgha⁻)	***0***	***40***	***80***	***120***	***0***	***40***	***80***	***120***
5WAE	1.19a	1.57b	1.69c	1.89d	1.15a	1.60b	1.74c	1.94d
6WAE	1.59b	1.88d	2.50f	2.70g	1.67c	1.97d	2.57f	2.80g
7WAE	1.88d	1.93d	2.40e	3.01h	1.96d	1.99d	2.47e	3.06h
8WAE	2.34e	2.51f	3.01h	3.86i	2.41e	2.59f	3.10h	3.99j

Effect of N rates on LAI

The LAI of maize under the N120 (2.68) and N80 (2.0) nitrogen rates did not differ significantly (P > 0.05) and the LAI of maize under the N0 (0.75) and N40 (1.20) nitrogen rates did not differ significantly from each other either. However the N80 and N120 rates had significantly (P < 0.05) higher LAI than the N0 and N40 rates.

Effect of time of sampling on LAI

Significant differences (P < 0.05) between some times of sampling on the LAI of maize were noted. No significant differences (P > 0.05) were noted between 5 WAE (1.18) and 6 WAE (1.26) and also not between 7 WAE (1.97) and 8 WAE (2.49). The LAI of maize at 7 WAE and 8 WAE was significantly higher than at 5 WAE and 6 WAE.

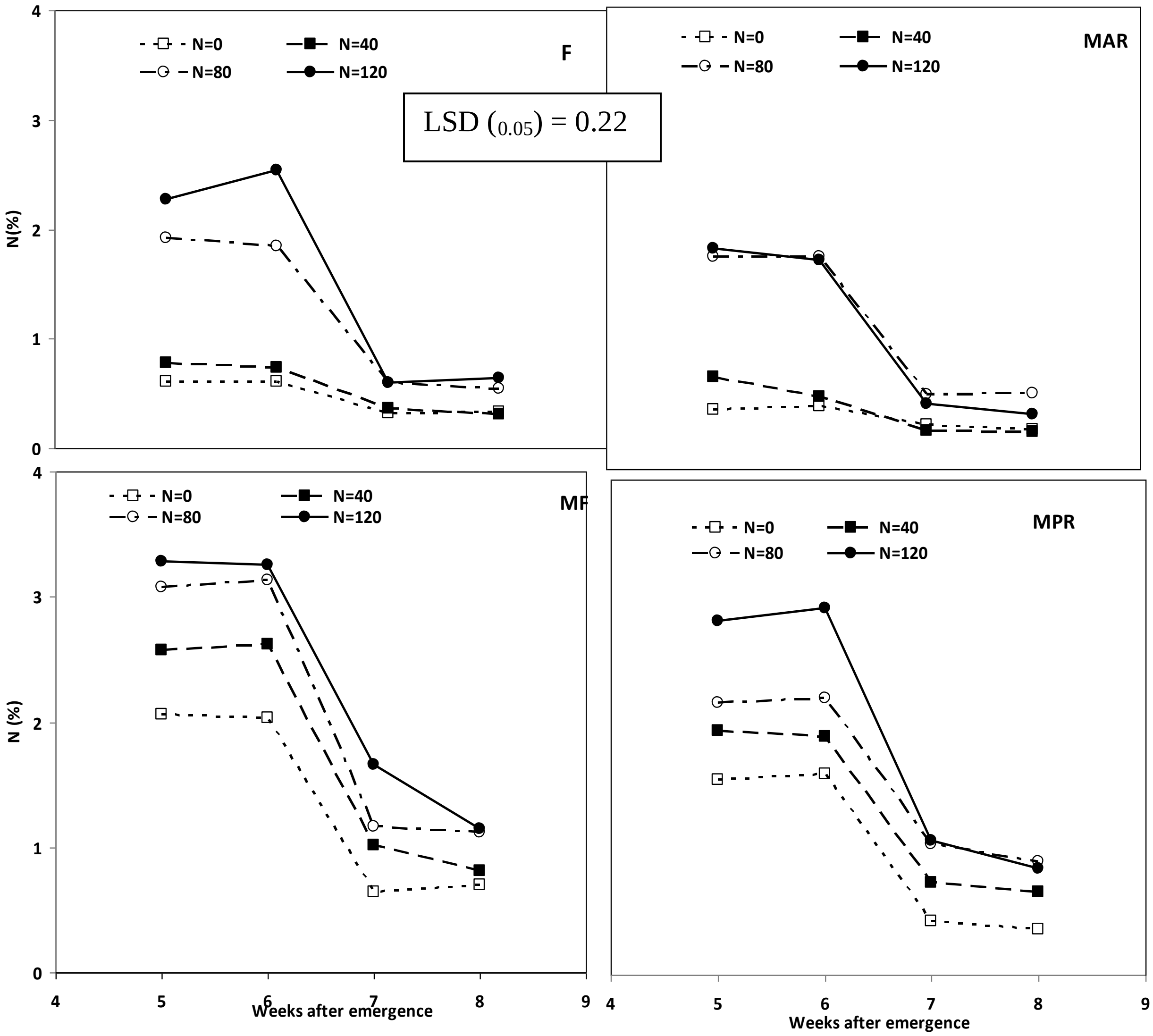

Figure 6.1 Average (2007 and 2008 seasons) nitrogen (%) in leaves of maize showing the mucuna management options, nitrogen rates and time interactions on a sandy loam in Zimbabwe (MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F = Fallow (control); N0 = 0 kg N ha^{-1}, N40 = 40 kg N ha^{-1}, N80 = 80 kg N ha^{-1}, N120 = 120 kg N ha^{-1} applied to the subsequent maize crop). LSD value is for all the mucuna management options.

Nitrogen content

Mucuna management options, nitrogen rats and time interaction in terms of N in maize leaves

The significant (P < 0.05) 3-way interaction of mucuna management option, nitrogen rates and time on N concentration in leaves of maize is illustrated in Figure 6.1. Nitrogen concentration in leaves of maize significantly (P < 0.05) decreased from 5 WAE when compared to that of 8 WAE through out the treatment combinations. Maize planted on the MF management option and N120 rate had significantly highest N through out the sampling times. However the MF management option and N0 rate treatment combination did not differ significantly from the F (control) management option and N80 rate combinations at 5 WAE. The MPR management option and N0 rate combinations did not differ significantly (P > 0.05) from the F management option and N40 rate combinations at 5 WAE. The MAR and F management option were not significantly different in most cases.

Phosphorus rate and time of sampling interaction in terms of N in leaves of maize

There was a significant (P < 0.05) 2-way interaction between the P treatments and time on N in the leaves of maize (Table 6.4). Nitrogen concentration in the leaves of maize significantly decreased from 5 when compared to that of 8 WAE. Maize under the P40 treatment had 9.9%, 7.3%, 21.7% and 24% more N than P0 at 5, 6, 7 and 8 WAE respectively. However N content in maize leaves receiving the P40 treatment at 5 and 6 WAE were not significantly different.

Table 6.4 Average nitrogen (%) in leaves of maize showing phosphorus and time interactions on a sandy loam soil during the 2007 and 2008 seasons. (WAE = weeks after emergence; P0 = No P applied (control) and P40 = 40 kg P ha^{-1}). Values followed by the same letter are not significantly different at P = 0.05

Time of sampling	P0	P40
5 WAE	1.73e	1.89g
6 WAE	1.78f	1.90g
7 WAE	0.61b	0.73d
8 WAE	0.51a	0.64c

Phosphorus

The P concentration in mucuna showed a significant ($P < 0.05$) 3-way interaction of mucuna management option, nitrogen rate and time (Figure 6.2). The P concentration in leaves of maize significantly ($P < 0.05$) increased systematically from 5 to 8 WAE in all the mucuna management options and in all the N rates.

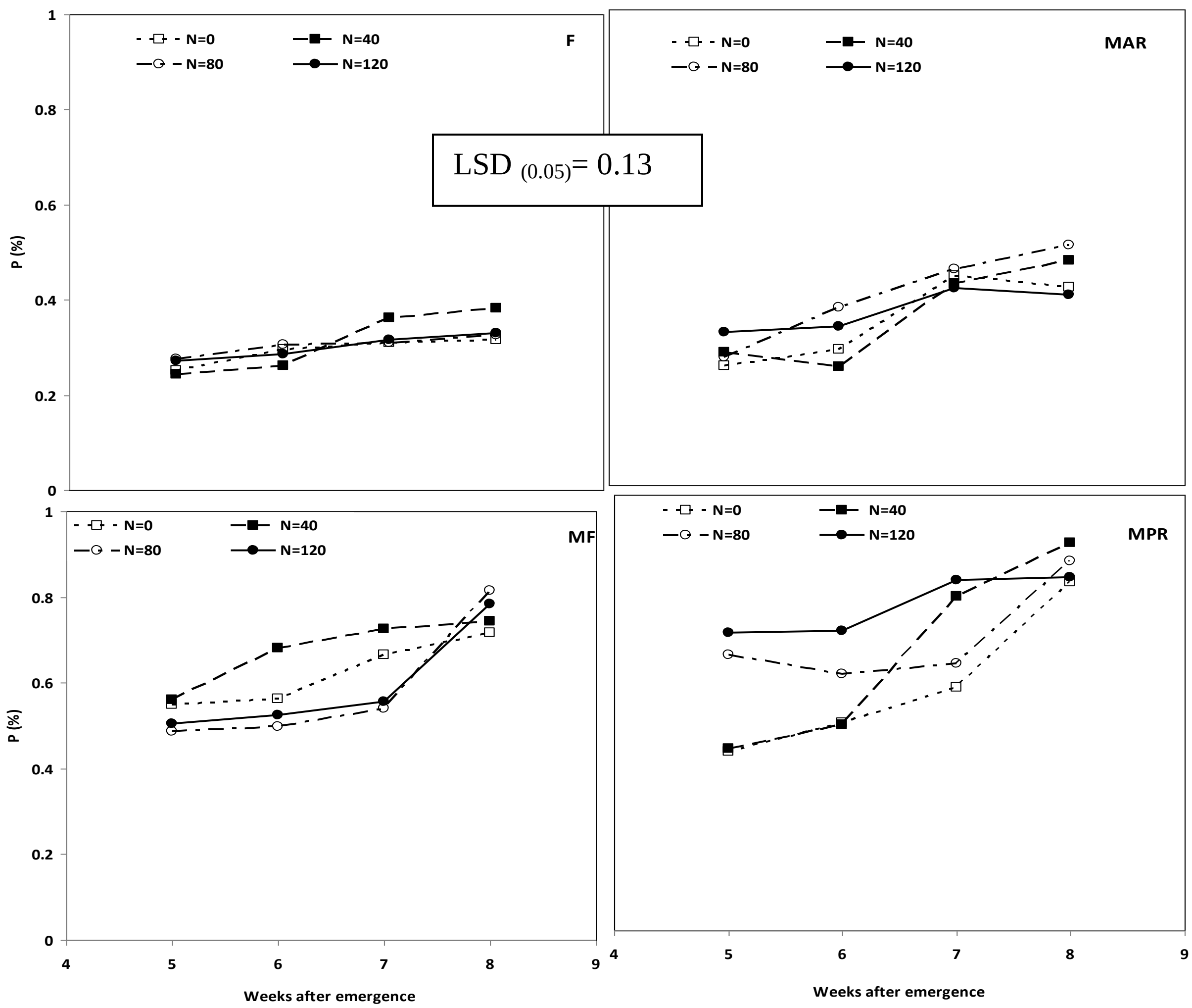

Figure 6.2 Average (2007 and 2008 seasons) phosphorus (%) in leaves of maize showing the mucuna management options, nitrogen rates and time interactions on a sandy loam in Zimbabwe (MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F = Fallow (control); N0 = 0 kg N ha^{-1}, N40 = 40 kg N ha^{-1}, N80 = 80 kg N ha^{-1},

N120 = 120 kg N ha^{-1} applied to the subsequent maize crop). LSD value is for all the mucuna management options.

The MF and MPR management options had more P in leaves at NO rate at 5 WAE than the F management option at N120 rate at 8 WAE. The MF and MPR management options had a bigger increase of P with time than the F and MAR management options. The MAR and F management options did not differ significantly in most of the sampling weeks and N treatments.

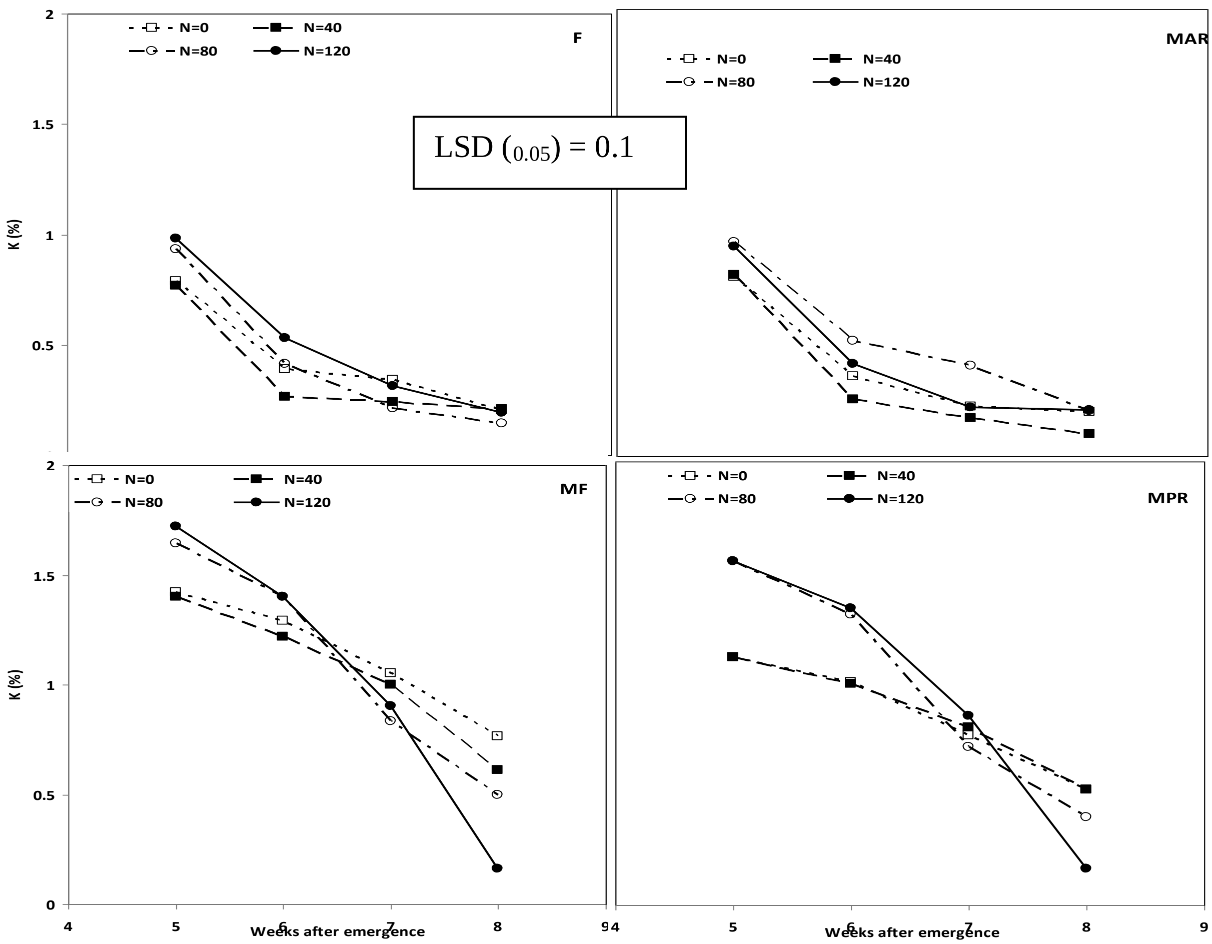

Figure 6.3 Average (2007 and 2008 seasons) potassium (%) in leaves of maize showing the mucuna management options, nitrogen rates and time interactions on a sandy loam in Zimbabwe (MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F = Fallow (control); N0 = 0 kg N ha^{-1}, N40 = 40 kg N ha^{-1}, N80 = 80 kg N ha^{-1},

N120 = 120 kg N ha^{-1} applied to the subsequent maize crop). LSD value is for all the mucuna management options.

Potassium

Figure 6.3 shows a significant (P < 0.05) 3-way interaction of mucuna management option, nitrogen rate and time in terms of K content of maize leaves. The K concentration in leaves of maize significantly (P < 0.05) decreased from 5 to 8 WAE in all the mucuna management options and in all the N rates. At 8 WAE the K content in the MF and MPR management option were inversely related to the N rate applied, in contrast with the situation at 5 WAE.

Calcium

As in the case of K, the concentration of Ca decreased when comparing the content at 5 WAE to that at 8 WAE in a 3-way interaction of mucuna management option, nitrogen rate and time (Figure 6.4). The Ca levels in the F and MAR management options did not differ significantly over all N rates. The MF and MPR management options showed differences between the N rates at 5 WAE which the MAR and F management option did not. However at 7 WAE and 8 WAE these differences disappeared.

Magnesium

The Mg concentration in maize showed a significant (P < 0.05) 3-way interaction of mucuna management option, nitrogen rate and time (Figure 6.5). The Mg concentration in leaves of maize significantly (P < 0.05) decreased from 6 to 8 WAE in the MF and MPR mucuna management options over all the N rates. The MF and MPR and N80 and N120 treatment combinations had significantly higher Mg in their leaves at 5 and 6 WAE compared to other N rates. The F (control) and the MAR management options did not differ significantly through-out the sampling times under all the N rates and there was no reduction in Mg content with time.

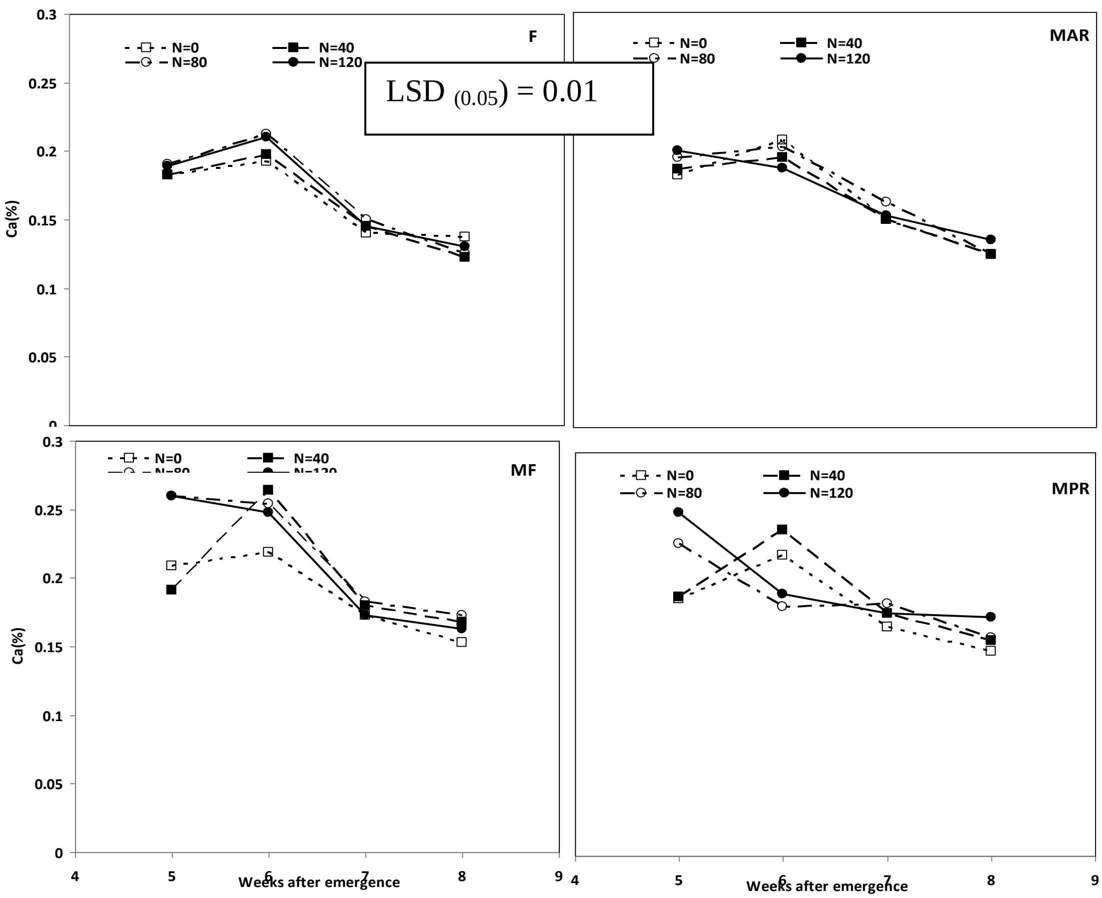

Figure 6.4 Average (2007 and 2008 seasons) calcium (%) in leaves of maize showing the mucuna management options, nitrogen rates and time interactions on a sandy loam in Zimbabwe (MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F = Fallow (control); N0 = 0 kg N ha^{-1}, N40 = 40 kg N ha^{-1}, N80 = 80 kg N ha^{-1}, N120 = 120 kg N ha^{-1} applied to the subsequent maize crop). LSD value is for all the mucuna management options.

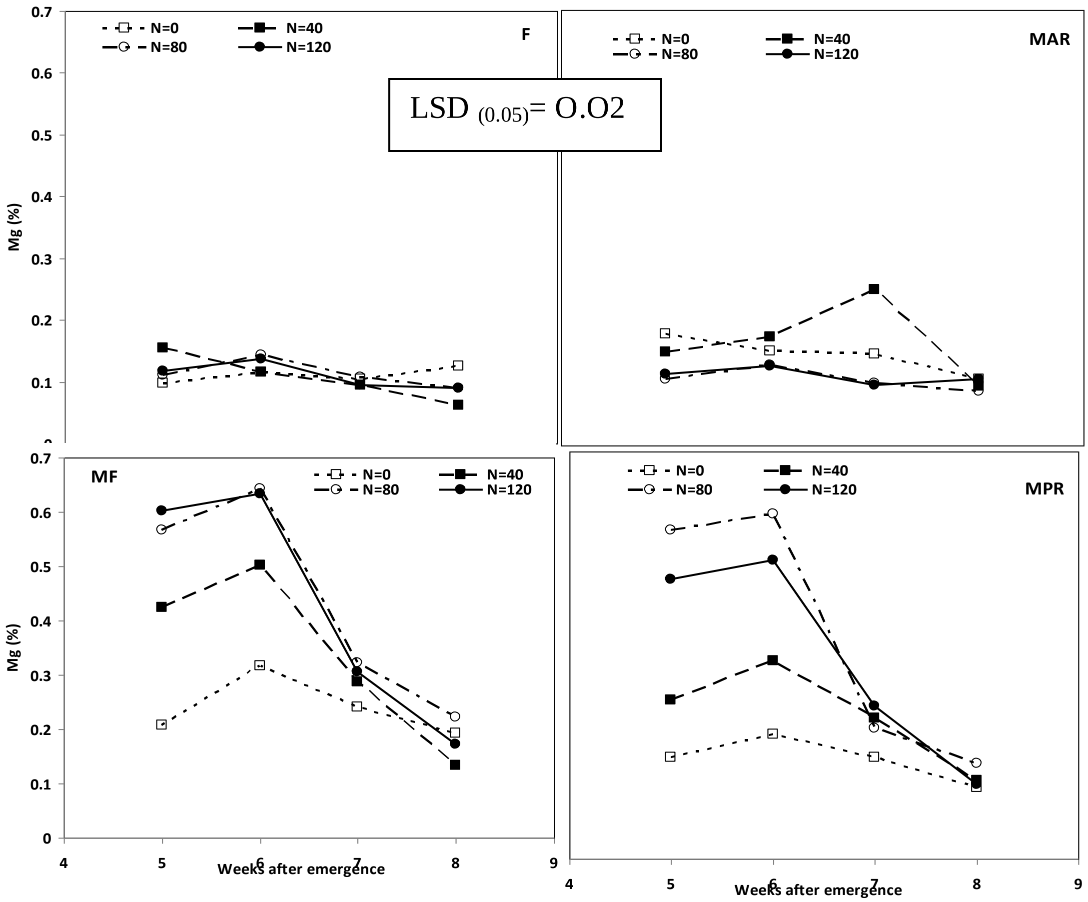

Figure 6.5 Average (2007 and 2008 seasons) magnesium (%) in leaves of maize showing the mucuna management options, nitrogen rates and time interactions on a sandy loam in Zimbabwe (MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F = Fallow (control); N0 = 0 kg N ha^{-1}, N40 = 40 kg N ha^{-1}, N80 = 80 kg N ha^{-1}, N120 = 120 kg N ha^{-1} applied to the subsequent maize crop). LSD value is for all the mucuna management options.

Effect of P on P, K, Ca and Mg concentration in leaves

There were significant differences ($P < 0.05$) between the P40 and P0 treatments with regards to P, K, Ca and Mg concentration in leaves of maize (Table 6.5). The P40 treatment resulted in higher P, K, Ca and Mg concentrations when compared to the P0 treatment.

Table 6.5 Effect of P levels applied to a preceding mucuna crop on the % P, K, Ca and Mg content in leaves of maize on a sandy loam soil in Zimbabwe (P0 = No P applied (control) and P40 = 40 kg P ha^{-1}). Values followed by the same letter in a row are non significantly different at P =0.05

Nutrients	P0	P40
Phosphorus (%)	0.48a	0.51b
Potassium (%)	0.70a	0.72b
Calcium (%)	0.17a	0.19b
Magnesium (%)	0.22a	0.23b

Discussion

Biomass

The MAR and F mucuna management options combined with the N0 treatment resulted in the lowest biomass throughout the sampling times during the 2007/2008 and 2008/2009 seasons. This trend could be attributed to low inherent N in the soil as well the inability of the mucuna root biomass in the MAR management option to supply sufficient N to the subsequent maize crop. These findings confirm research done by Smyth *et al.* (1991) and Oikeh *et al.* (1998). The MF management option resulted in the highest maize biomass production in all the N treatments throughout the sampling weeks. This high biomass values could be due to the high N content of the incorporated mucuna green manure (incorporated at flowering) enhanced by the supplementation of inorganic N. This is supported by Carsky *et al*. (1999) and Giller *et al.* (1998) who found that mucuna incorporated at maturity did not add as much N as when incorporated at flowering because most N will be removed with the harvested pods unlike in green manuring systems. The results of this work also showed that the MF and N0 treatment combinations did not differ significantly from the F and N120 treatment combination at 6 WAE. In critical fertilizer shortage times in Zimbabwe farmers can still obtain high biomass which will translate into high yield potential when they use mucuna and incorporate it at flowering with no N supplements. If farmers decide to use the MPR management option alone they may realize the same biomass yield as when using F and supplementing with N80 (60% of the recommended rate).

The biomass yield of maize was significantly higher under the N120 treatment in both P treatments. The higher biomass obtained at the N120 rate in the P40 treatment at 8 WAE could be attributed to the influence of P at this late stage. Phosphorous is immobile in the soil and therefore for the first 6 WAE after emergence the maize crop could have suffered from P deficiencies due to a still developing root system.

Leaf Area Index

The LAI of maize under the MF and MPR mucuna management options were 2.73 and 1.99 respectively. Since the maize was planted in 0.9m row widths these LAI values will maximize interception of photosynthetic active radiation (PAR) since they are greater than or equal to 2.0 (Keating & Wafula, 1992; Zhou, *et al.*, 2003). The high LAI could be due to the increase in soil N from the MF and MPR management options which were incorporated (Shoko *et al*, unpublished data). High N concentrations influence foliar expansion and elongation (Amanulla *et al.*, 2007).

The application of N80 and N120 did not result in significant LAI differences between the two rates. The LAI of maize from these two rates were above 2.0. This means maize under these treatments would maximize interception of PAR and hence have maximum net productivity. This could be due to the influence of N on foliar elongation and expansion (Amanulla *et al.*, 2007).

Nutrient content in leaves

Determining nutrient levels in leaves is important as they may give a guide to supplementation with inorganic fertilizers to improve crop productivity. The critical N levels considered to be sufficient for maize are 3.0- 5.0 % and 1.8 – 2.7% for the vegetative growth and tasselling stages respectively (Mills & Jones, 1996). The vegetative stage for the variety under study is up to about 6 WAE and the tasseling is up to 8 WAE. This study shows that the MF management option at N80 and N120 rates as well as the MPR management option at the N80 rate may give the farmer's maize sufficient N for the early vegetative growth as well as at tasseling. Work done by Muhr *et* *al.* (1999) in West Africa supports my findings when they also found that green manuring of mucuna contributed to higher N content in subsequent maize crop than incorporating mucuna at maturity. The sufficient N levels could be attributable to additional accumulation of fixed N by the MF and MPR management options. The sufficient N levels will enhance chlorophyll formation and then boost protein synthesis and general productivity of the crop on sandy loam soils (Brady & Weil, 1996). The F and MAR management options resulted in N levels which was less than the critical levels at both growth stages.

The MF and MPR management options had sufficient P to sustain maize production at the vegetative stage. These treatments had more than the critical level of 0.3 – 0.5 % required (Mills & Jones, 1996). This P level is important for root development and hence efficient nutrient absorption. However the F and MAR management option under all the N rates were below the critical levels at the vegetative stage. The F and MAR management option were below the critical level of 0.20 – 0.40 % at tasseling stage. The steady increase in P level in the leaves of maize as the crop matures can be attributed to the slow mineralization of P, which will be readily available to plants when they have matured (Tisdale *et al.*, 1999).

The results of this study show that all the treatment combinations reflected K levels which were below the recommended critical level of 2.0 - 4.0% and 1.2% at the vegetative and tasseling stages respectively (Mills & Jones, 1996). Sandy soils have limited inherent K (Hussein, 1997). This will call for K supplementation with inorganic fertilizers.

Generally Ca levels were sufficient under all the treatment combinations at the vegetative stage (> 0.2 %). The satisfactory Ca levels could also be attributable to sufficient inherent soil Ca at the site (Shoko, unpublished data).

Magnesium plays an important role in photosynthesis. The results of the study show that the F (control) and the MAR generally had lower Mg levels than the recommended level of 0.15 % at the vegetative stage (Mills & Jones, 1996). However the MF and MPR management options under all the N rates had higher Mg levels than the recommended level at the vegetative stage. At the tasseling stage the Mg level was within the recommended critical level of 0.10- 0.30 %. Memon *et al.* (2007) found that legume management practices which enhance N availability will lead to crops not showing deficiency symptoms of Mg. These findings can be loosely linked to the enhancement of N by the MF and MPR management options to the subsequent maize crop and hence sufficient Mg being found in the leaves of maize.

Conclusion

Mucuna incorporated at flowering and supplemented with either 80 or 120 kg N ha^{-1} resulted in a maize crop with the highest biomass through out the sampling weeks. The LAI is also higher with application of higher N rates and the use of the MF and MPR management options. This study emphasizes the need to use organic sources of N such as mucuna because they slowly mineralize N. However farmers can supplement with about 30% of the recommended N when they decide to use the MPR management option (harvest the mucuna pods at maturity and plough under the rest of the biomass) and realize biomass and LAI values similar to adding 120 kg N ha^{-1} in a maize monoculture system. The use of the MF management option alone can see farmers realize the same biomass and LAI values as with the application of 120 kg N ha^{-1} in a maize monoculture system.

The analysis of the nutrient content of maize tissue is important as it will give farmers a more accurate indication regarding the deficiency levels of nutrients. This will also give the farmers the correct fertilizer supplementation rates. The MF and MPR management options can help to supply the soil with some nutrients since they represent the organic part of mucuna which will be incorporated. These sources of nutrients can help to guard against the loss pathways of N such as leaching and volatilization (Hussein, 1997).

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Chapter 7

The effect of P, mucuna management options and N on the yield and yield components of maize on a depleted sandy loam soil in Zimbabwe

Abstract

Most of the smallholder farmers use sub-optimal amounts of fertilizers due to cash limitations and poor access to fertilizer markets hence the need to integrate legumes like mucuna into their cropping systems. In this study, the effect of P, mucuna management options and N on the yield and yield components of maize on a depleted sandy loam soil in Zimbabwe was investigated. The experimental design was a split- split- plot with two P rates (P0 and P40) applied to a preceding mucuna crop, four mucuna management options [1) fallow (F) (no mucuna planted = control), 2) mucuna ploughed-in at flowering (MF), 3) all mucuna above ground biomass removed at maturity and only roots were ploughed-in (MAR) and 4) mucuna pods removed and the residues ploughed-in (MPR)] and four N treatments [N0 = 0 kg N ha^{-1}, N40 = 40 kg N ha^{-1}, N80 = 80 kg N ha^{-1} & N120 = 120 kg N ha^{-1}] applied to a subsequent maize crop. The cob length, number of grains per cob, cob diameter, 1000 dry grain weight, grain yield, stalk weight and harvest index of maize were determined. Significant three-way interactions between phosphorus, mucuna management options and nitrogen rates were observed in terms of cob length, harvest index and 1000 grain weight. Significant two-way interactions between mucuna management options and nitrogen rates was observed in terms grain yield, stalk weight and cob diameter. Differences were also noted between mucuna management options and nitrogen rates as independent factors in terms of number of grains per cob. In general the MF management option gave a higher yield across all the treatment combinations.

Keywords: biomass, maize yield, mucuna management options, N rates, smallholder farmer, yield components

Introduction

Positive residual effects of N-fixing legumes on subsequent cereals in rotations have been widely reported in both old and modern agriculture (Giller & Wilson, 1991; Kumwenda *et al*., 1995). The yield increases have been primarily attributed to an improvement in the N availability in the soils. Studies on the predominantly sandy soils of Southern Africa have shown the complexity of soil fertility problems on smallholder farms and the challenges in developing sustainable management options (Scoones *et al.*, 1996; Snapp *et al*., 1998). There are limited opportunities for building soil organic matter in the smallholder farming mainly because of monoculture production systems (Giller & Wilson, 1991), rendering farmers to rely heavily on external nutrient inputs on a seasonal basis. However, most of the smallholder farmers use sub-optimal amounts of fertilizers due to cash limitations and poor access to fertilizer markets (Kumwenda *et al*., 1995; Ahmed *et al*., 1996).

This whole issue of nutrient supply to maize production systems calls for increased efficiency in use and recycling of both exogenous and endogenous nutrient pools in the cropping systems. Although work has been done on mucuna as a rotational crop (Mausolff & Farber, 1995) not much has been done on the ability of a mucuna crop which was managed differently with regard to P application and residue handling on the growth and yield of the subsequent maize crop management on a kaolitic sandy loam soil in Zimbabwe.

The aim of this study was to determine the effects of P application to a preceding mucuna crop, mucuna management options and N fertilizer application rates on the yield and yield components of a subsequent maize crop on a sandy loam soil in Zimbabwe. Mucuna was chosen for this study because of its ability to grow on relatively infertile soil and its tolerance to drought and other environmental stress (Maasdorp & Titterton, 1997; Muhr *et al*., 1999).

Materials and methods

Experimental site

The experiment was carried out at the Grasslands Research Station in Marondera in Zimbabwe. The Grasslands Research Station is situated at approximately 18^{o} 11^{1}S latitude and 31° 30¹E longitude at an altitude of 1200 m above sea level. At this site the average annual rainfall is 900 mm per annum (20-year mean), falling predominantly in the hot summer months (November to March). The winters are relatively cool and dry (Table 7.1) (http://www.worldweather.org/130/c00958.htm). The mean US Weather Bureau class A pan evaporation is 1750 mm (Nyakanda, 1997).

Table 7.1 Rainfall data for the experimental site for 2007 and 2008 (Grasslands Research Station, Marondera, Climatological Section) and long-term climatological data for Marondera (http://www.worldweather.org/130/c00958.htm)

Month	Mean temperature (°C)		Mean total rainfall (mm)				Mean number of rain days
	Daily minimum	Daily maximum	Long term	2007	2008	2009	
Jan	15.3	23.6	193.4	333.1	352.5	366.3	14
Feb	13.1	24.5	149.1	48	10	56.6	12
Mar	15.8	23.9	90.3	14	74	86.5	9
Apr	12.5	22.8	48.7	0	0	12	5
May	11.9	21.0	10.1	0	0	0	2
Jun	6.2	18.3	5.4	0	0		1
Jul	5.3	18.4	3.0	0	0		1
Aug	6.3	25.0	3.0	0	0		1
Sep	12.5	25.5	6.8	0	0		1
Oct	13.5	26.0	40.3	85.5	11		5
Nov	14.8	25.9	113.1	157.2	137.4		10
Dec	14.5	24.3	187.7	429.2	282.6		15

The soils are classified as humic Ferrolsols based on the FAO/UNESCO system (FAO UNESCO, 1994) and are equivalent to a Kandiudalfic Eutaudox in the USDA soil taxonomy system (Soil Survey Staff, 1994). The soils are predominantly of the kaolinitic order with loamy sands of low fertility (Hussein, 1997). In general these soils are slightly acid (pH $_{CaCl}$ = 5.1) with organic matter content of 0.33% (Hussein,1997). Soil analyses performed on soil samples taken before the trial was established showed a mineral N content of 15 ppm at the time of sampling as well as a P content of 15.8 ppm, K content of 0.15 meq%, Ca content of 0.2 meq%, Mg content of 0.03 meq% and organic matter was 0.26 % (Shoko *et al.*, unpublished data).

Crop establishment

The field which was planted to mucuna in both seasons (2007 and 2008) was ploughed, disced and planted to the subsequent maize crop, variety, SC 513 (early maturing). The maize crop was planted on 22 December 2007 (first season crop) and 8 December 2008 (second season crop). An inter-row spacing of 90 cm and intra row spacing of 25 cm was used to achieve a plant population of about 44444 plants ha^{-1}. A seeding rate of 25 kg ha^{-1} was employed. Planting was done by hand. No basal fertilizer was applied to the maize crop. This was done to simulate the resource- poor farmers' practice. The N treatments were split-applied twice at as a top dressing. The first dressing of 40 kg N ha^{-1} was applied at 4 weeks after emergence (WAE) and the balance of each of the treatments was applied at tasseling stage in both seasons. Weed control was done twice using mechanical methods. Rains were above normal during the experimental season so that was no irrigation supplementation.

Experimental design and treatments applied

The experimental design was a split-split-plot with 2 P treatments applied to the mucuna crop as main plot factors [P0 = 0 kg P ha^{-1} and P40 = 40 kg P ha^{-1} which is 0 and 100% of the recommended rate], four mucuna management options [1) fallow (F) (no mucuna planted = control), 2) mucuna ploughed-in at flowering (MF), 3) all mucuna above ground biomass removed at maturity (MAR) and 4) mucuna pods removed and the residues ploughed-in (MPR)] as sub plot factors and 4 N treatments [N0 = 0 kg N ha^{-1}, N40 = 40 kg N ha^{-1}, N80 = 80 kg N ha^{-1} and N120 = 120 kg N ha^{-1} representing about 0, 33, 66 and 100 % of the recommended rate] applied to the subsequent maize crop as sub-sub-plot factors. The treatments were replicated 4 times. The plot size was 10 m x 10 m. The following variables were determined; dry de-husked cob length, dry cob diameter, number of grains per cob, 1000 grain weight, grain yield, dry stalk weights and harvest index. A net plot of 5 m x 5 m (25 m^2) was used to determine the variables

Dry de-husked cob length

At harvest 20 plants per plot were selected and de-husked cob lengths were recorded by means of a measuring tape and mean lengths were calculated.

Dry Cob diameter

The diameters from the same cobs that were used for length measurements were recorded with the help of a measuring tap at harvest and the mean diameter was calculated.

Number of grains per cob

The number of grains was counted on the same cobs that were used for cob length measurements and their means were calculated.

1000 maize grain weight

At harvest maize cobs collected from each plot was air dried and threshed separately. A sample of 1000 grains from each treatment was obtained and the weight was recorded by means of an electronic balance.

Maize grain yield

After threshing of cobs from each plot the dry grains (moisture content of 9 %) were weighed on an electrical balance and grain yield ha^{-1} was calculated by using the following model:

$$\text{Grain yield (t ha}^{-1}\text{)} = \frac{\text{Grain yield nett plot}^{-1}\text{ (kg)}}{\text{Area of nett plot (m}^{-2}\text{)}} \times \frac{10}{1} \qquad \text{Equation 1}$$

Dry maize stalk weight

The dry stalks from each plot were harvested and weighed on a mechanical weighing scale and the stalk weight (t ha^{-1}) was calculated using the following model:

$$\text{Maize stalk weight (t ha}^{-1} = \frac{\text{Stalk weight nett plot}^{-1}\text{(kg) x 10}}{\text{Area of nett plot (m}^{-2})} \quad \text{Equation 2}$$

Maize harvest index (HI)

This was calculated from the data from the maize grain yield and the stalk weight using the following model:

$$\text{Harvest index} = \frac{\text{Maize grain yield nett plot}^{-1}\text{ (kg)}}{\text{Total biomass nett plot}^{-1}\text{ (kg)}} \quad \text{Equation 3}$$

Statistical analyses

Statistical analysis of the data was performed using the Statistica package (Software, version 8.02). Analysis of variance (ANOVA) was conducted to determine the interaction of factors. Means were separated using Bonferroni adjustment for testing least significant differences at the 5% level when ANOVA revealed significant ($P < 0.05$) differences among the treatments. The treatment factors which were compared were P rates, mucuna management options and N rates.

Results

The data for the 2007/08 and 2008/09 were combined during analyses because there non significant seasonal effects.

Cob length

The significant ($P < 0.05$) 3-way interaction of P rate, mucuna management option and nitrogen rate is shown in Table 7.2. Cob lengths significantly ($P < 0.05$) increased with an increase in N and P rates across all the management options. The MF management option and the N 120 treatment combination generally produced the longest cobs. The MF and the N0 treatment combination did not differ significantly from the F and N80 treatment combination in both P treatments. The MPR management option was always second to the MF management option. The F and MAR mucuna management options did not show significant differences at N0 and N40 rates in both P treatments but in the P 40 treatment the N80 and N120 and MAR treatment combinations produced longer cobs than the F management option had.

Table 7.2 Dry dehusked cob lengths (2007/08 and 2008/09 seasons combined) of maize as influenced by interactions of P rate, mucuna management option and N rate on a sandy loam soil in Zimbabwe after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1}) applied to the mucuna crop and four N rates (N0 = 0 kg N ha^{-1}, N40 = 40 kg N ha^{-1} , N80 = 80 kg N ha^{-1} , N120 = 120 kg N ha^{-1}) applied to the maize crop. (MF = mucuna incorporated at flowering, MAR = mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F = Fallow (control)). Values followed by the same letter are not significantly different at P = 0.05

		………………………… *N (kg ha^{-1})*……………..............			
P treatments	***Mucuna options***	***0***	***40***	***80***	***120***
		………………….*Cob length (cm)*………………………..			
	F	7.4a	8.3b	11.1e	13.3g
P0	MF	10.8e	13.8g	16.8j	17.9k
	MPR	10d	11.5f	15.0i	15.5i
	MAR	7.5a	8.9b	11.5f	13.9g
	F	7a	9.3c	11.1e	14.3h
P40	MF	10.9e	14.5h	18.5k	20.2L
	MPR	9.9d	12.7f	16.8j	17.2k
	MAR	7.2a	9.2c	13.2g	15.1i

Number of grains per cob

There were not any significant (P > 0.05) interactions between the three factors (P rate, mucuna management option and N rate) used in this study in terms of number of grains per cob. However there were significant (P < 0.05) differences between treatments within factors of N rates and mucuna management options. There were no P treatment effects.

Effect of mucuna management options on number of grains cob^{-1}

The MF mucuna management option had significantly ($P < 0.05$) more grains (352) cob^{-1} than the other three [F (223), MAR (240) and MPR (286)] mucuna management options, which were not significantly different from each other.

Effect of N rates on number of grains cob^{-1}

The number of grains cob^{-1}under the N120 rate (310) was significantly ($P < 0.05$) more than the N 80 (290), N0 (249) and N40 (251) rates. The N0 and N40 rates did not differ significantly.

1000 grain weight

A significant interaction ($P < 0.05$) between P rate, mucuna management option and N rate in terms of 1000 grain weight were noted (Table 7.3). The MF and N80 and N120 treatment combination had a significantly ($P < 0.05$) higher 1000 grain weight under both P treatments than the other combinations except for the MPR and N120 treatment combination in the P40 treatment. No significant differences were noted between the N80 and N120 rates under the MF management option under both P treatments. The MPR management option showed no significant differences between the N0, N40 and N80 rates under the P0 treatment. The MF and N0 treatment combination under the P0 treatment did not differ significantly from the F (control) and N120 treatment combination at both P treatments. The MAR and the F management options generally did not show significant differences between them across all the treatments.

Cob diameter

There was a significant ($P < 0.05$) 2-way interaction between the mucuna management option and N rate in terms of the cob diameters of maize (Table 7.4). The cob diameters increased with the increase in the N rates across all the mucuna management options. The cobs of the MF and N120 treatment combination had significantly ($P < 0.05$) larger diameters than the other treatment combinations. There was no significant difference between the MF and NO treatment combination and the F and N80 and N120 treatment combinations. The F and the MAR management options did differ significantly.

Table 7.3 Dry 1000 grain weight (2007/08 and 2008/09 seasons combined) of maize as influenced by interactions of P rate, mucuna management option and N rate on a sandy loam soil in Zimbabwe after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1}) applied to the mucuna crop and four N rates (N0 = 0 kg N ha^{-1}, N40 = 40 kg N ha^{-1} , N80 = 80 kg N ha^{-1} , N120 = 120 kg N ha^{-1}) applied to the maize crop. (MF = mucuna incorporated at flowering, MAR = mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F = Fallow (control)). Values followed by the same letter are not significantly different at P = 0.05

		……………………… *N (kg ha^{-1})*…………..............			
P treatments	***Mucuna options***	***0***	***40***	***80***	***120***
		………………..*1000 grain wt (g)*……………………			
P0	F	160.0a	171.9b	184.8c	237.8e
	MF	226.4e	254.8e	260.9f	265.4f
	MPR	213.8d	246.4e	252.3e	254e
	MAR	160.6a	173.1b	251.5e	239.5e
P40	F	194.8c	217.9d	227.6e	232.8e
	MF	239.8e	262f	297.4h	311.6h
	MPR	256.1e	249.3e	284g	297.2h
	MAR	193.0c	210.7d	228.7e	227.7e

Grain yield

Effect of mucuna management options and N rates interactions

The significant ($P < 0.05$) 2-way interaction between the mucuna management option and the N rate on grain yield shown in Table 7.4 illustrates that the grain yield increased with increased N rates across all the mucuna management options. However the MF and N120 treatment combination produced significantly ($P < 0.05$) higher grain yields followed by the MPR and N120 treatment combination. No significant differences were observed between the MF and N0 treatment combination and the F and N120 treatment combination. Also the MF and MPR management options did not differ significantly under the N80 and N120 rates respectively. The F and MAR management options did not differ significantly across all the N rates except at the N40 rate.

Effect of P application rates

There were significant (P < 0.05) differences between the P0 (2.29 t ha^{-1}) and the P40 (2.34 t ha^{-1}) treatments in term of the grain yield of maize.

Dry stalk weight

Effect of mucuna management options and N rates interactions

The significant (P < 0.05) 2-way interaction between mucuna management option and N rate on dry stalk weight is shown in Table 7.4. The stalk weight increased with increase in N rates across all the mucuna management options. The MF and N120 treatment combination had a significantly (P < 0.05) higher stalk weight than the other treatment combinations. However the MF and N0 treatment combination did not differ significantly with the F and N120 treatment combination. The F and MAR management options did not differ significantly at the N 80 and the N120 rates.

Effect of P treatments and N rates interactions

The significant (P < 0.05) 2-way interaction between the P rate and N rate showed no differences between the P0 and N0 (2.55 t ha^{-1}), N40 (3.80 ha^{-1}) and N120 (6.23 ha^{-1}) treatment combinations and the corresponding P40 and N0 (2.59), N 40 (3.87) and N120 (6.27) treatment combinations. However there were significant (P < 0.05) differences between the P0 and N80 (5.33) treatment combination and the P40 and N80 (5.49) treatment combination.

Table 7.4 Dry cob diameter, dry stalk weight and grain yield (2007/08 and 2008/09 seasons combined) of maize as influenced by interactions of mucuna management option and N rate on a sandy loam soil in Zimbabwe. N rates (N0 = 0 kg N ha^{-1}, N40 = 40 kg N ha^{-1} , N80 = 80 kg N ha^{-1} , N120 = 120 kg N ha^{-1}) applied to the maize crop. (MF = mucuna incorporated at flowering, MAR = mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F = Fallow (control). Values followed by the same letter in a **column** are not significantly different at P = 0.05

Mucuna options	***N (kg ha^{-1})***	***cob diameter(cm)***	***stalk wt*(t ha^{-1})**	***grain yield*(t ha^{-1})**
F	0	4.5b	2.0a	0.36a
	40	5.0c	2.3b	0.55b
	80	6.1e	4.6d	2.02d
	120	6.3e	5.5f	2.53e
MF	0	6.0e	3.3c	2.49e
	40	6.4e	5.1f	3.12f
	80	7.1e	6.5h	4.05h
	120	7.9g	7.1j	5.06j
MPR	0	5.0c	2.4b	0.63b
	40	5.6d	4.8d	2.06d
	80	6.3e	5.8g	3.40g
	120	7.1f	6.9i	4.12h
MAR	0	4.2a	2.5b	0.43a
	40	5.3c	3.1c	0.99c
	80	6.3e	4.6d	2.29d
	120	6.4e	5.5f	2.53e

Harvest Index (HI)

A significant interaction ($P < 0.05$) between P treatments, mucuna management options and N rates in terms of the HI of maize was noted (Table 7.5). The HI significantly ($P < 0.05$) increased with increase in N rates across the mucuna management options in both P treatments. The MF and N120 treatment combination had a significantly ($P < 0.05$) higher HI under both P treatments than the other combinations. However no significant differences were noted between the MF and NO treatment combination and the F and N80 treatment combination in both P treatments. The MAR and the F management options did not show significant differences between P treatments across all the N treatments except at the N40 rate.

Table 7.5 Harvest index (HI) (2007/08 and 2008/09 seasons combined) of maize as influenced by interactions of P rate, mucuna management option and N rate on a sandy loam soil in Zimbabwe after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1}) applied to the mucuna crop and four N rates (N0 = 0 kg N ha^{-1}, N40 = 40 kg N ha^{-1} , N80 = 80 kg N ha^{-1} , N120 = 120 kg N ha^{-1}) applied to the maize crop. (MF = mucuna incorporated at flowering, MAR = mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F = Fallow (control). Values followed by the same letter are not significantly different at P = 0.05

		………………………. ***N (kg ha^{-1})***…………..............			
P treatments options	***Mucuna***	***0***	***40***	***80***	***120***
		………………….*Harvest Index*……………………..			
	F	0.15a	0.19b	0.34d	0.39e
P0	MF	0.40d	0.58e	0.60e	0.68f
	MPR	0.21b	0.41d	0.54d	0.59e
	MAR	0.13a	0.30c	0.48d	0.57e
	F	0.17a	0.22b	0.40d	0.58e
P40	MF	0.44d	0.59e	0.58e	0.68f
	MPR	0.25c	0.40d	0.56e	0.58e
	MAR	0.15a	0.31c	0.45d	0.56e

Discussion

Cob size

The results of this study showed that the use of the MF management option with any P treatment applied to the mucuna and no nitrogen applied to the subsequent maize crop will give the same results as the F (control) management option which did not include mucuna crop with any P treatment applied and N80 rate applied in terms of cob length. This could be attributed to the N fixed by mucuna at flowering (Carsky *et al*., 1999). Therefore farmers may save about 80 kg N ha^{-1} if they use the MF management option. If farmers decide to leave mucuna up to maturity (MPR) the results will be similar to using the F and N40 rate treatment combination. The total removal of above ground biomass of mucuna at maturity may yield the same as the F management option under all the P treatments and N rates and will thus not result in any savings of N fertilizer. Legumes such as mucuna have a high harvest index (Giller & Wilson, 1991) and therefore the removal of above ground biomass prevents addition of N reserves to the soil. There is a strong correlation between cob length and maize grain yield (Memon *et al*., 2007).

The MF and N0 treatment combination resulted in the same cob diameter as the F management option and the N120. The MPR management option and the N0 combination may give the smallholder farmer the same diameter as the F (control) and the N120 treatment combination. Therefore the same cob size can be attained by the MF and MPR management options with little or no N supplementation as can be attained with the F and N120 treatment combination.

Grain characteristics

The MF management option had more grains probably because of its ability to provide high N levels which is an essential nutrient for grain development and filling (Tisdale *et al*. 1999). The N120 rate produced more grains than the other rates. This again can be attributed to the positive effect of N on grain development and cob-filling. Work carried out by Memon *et al*. (2007) showed that the number of grains will add to the total yield per hectare, but the weight of the grains also plays an important role.

The 1000 grain weight is an important measurement as it determines the final grain yield (Memon *et al*.2007). Nyakanda (1997) also reported that that there is a very close link between 1000 grain weight and the final yield of the maize crop. The results show that if a smallholder farmer does not apply P to the mucuna crop and ploughs under the mucuna crop at flowering (MF) and then applies no N fertilizer to the subsequent maize crop he may attain the same 1000 grain weight as the F and N120 treatment combination at the P0 or P40 treatment in the subsequent maize crop. These results show the importance of N in protein synthesis which also helps in weight enhancement of the grain (Tisdale *et al*.1999). The removal of the mucuna pods and incorporation of the rest of the mucuna biomass (MPR) in the P0 and P40 treatments may give the same weight as the F management option at any P treatment and N40. The removal of all above ground biomass (MAR) will have the same effect as the F management option under any P and N treatment.

Grain yield

Maize grain yield was higher in the MF management option across all the N rates. The MF and N0 treatment combination increased grain yield by almost 590% compared to the F and N0 treatment combination. The higher yield in the MF management option could partly be due to the higher 1000 grain weight parameter. These findings are corroborated by Mandimba (1995) who found that green manuring of mucuna gave a higher yield than natural fallows in the Congo. Sanginga *et al.* (1996) and Mausolff and Farber (1995) also found that green manuring with mucuna resulted in a subsequent maize yield which was equivalent to the yield of a crop receiving 120 kg N ha^{-1} inorganic fertilizer. The incorporation of root biomass (MAR) only gave the same yield as the F (control). These findings differ from findings by Smyth *et al.* (1991) who found that incorporation of the root biomass of legumes gave a higher yield than the control. However their work was in an Amazon ecosystem with different soil and climatic regimes than those of this study.

Dry stover weight

The MF management option produced more stover than the other options under the same N rates. This could be attributed to the K incorporated with mucuna at flowering. K is an essential nutrient for stalk development (Tisdale *et al.*, 1999; Shoko *et al.*, 2009).

Harvest Index (HI)

The MF management option produced a higher HI through-out the treatment combinations. A higher HI indicates higher yield potential at the same vegetative biomass (Memon *et al*., 2007). Therefore incorporation of mucuna green manure at flowering improved the ability of maize to produce grain yield from a given vegetative biomass.

Conclusion

The results of this study clearly widened the scope for the smallholder farmer when it comes to manipulation of mucuna. Farmers can benefit from either mucuna at maturity being incorporated or incorporating mucuna at flowering. The findings have shown that the MF and MPR management options improves maize yield compared to the normal farmer practice of natural fallows (F). Implementation of these two mucuna management systems should increase the yield and profit of smallholder farmers whilst slowing down the rate of soil degradation in crop fields compared to the traditional maize monoculture systems.

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Chapter 8

General summary, conclusion and recommendations for further research

Discussion

The effect of P on the productivity of mucuna on a kaolinitic sandy soil

Phosphorus (P) is an essential macronutrient for legume growth and function (Ribet & Drevon, 1996). The influence of P on symbiotic nitrogen fixation in mucuna (*Mucuna pruriens*) has received considerable attention, but its role in the process still remains unclear (Hairiah *et al.*, 1995). Robson and O'Hara (1981) concluded that P nutrition increased symbiotic nitrogen fixation in most legumes by stimulating host plant growth rather than by exerting specific effects on rhizobial growth or on nodule formation and function. The hypothesis that P did not affect mucuna productivity was rejected.

This study indeed revealed that the nodulation, growth and development and yield of mucuna on a sandy loam soil can be stimulated by exogenous P supply (Jakobsen, 1985; Sanginga *et al.*, 1996; Gentili & Huss-Danell, 2002). So there is need for the small holder farmers to apply P as a basal fertilizer during land preparation for planting mucuna to maximize on its productivity. The benefits from mucuna productivity will have a positive effect on the production of the subsequent maize crop.

The application of 40 kg P ha^{-1} has shown some great improvement in biomass production by mucuna as well as an increase in LAI which is an essential biophysical parameter for the interception of PAR. More nodules were found on P application than on non P application. The high nodule population resulted in high N fixation by the mucuna crop.

Phosphorus played an important role in nutrient (N, P, K, Ca and Mg) accumulation in mucuna foliage. Most nutrient levels were higher in the P40 treatment than in the P0 treatment. These high nutrients when incorporated will improve both the biological and economic yield of the subsequent maize crop. The higher pod yield in the treatments where P was applied also indicates the positive effect of P. The influence of P on luxurious growth of mucuna had a positive effect on protein content. However the fibre content was lower when P was applied.

The effect of P and mucuna management option on the physical and chemical properties of a depleted sandy loam soil

It has been shown that on the poorly buffered kaolinitic soils found in many areas in the tropics, including sub-Saharan Africa, continuous use of fertilizer alone cannot sustain crop yield and may lead to the deterioration of the soil condition in the long run (Juo *et al*., 1995).

The hypothesis that P and mucuna did not affect soil properties was rejected. The results of this study shows that the incorporation of a legume crop at flowering will help to increase N, K and Ca levels in the soil and improve SOM (Shoko *et al*., 2007). The incorporation of mucuna at flowering somehow acidified the soil pH at P40 only. This could be due to the acidifying effect of N fixed by mucuna. The incorporation of mucuna will improve SOM and thereby improving bulk density (Db) of the soil. The improvement of Db will also have a positive effect on porosity. This improved porosity will enhance microbial activity and root respiration.

Mucuna has the potential to improve soil chemical characteristics for the small holder resource-poor-farmers in Sub Saharan Africa. The results of the study indicated that mucuna incorporated at flowering had acceptable mineral N content to sustain maize productivity. The soils in this study, similar to many other soils in sub Saharan Africa, may not sustain satisfactory maize production because of serious P deficiencies (Pal, 1991; Akinnifesi *et al*., 2006). According to the recommendations by Tagwira (1992), Hussein (1997) and Nyakanda (1997) the results of this study showed that P in the soil was inadequate at all P and mucuna management treatment combinations. There may be need for farmers to apply P as a basal fertilizer to the subsequent maize crop to counter its deficiencies in such soils.

The level of exchangeable bases in this study indicated that they have been improved by the MF and MPR mucuna management options. Calcium, Mg and K are key to the production of maize and these results are very favourable to the small holder farmer. The application of mucuna management options under the P40 treatment showed lower Zn content than under the P0 treatment. The results of this study indicated that P0 and MF treatment combination will supply about 50% of the optimum Zn requirements of a maize crop. However about 75% of Zn requirements needs to be supplemented when using other mucuna management options with either the P0 or P40 treatments.

The effect of P, mucuna management option and N on the production of the subsequent maize crop on a depleted kaolinitic sandy loam soil

The maize monoculture production system resulted in the lowest biomass, LAI and foliar nutrient content in the subsequent maize crop. The leaf analyses showed deficiencies of most essential nutrients. This has a very negative impact on the final yield of maize. This production system is the one which most smallholder farmers practice. This trend of low biomass, LAI and foliar nutrient content may be attributed to depletion of soil fertility associated with this practice (Tisdale *et al.*, 1999). However the inclusion of mucuna as a fallow crop may help to increase biomass and LAI as well as reducing deficiencies of most essential nutrients for maize production. The results of this study also confirmed that the incorporation of mucuna at flowering and at maturity will improve soil fertility as indicated by high biomass accumulation, higher LAI and sufficient nutrients in leaves of the maize crop.

The hypothesis that mucuna management option did not influence maize vegetative production was rejected. The results of this study showed that the use of the MF management option with any P treatment applied to the mucuna and no nitrogen applied to the subsequent maize crop will give the same results as the F (control) management option with any P treatment applied and N80 rate applied in terms of cob length, number of grains per cob, cob diameter, 1000 grain weight and the final grain yield. This could be attributed to the N fixed by mucuna at flowering (Carsky *et al.*, 1999). The findings also showed that with incorporating mucuna at maturity (MPR), the results will be similar to using the F and N40 rate treatment combination. All in all the use of mucuna as fallow crop will benefit the smallholder farmer in terms of maize productivity.

Conclusion

The results of this study clearly widened the scope for the smallholder farmer when it comes to manipulation of P fertilizer, mucuna and N fertilizer. The effect of P on general productivity of mucuna, as a preceding crop to maize has been positive in this study. These positive effects which resulted in high N fixed influenced the yield of the subsequent maize crop.

The findings of this study also noted that the incorporation of mucuna at either flowering or maturity has some positive effects to soil health in general. However it is the incorporation of mucuna at flowering which had a greater positive influence on soil fertility and physical properties than when incorporated later. The findings of this research have shown that the MF and MPR management options improve maize productivity compared to the normal farmer practice of natural fallows (F). Implementation of these two mucuna management systems with some N supplementation can increase the yield and profit of smallholder farmers whilst slowing down the rate of soil degradation in crop fields compared to the traditional maize monoculture systems. This study also widened the scope of income for the small holder farmer. It revealed that farmers can realize some income when they do not apply fertilizer and incorporate mucuna at maturity. This has more economic benefits than using P fertilizer and 120kg N ha^{-1} ha under fallow production system.

Recommendation for further research

1. There is need to do similar work under dryland conditions since this research was done under irrigation, a facility which most small holder farmers in Zimbabwe don't have.
2. There may be need to look at the use of Dorowa Phosphate rock as source of P instead of Single Super Phosphate. The Rock is readily available in Zimbabwe.

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APPENDICES

Appendix 1: ANOVA for Chapter 3 :The effect of P on the productivity of mucuna *(Mucuna pruriens)* on a depleted sandy loam soil in Zimbabwe

1.1 Biomass of mucuna leaves

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	29	8178.187500	282.006466	4.88	0.0005
Error	18	1039.625000	57.756944		
Corrected Total	47	9217.812500			

1.2 Biomass of mucuna stems

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	29	2265.687500	78.127155	3.01	0.0086
Error	18	466.625000	25.923611		
Corrected Total	47	2732.312500			

1.3 Number of nodules per mucuna plant

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	16181.83333	1471.07576	12.61	<.0001
Error	12	1400.00000	116.66667		
Corrected Total	23	17581.83333			

1.4 Number of alive nodules per plant

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	14587.29167	1326.11742	11.03	0.0001
Error	12	1442.33333	120.19444		
Corrected Total	23	16029.62500			

1.5 Nodule biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	1.65500000	0.15045455	4.77	0.0060
Error	12	0.37833333	0.03152778		
Corrected Total	23	2.03333333			

1.6 Days to 50 % flowering of mucuna

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	838.958333	76.268939	4.47	0.0079
Error	12	204.666667	17.055556		
Corrected Total	23	1043.625000			

1.7 Leaf area index of mucuna

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	35	4.69436667	0.13412476	28.01	<.0001
Error	36	0.17238333	0.00478843		
Corrected Total	71	4.86675000			

1.8 Mucuna grain yield

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	1.28750000	0.14305556	9.54	0.0063
Error	6	0.09000000	0.01500000		
Corrected Total	15	1.37750000			

1.9 Protein content of mucuna pods

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	25851.75000	2872.41667	15.87	0.0016
Error	6	1086.00000	181.00000		
Corrected Total	15	26937.75000			

1.10 Fibre content of mucuna pods

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	6186.562500	687.395833	32.51	0.0002
Error	6	126.875000	21.145833		
Corrected Total	15	6313.437500			

1.11 Nitrogen content of mucuna leaves at flowering

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	5.97432917	0.54312083	4.00	0.0124
Error	12	1.63126667	0.13593889		
Corrected Total	23	7.60559583			

1.12 Phosphorus content of mucuna leaves at flowering

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.42576667	0.03870606	13.92	<.0001
Error	12	0.03336667	0.00278056		
Corrected Total	23	0.45913333			

1.13 Potassium content of mucuna leaves at flowering

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.79022917	0.07183902	3.40	0.0229
Error	12	0.25346667	0.02112222		
Corrected Total	23	1.04369583			

1.14 Calcium content of mucuna leaves at flowering

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	3.44214583	0.31292235	6.54	0.0015
Error	12	0.57441667	0.04786806		
Corrected Total	23	4.01656250			

1.15 Magnesium content of mucuna at flowering

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.16195000	0.01472273	1.19	0.3822
Error	12	0.14823333	0.01235278		
Corrected Total	23	0.31018333			

1.16 Nitrogen content of mucuna leaves at maturity

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	0.88615000	0.09846111	1.28	0.3940
Error	6	0.46075000	0.07679167		
Corrected Total	15	1.34690000			

1.17 Phosphorus content of mucuna leaves at maturity

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	1.62320000	0.18035556	27.62	0.0003
Error	6	0.03917500	0.00652917		
Corrected Total	15	1.66237500			

1.18 Potassium content of mucuna leaves at maturity

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	0.23077500	0.02564167	14.25	0.0021
Error	6	0.01080000	0.00180000		
Corrected Total	15	0.24157500			

1.19 Calcium content of mucuna leaves at maturity

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	1.25935625	0.13992847	14.85	0.0019
Error	6	0.05653750	0.00942292		
Corrected Total	15	1.31589375			

1.20 Magnesium content of mucuna leaves at maturity

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	0.69960625	0.07773403	13.47	0.0025
Error	6	0.03463750	0.00577292		
Corrected Total	15	0.73424375			

1.21 Nitrogen content of mucuna pods

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	6.38822500	0.70980278	7.83	0.0105
Error	6	0.54397500	0.09066250		
Corrected Total	15	6.93220000			

1.22 Phosphorus content of mucuna pods

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	0.22622500	0.02513611	76.36	<.0001
Error	6	0.00197500	0.00032917		
Corrected Total	15	0.22820000			

1.23 Potassium content of mucuna pods

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	0.96482500	0.10720278	26.72	0.0004
Error	6	0.02407500	0.00401250		
Corrected Total	15	0.98890000			

1.24 Calcium content of mucuna pods

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	0.45285625	0.05031736	9.59	0.0062
Error	6	0.03148750	0.00524792		
Corrected Total	15	0.48434375			

1.25 Magnesium content of mucuna pods

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	0.36360625	0.04040069	328.68	<.0001
Error	6	0.00073750	0.00012292		
Corrected Total	15	0.36434375			

Appendix 2: ANOVA for Chapter 4 : The effect of P and mucuna *(Mucuna pruriens)* management options on soil organic matter, soil pH and physical properties of a kaolinitic sandy soil in Zimbabwe

2.1 Soil pH after incorporation of mucuna

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	39	1.54948594	0.03973041	2.05	0.0325
Error	24	0.46418750	0.01934115		
Corrected Total	63	2.01367344			

2.2 SOM after incorporation of mucuna

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	39	2.76681094	0.07094387	12.71	<.0001
Error	24	0.13391250	0.00557969		
Corrected Total	63	2.90072344			

Appendix 3: ANOVA for Chapter 5: The effects of P and mucuna *(Mucuna pruriens)* management options on the chemical characterisation of a depleted sandy loam soil in Zimbabwe

3.1 Mineral N after incorporation of mucuna

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	39	761.9375000	19.5368590	13.59	<.0001
Error	24	34.5000000	1.4375000		
Corrected Total	63	796.4375000			

3.2 P after incorporation of mucuna

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	39	233.4843750	5.9867788	6.72	<.0001
Error	24	21.3750000	0.8906250		
Corrected Total	63	254.8593750			

3.3 Exchangeable K after incorporation of mucuna

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	39	10.69849844	0.27432047	49.96	<.0001
Error	24	0.13178750	0.00549115		
Corrected Total	63	10.83028594			

3.4 Exchangeable Ca after incorporation of mucuna

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	39	84.73749375	2.17275625	637.87	<.0001
Error	24	0.08175000	0.00340625		
Corrected Total	63	84.81924375			

3.5 Exchangeable Mg after incorporation of mucuna

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	39	0.50665000	0.01299103	45.62	<.0001
Error	23	0.00655000	0.00028478		
Corrected Total	62	0.51320000			

3.6 Zn after incorporation of mucuna

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	39	183.3247000	4.7006333	5.93	<.0001
Error	24	19.0393000	0.7933042		
Corrected Total	63	202.3640000			

Appendix 4: ANOVA for Chapter 6: The effect of phosphorus, mucuna management options and nitrogen on the biomass, leaf area index and foliar nutrient content of maize on a depleted sandy loam soil in Zimbabwe

4.1 Biomass of the subsequent maize crop

	SS	DF	MS	F	p
Intercept	441.1227	1	441.1227	70128.46	0.000000
{5}Block	0.0000	1	0.0000	0.00	1.000000
{1}P aplction	0.0410	1	0.0410	6.51	0.011095
{2}MucTrtmt	95.5024	3	31.8341	5060.90	0.000000
{3}N apliction	98.1213	3	32.7071	5199.69	0.000000
{4}Time	121.5333	3	40.5111	6440.34	0.000000
P aplction*MucTrtmt	0.0004	3	0.0001	0.02	0.995965
P aplction*N apliction	0.0007	3	0.0002	0.04	0.990761
MucTrtmt*N apliction	5.9407	9	0.6601	104.94	0.000000
P aplction*Time	0.0012	3	0.0004	0.06	0.979758
MucTrtmt*Time	4.9843	9	0.5538	88.04	0.000000
N apliction*Time	12.2316	9	1.3591	216.06	0.000000
P aplction*MucTrtmt*N apliction	0.0078	9	0.0009	0.14	0.998596
P aplction*MucTrtmt*Time	0.0041	9	0.0005	0.07	0.999903
P aplction*N apliction*Time	0.0081	9	0.0009	0.14	0.998419
MucTrtmt*N apliction*Time	7.9734	27	0.2953	46.95	0.000000
1*2*3*4	0.0127	27	0.0005	0.07	1.000000
Error	2.4091	383	0.0063		

4.2 LAI of the subsequent maize crop

	SS	DF	MS	F	p
Intercept	125.712	1	125.7121	6.571856	0.010741
{5}Block	34.294	1	34.2944	1.792810	0.181378
{1}P aplction	20.801	1	20.8013	1.087427	0.297700
{2}MucTrtmt	336.025	3	112.0083	5.855459	0.000644
{3}N apliction	355.447	3	118.4824	6.193905	0.000406
{4}Time	102.830	3	34.2767	1.791882	0.148195
P aplction*MucTrtmt	58.249	3	19.4165	1.015036	0.385953
P aplction*N apliction	55.772	3	18.5907	0.971865	0.405975
MucTrtmt*N apliction	225.488	9	25.0542	1.309760	0.229818
P aplction*Time	55.323	3	18.4410	0.964038	0.409697
MucTrtmt*Time	124.171	9	13.7968	0.721257	0.689482
N apliction*Time	154.204	9	17.1338	0.895703	0.529089
P aplction*MucTrtmt*N apliction	176.237	9	19.5819	1.023682	0.420203
P aplction*MucTrtmt*Time	175.832	9	19.5368	1.021328	0.422092
P aplction*N apliction*Time	167.454	9	18.6060	0.972668	0.462160
MucTrtmt*N apliction*Time	533.933	27	19.7753	1.033794	0.420768
1*2*3*4	527.838	27	19.5496	1.021993	0.436854
Error	7326.354	383	19.1289		

4.3 N content in maize leaves

	SS	D F	MS	F	p
Intercept	129.1664	1	129.1664	205187.1	0.000000
{5}Block	0.0000	1	0.0000	0.0	1.000000
{1}P aplction	1.3173	1	1.3173	2092.5	0.000000
{2}MucTrtmt	91.2051	3	30.4017	48294.6	0.000000
{3}N apliction	70.2993	3	23.4331	37224.6	0.000000
{4}Time	185.8287	3	61.9429	98399.3	0.000000
P aplction*MucTrtmt	0.0012	3	0.0004	0.6	0.602407
P aplction*N apliction	0.0006	3	0.0002	0.3	0.826728
MucTrtmt*N apliction	3.9462	9	0.4385	696.5	0.000000
P aplction*Time	0.0039	3	0.0013	2.1	0.101352
MucTrtmt*Time	18.5244	9	2.0583	3269.7	0.000000
N apliction*Time	19.2471	9	2.1386	3397.2	0.000000
P aplction*MucTrtmt*N apliction	0.0019	9	0.0002	0.3	0.965973
P aplction*MucTrtmt*Time	0.0060	9	0.0007	1.1	0.398804
P aplction*N apliction*Time	0.0062	9	0.0007	1.1	0.369277
MucTrtmt*N apliction*Time	6.5758	27	0.2435	386.9	0.000000
1*2*3*4	0.0159	27	0.0006	0.9	0.561394
Error	0.2411	383	0.0006		

4.4 P content in maize leaves

	SS	DF	MS	F	p
Intercept	22.50225	1	22.50225	40501.29	0.000000
{5}Block	0.00051	1	0.00051	0.91	0.339733
{1}P aplction	0.11822	1	0.11822	212.78	0.000000
{2}MucTrtmt	12.00868	3	4.00289	7204.71	0.000000
{3}N apliction	0.14867	3	0.04956	89.20	0.000000
{4}Time	2.93834	3	0.97945	1762.89	0.000000
P aplction*MucTrtmt	0.00059	3	0.00020	0.35	0.788398
P aplction*N apliction	0.00082	3	0.00027	0.49	0.688251
MucTrtmt*N apliction	0.61979	9	0.06887	123.95	0.000000
P aplction*Time	0.00113	3	0.00038	0.68	0.567531
MucTrtmt*Time	0.66626	9	0.07403	133.24	0.000000
N apliction*Time	0.27442	9	0.03049	54.88	0.000000
P aplction*MucTrtmt*N apliction	0.00567	9	0.00063	1.13	0.337491
P aplction*MucTrtmt*Time	0.00201	9	0.00022	0.40	0.933501
P aplction*N apliction*Time	0.00255	9	0.00028	0.51	0.866818
MucTrtmt*N apliction*Time	0.65506	27	0.02426	43.67	0.000000
1*2*3*4	0.01124	27	0.00042	0.75	0.815835
Error	0.21279	383	0.00056		

4.5 K content in maize leaves

	SS	DF	MS	F	p
Intercept	42.75187	1	42.75187	43843.11	0.000000
{5}Block	0.00118	1	0.00118	1.21	0.271461
{1}P aplction	0.11520	1	0.11520	118.14	0.000000
{2}MucTrtmt	43.18759	3	14.39586	14763.31	0.000000
{3}N apliction	0.90899	3	0.30300	310.73	0.000000
{4}Time	49.99482	3	16.66494	17090.31	0.000000
P aplction*MucTrtmt	0.00000	3	0.00000	0.00	1.000000
P aplction*N apliction	0.00000	3	0.00000	0.00	1.000000
MucTrtmt*N apliction	0.70341	9	0.07816	80.15	0.000000
P aplction*Time	0.00000	3	0.00000	0.00	1.000000
MucTrtmt*Time	5.81860	9	0.64651	663.01	0.000000
N apliction*Time	3.51295	9	0.39033	400.29	0.000000
P aplction*MucTrtmt*N apliction	0.00000	9	0.00000	0.00	1.000000
P aplction*MucTrtmt*Time	0.00000	9	0.00000	0.00	1.000000
P aplction*N apliction*Time	0.00000	9	0.00000	0.00	1.000000
MucTrtmt*N apliction*Time	1.91864	27	0.07106	72.87	0.000000
1*2*3*4	0.00000	27	0.00000	0.00	1.000000
Error	0.37347	383	0.00098		

4.6 Ca content in maize leaves

	SS	DF	MS	F	p
Intercept	3.676901	1	3.676901	2990.132	0.000000
{5}Block	0.001308	1	0.001308	1.064	0.302995
{1}P aplction	0.251606	1	0.251606	204.612	0.000000
{2}MucTrtmt	0.156554	3	0.052185	42.438	0.000000
{3}N apliction	0.006047	3	0.002016	1.639	0.179804
{4}Time	0.458896	3	0.152965	124.395	0.000000
P aplction*MucTrtmt	0.003549	3	0.001183	0.962	0.410649
P aplction*N apliction	0.003796	3	0.001265	1.029	0.379674
MucTrtmt*N apliction	0.016363	9	0.001818	1.478	0.153787
P aplction*Time	0.004604	3	0.001535	1.248	0.292073
MucTrtmt*Time	0.027721	9	0.003080	2.505	0.008558
N apliction*Time	0.028883	9	0.003209	2.610	0.006190
P aplction*MucTrtmt*N apliction	0.007946	9	0.000883	0.718	0.692535
P aplction*MucTrtmt*Time	0.009456	9	0.001051	0.854	0.566351
P aplction*N apliction*Time	0.013803	9	0.001534	1.247	0.264607
MucTrtmt*N apliction*Time	0.053441	27	0.001979	1.610	0.029437
1*2*3*4	0.024352	27	0.000902	0.733	0.833583
Error	0.470967	383	0.001230		

4.7 Mg content in maize leaves

	SS	DF	MS	F	p
Intercept	4.296033	1	4.296033	17402.34	0.000000
{5}Block	0.003151	1	0.003151	12.76	0.000399
{1}P aplction	0.012800	1	0.012800	51.85	0.000000
{2}MucTrtmt	5.689316	3	1.896439	7682.08	0.000000
{3}N apliction	0.684316	3	0.228105	924.01	0.000000
{4}Time	2.433841	3	0.811280	3286.33	0.000000
P aplction*MucTrtmt	0.000000	3	0.000000	0.00	1.000000
P aplction*N apliction	0.000000	3	0.000000	0.00	1.000000
MucTrtmt*N apliction	1.112941	9	0.123660	500.92	0.000000
P aplction*Time	0.000000	3	0.000000	0.00	1.000000
MucTrtmt*Time	1.551016	9	0.172335	698.09	0.000000
N apliction*Time	0.595316	9	0.066146	267.94	0.000000
P aplction*MucTrtmt*N apliction	0.000000	9	0.000000	0.00	1.000000
P aplction*MucTrtmt*Time	0.000000	9	0.000000	0.00	1.000000
P aplction*N apliction*Time	0.000000	9	0.000000	0.00	1.000000
MucTrtmt*N apliction*Time	0.661953	27	0.024517	99.31	0.000000
1*2*3*4	0.000000	27	0.000000	0.00	1.000000
Error	0.094549	383	0.000247		

Appendix 5: ANOVA for Chapter 7: The effect of P, mucuna management options and N on the yield and yield components of maize on a depleted sandy loam soil in Zimbabwe

5. 1 Cob length of maize

	SS	DF	MS	F	p
Intercept	6737.688	1	6737.688	52678.00	0.000000
Block	0.046	1	0.046	0.36	0.547925
P aplction	55.223	1	55.223	431.76	0.000000
MucTrtmt	1108.366	3	369.455	2888.55	0.000000
N apliction	1992.225	3	664.075	5192.01	0.000000
P aplction*MucTrtmt	3.573	3	1.191	9.31	0.000008
P aplction*N apliction	32.714	3	10.905	85.26	0.000000
MucTrtmt*N apliction	40.688	9	4.521	35.35	0.000000
P aplction*MucTrtmt*N apliction	4.214	9	0.468	3.66	0.000273
Error	28.522	223	0.128		

5.2 No of grains per cob

	SS	DF	MS	F	p
Intercept	3172992	1	3172992	192.2354	0.000000
Block	371	1	371	0.0225	0.880980
P aplction	45609	1	45609	2.7632	0.097859
MucTrtmt	641945	3	213982	12.9641	0.000000
N apliction	173337	3	57779	3.5005	0.016295
P aplction*MucTrtmt	28899	3	9633	0.5836	0.626343
P aplction*N apliction	51304	3	17101	1.0361	0.377407
MucTrtmt*N apliction	135453	9	15050	0.9118	0.515652
P aplction*MucTrtmt*N apliction	156912	9	17435	1.0563	0.396423
Error	3680784	223	16506		

5.3 Cob diameter

	SS	DF	MS	F	p
Intercept	1447.707	1	1447.707	36038.92	0.000000
Block	0.996	1	0.996	24.79	0.000001
P aplction	1.485	1	1.485	36.98	0.000000
MucTrtmt	78.866	3	26.289	654.43	0.000000
N apliction	155.274	3	51.758	1288.46	0.000000
P aplction*MucTrtmt	0.049	3	0.016	0.41	0.749194
P aplction*N apliction	0.078	3	0.026	0.65	0.584190
MucTrtmt*N apliction	6.688	9	0.743	18.50	0.000000
P aplction*MucTrtmt*N apliction	0.332	9	0.037	0.92	0.510188
Error	8.958	223	0.040		

5.4 Stover weight

	SS	DF	MS	F	p
Intercept	886.1603	1	886.1603	46194.98	0.000000
Block	0.0913	1	0.0913	4.76	0.030189
P aplction	0.4136	1	0.4136	21.56	0.000006
MucTrtmt	149.0925	3	49.6975	2590.70	0.000000
N apliction	516.3433	3	172.1144	8972.22	0.000000
P aplction*MucTrtmt	0.0483	3	0.0161	0.84	0.473449
P aplction*N apliction	0.1723	3	0.0574	2.99	0.031693
MucTrtmt*N apliction	27.5773	9	3.0641	159.73	0.000000
P aplction*MucTrtmt*N apliction	0.2285	9	0.0254	1.32	0.225669
Error	4.2778	223	0.0192		

5.5 Grain yield

	SS	DF	MS	F	p
Intercept	219.4940	1	219.4940	25926.47	0.000000
Block	0.1174	1	0.1174	13.87	0.000248
P aplction	0.1754	1	0.1754	20.71	0.000009
MucTrtmt	142.4751	3	47.4917	5609.69	0.000000
N apliction	376.6119	3	125.5373	14828.38	0.000000
P aplction*MucTrtmt	0.0022	3	0.0007	0.09	0.966620
P aplction*N apliction	0.0493	3	0.0164	1.94	0.123844
MucTrtmt*N apliction	13.3534	9	1.4837	175.26	0.000000
P aplction*MucTrtmt*N apliction	0.1196	9	0.0133	1.57	0.125456
Error	1.8879	223	0.0085		

5.6 Harvest Index

	SS	DF	MS	F	p
Intercept	8.115120	1	8.115120	13535.98	0.000000
Block	0.018450	1	0.018450	30.78	0.000000
P aplction	0.003910	1	0.003910	6.52	0.011327
MucTrtmt	2.171303	3	0.723768	1207.24	0.000000
N apliction	4.709384	3	1.569795	2618.41	0.000000
P aplction*MucTrtmt	0.000342	3	0.000114	0.19	0.902892
P aplction*N apliction	0.013026	3	0.004342	7.24	0.000117
MucTrtmt*N apliction	0.468898	9	0.052100	86.90	0.000000
P aplction*MucTrtmt*N apliction	0.015561	9	0.001729	2.88	0.003045
Error	0.133693	223	0.000600		

5.7 1000 grain weight

	SS	DF	MS	F	p
Intercept	2345391	1	2345391	58101.81	0.000000
Block	120	1	120	2.98	0.085682
P aplction	30159	1	30159	747.11	0.000000
MucTrtmt	177905	3	59302	1469.07	0.000000
N apliction	124284	3	41428	1026.29	0.000000
P aplction*MucTrtmt	3962	3	1321	32.72	0.000000
P aplction*N apliction	290	3	97	2.39	0.069283
MucTrtmt*N apliction	9093	9	1010	25.03	0.000000
P aplction*MucTrtmt*N apliction	25768	9	2863	70.93	0.000000
Error	9002	223	40		