EVALUATION OF THE POTENTIAL OF MUCUNA, PUERARIA AND COWPEA AS COVER CROPS IN TREE CROP PLANTATIONS.

BY

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DEDICATION

Dedicated to my husband Kobby, and our children Maame Yeboaa and Paa Kwasi.

DECLARATION

I hereby declare that except for references to people's work which have been duly cited, this work herein presented is the result of my own original research and that this thesis either in whole or in part has not been presented for another degree elsewhere.

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ABSTRACT

Nodulation, dry matter yield, nitrogen accumulation and the potential for weed control of cowpea (*Vigna unguiculata*), mucuna (*Mucuna pruriens var utilis*) and pueraria(*Pueraria phaseoloides*) cover crops were assessed in pot and field experiments at the University of Ghana, Legon and the Oil Palm Research Institute, Kade respectively.

The response of these cover crops to bradyrhizobial inoculation in two soil series, Kokofu and Nzima, was also studied. Rhizobial inoculation on the average, increased dry matter yield of cowpea and mucuna. *Pueraria phaseoloides,* however, produced higher dry matter yield without inoculation than with inoculation. *Mucuna pruriens var utilis* Accession 1745 gave the highest shoot dry weight and shoot nitrogen content, with *Pueraria phaseoloides* recording the least shoot dry weight over the period of study in both experiments. Shoot dry weight did not differ significantly between the two soils, but generally the two mucuna accessions and cowpea produced higher shoot dry weights on Kokofu soil than Nzima. *Pueraria phaseoloides* produced the highest nodule number and nodule dry weight in both pot and field studies but this did not result in higher dry matter and nitrogen production. The two mucuna accessions effectively controlled weeds present including *Chromolaena odorata,* which was prevalent in the area. The relatively fast growth exhibited by mucuna indicates a potential for use as a cover crop for weed control in tree crop plantations especially during the early establishment phase.

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CHAPTER ONE

1. INTRODUCTION

The use of living plants for ground cover management has been practiced in agriculture for decades in tree crop plantations around the world (Mason, 1964; Moore, 1962). Legume cover crops contribute to the productivity of a plantation by improving the growth and yields of the main tree crop (Ikram *et al.*, 1976). Cover crops are also known to help maintain a stable soil structure as well as prevent the encroachment of noxious weed species (Broughton, 1977a).

Weed management is an important agronomic practice in tree crop plantations during the early years of field establishment. This is because, initial growth of these tree crop seedlings that has been transplanted, are usually slower than that of the weeds with which they are associated. In addition, most tree crops do not develop full canopy in time to shade weeds out (Akobundu, 1987). Yield losses due to weeds alone have been estimated to be greater than 50% of the potential yield of cultivated crops in the tropics (Deat, 1982; Terry, 1983).

Small scale farmers in Ghana use manual weed control methods, which are rather labour intensive. Six weeding per year is common in immature oil palm plantations but this method is becoming more difficult due to the rising cost of labour and unavailability of farm labourers. On large scale commercial oil palm plantations for example, the recommended practice has been to plant *Pueraria phaseoloides* to provide a cover to help in weed control. It has however been difficult to get it adopted by the small scale farmers, who account for over 50% of the planted area of oil palm in Ghana (Anon., 1989). This is partly because the pueraria does not provide any food or income to the farmer.

The small scale farmers usually intercrop tree crops with food crops to provide food and /or cash during the first few years, when the tree crop has not come into bearing. This practice however, may have detrimental effects on the growth and yield of the plantation crop probably because of competition effects.

Several researchers have demonstrated the importance of leguminous cover crops in smothering weeds, producing large quantities of dry matter, controlling soil erosion and improving the nutrition and yield of tree crop plantations. (Broughton, 1977a; Agamuthu and Broughton, 1985; Zaharah *et al.*, 1986; Ismail, 1990; Pearson *et al.*, 1995). For the small scale farmers, the need for food and/or cash during the early stages of establishing plantations take precedence over nodulation, nitrogen fixation and weed control with cover crops. It is therefore expedient to identify cover crops, which besides fixing nitrogen and controlling weeds also provide food and/or income for the farmers.

The objectives of this study were therefore to evaluate nodulation, nitrogen accumulation and dry matter production of mucuna, pueraria and cowpea cover crops. The study also aimed at evaluating the potential of these cover crops in controlling weeds in tree crop plantations, especially oil palm plantations.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Cover cropping

2.1.1 Types of cover crops

Different types of cover crops have been used in different parts of the world. Both legumes and non-legumes have been used as cover crops. Legume cover crops have been known to confer a multitude of desirable characteristics to the soil (Mullins *et al.*, 1998). These legumes can be divided into edible and non-edible ones. The non-edible legumes that have been used include *Pueraria phaseoloides, Centrosema pubescens, Calopogonium mucunoides, Crotalaria species, Desmodium species, Mimosa pudica, Macroptilium atropurpureum, Stylosanthes guyanensis, Moghana macrophylla, Indigofera hirsuta* and *Flemingia congesta.*

Edible legumes that have been used as cover crops include some species of cowpea (*Vigna unguiculata),* jack bean *(Canavalia ensiformis)*, velvet bean (*Mucuna species),* winged bean *(Psophocarpus tetragonolobus),* lablab bean *(Lablab purpureum)* and mung bean *(Vigna radiata).* Field peas (*Pisum sativum*) and soybean (*Glycine max*) have also been evaluated as cover crops to control weeds under coffee. Although both legumes suppressed growth of grasses in the coffee fields, coffee yield was not significantly affected by cover cropping (Dubale, 1987).

There are some few edible non-legumes that have been tried as cover crops. Early season weed suppression with the low-growing 'Egusi' melon (*Cucumeropsis edulis*) followed by sweet potato (*Ipomea batatas*) has been reported (IITA, 1980). Niel (1982), has also

reported the potential use of sweet potato as cover crop in a field infested with *Merremia spp.* The weeds were effectively controlled.

Non-legume cover crops also include grasses such as *Panicum maximum, Brachiara brizantha, Axonopus compressus, Paspalum conjugatum and Ottochloa nodosa. Axonopus compressus* and *Paspalum conjugatum* have been shown to be helpful especially in areas, which are low lying, waterlogged or prone to periodic flooding (Chung, 1998). Legume covers, on the other hand, are difficult to establish under such conditions (Chung, 1998). Chung (1998), also indicated that *Nephrolepis bisserata,* a fern, could be used as a ground cover. Chan *et al.* (1977), however, observed that legumes provided better soil protection by the return of larger amount of decomposable material compared to grasses.

2.1.2 Qualities of a good leguminous cover crop

The desirable attributes of suitable legume cover crops or live mulch species for the tropics include several growth features. Paramount among them are ease of establishment from seeds, aggressiveness and competitiveness against weeds and ability to provide complete ground cover rapidly. Other attributes are deep rooting habits, high root density and large root diameters, ability to fix nitrogen through nodulation and pest and disease resistance. They should also be drought tolerant, shade tolerant, have high dry matter production and high nutrient content of above and below ground residues (Akobundu, 1987; Barber and Navara, 1994). It may be difficult to get a legume cover with all the above attributes but it is expected that a chosen legume should have quite a number of desirable attributes.

2.1.3 Nutrient contributions from cover crops

Nitrogen (N) and phosphorus (P) deficiencies are the most pronounced nutrient constraints to crop production in smallholder farming systems in sub-Saharan Africa (Nyemba *et*

al., 1998). Legumes offer the most promising alternative for alleviating N deficiency in soils due to their ability to freely establish effective symbiosis with the Rhizobia bacteria. The nitrogen fixed through this association can support growth of the host legume and be available to associated crops after decomposition and mineralization of the legume (Nyemba *et al.*, 1998).

The direct N benefits from a well developed leguminous forage cover crop on subsequent grain legumes have been quantified by a number of authors and are in the range of 50 – 100 kg N ha^{-1} applied as commercial fertilizer (Greenland, 1985; Bouldin, 1988; Hairiah and van Noordwijk, 1989). Rajaratnam and Ang (1972) and Oke 1967), using potted plants in sand culture fed with nitrogen free nutrient solution, measured N fixation by *Pueraria phaseoloides*. The amounts fixed were found to be 176 mg and 756 mg N $plant^{-1}$ after 12 and 20 weeks growth respectively. Broughton (1977 b), indicated in a review that N_2-fixed by legumes grown in association with rubber, averaged 150 kg ha^{-1} $year^{-1}$ over a five year period. According to Broughton (1977 b), the legume cover made up of *Calopogonium mucunoides, Centrosema pubescens* and *Pueraria phaseoloides* benefited the rubber by increasing yields over the first 10 years of tapping and this persisted up to 20 years even though the legumes died out after only 4 to 5 years. Nutman (1976), reported amounts of N fixed by *Pueraria phaseoloides* in tropical and sub-tropical areas to average 99 kg N ha^{-1} $year^{-1}$.

Hairah and van Noordwijk (1989), compared *Mucuna pruriens var utilis, Pueraria phaseoloides, Psophocarpus palustris, Desmodium ovalifolium, Vigna unguiculata* and *Centrosema macrocarpum,* and observed that *Mucuna pruriens var utilis* produced the highest biomass and exhibited the fastest growth. In pure cultivation, the production of mucuna biomass was about 9 tons dry matter ha^{-1} (Segda *et al.*, 1998). Osei–Bonsu *et al.* (1996), also reported up to 9 t ha^{-1} of dry matter of mucuna containing an estimated 150 kg ha^{-1} of nitrogen.

Sanginga *et al.* (1996), found that mucuna accumulated in 12 weeks, about 313 kg N ha^{-1} as a sole crop and 166 kg N ha^{-1} when intercropped with maize. Sanginga *et al.* (1996), also observed that mucuna interplanted with maize produced a greater proportion of its nitrogen (74%) from fixation than did mucuna grown alone (66%), suggesting that competition for soil N influences the proportion of N fixed by mucuna. Intercropping experiments conducted at various experimental stations with legume and maize, sorghum, wheat, cotton and oats showed that mucuna was superior to cowpea or soybean for improving yield (Buckles, 1995).

Calopogonium mucunoides produced about 2.5 kg ha^{-1} of dry weight in 6 weeks with an estimated N contribution to the soil of about 65 kg ha^{-1} (Hairah and van Noordwijk, 1989). Legumes may not always make a net contribution of N to soils in which they grow. Evans *et al.* (1989), reported a large range of N balances of - 41 to + 135 kg ha^{-1} for Lupin and –32 to + 96 kg ha^{-1} for pea. Negative balances, however, were the exception.

Pueraria phaseoloides was estimated by ^{15}N isotope dilution method to fix between 60 and 80% of the N it accumulated in a two-year old palm plantation,amounting to 151 kg N ha^{-1} $year^{-1}$ (Zaharah *et al.*, 1986).

According to Foster (1976), a legume cover in a tree crop plantation can be expected to benefit the tree crop in the initial year because it does not compete for soil nitrogen, while in the fourth to sixth year it will return a considerable amount of nitrogen to the soil.

Leguminous covers were also found to increase oil palm laminae contents of N, P and Mn over those obtained with the other types of cover crops (Broughton, 1977a). Broughton (1977a), concluded that presumably, as a result of better nutrition, oil palms grown in association with legumes produced average yield increase of about 2 metric tonnes fresh fruit bunch (FFB) $ha^{-1}year^{-1}$ more than palms growing with natural covers or palms on bare soil.

2.1.4 Advantages and disadvantages of cover cropping

Cover crops have been used for a long time by small scale farmers in the tropics to protect the soil from the erosive effects of heavy rainfall, to control weeds and to assist in maintaining fertility during fallow periods or intercropped with a main crop (Skerman, 1977). Cover crops, which are aggressive, will not be suitable for growing in combinations with annual food crops because they may smother the food crops. They could therefore be grown as "improved fallows" or used under plantation crops to smother weeds.

Danso (1998), reported that based on current knowledge, legumes have the greatest potential for providing the highest amounts of biologically fixed N, for preserving substantial amounts of soil N, and capable of assisting in reducing declines in soil fertility and dependence on commercial fertilizers. This is particularly relevant in the humid tropics, where high rainfall has often depleted soil nutrients especially N, which leaches easily (De Willigen, 1985). The benefits derived from the use of cover crops have been attributed mainly to their nitrogen-fixing ability and the improvement in soil organic matter (Mulongoy, 1986; Mulongoy and Akobundu, 1990; Peoples and Herridge, 1990). In Malaysia, it was found that in the long term, a ground cover of legumes led to more suitable physical conditions such as better structure, lower bulk density and larger values of total and air filled porosity than with grasses (Chan *et al.*, 1977).

Maintaining a legume cover in plantations has been shown to reduce soil erosion (Pearson *et al.*, 1995). Reductions in soil erosion are due in part to improved aggregation of soil particles and increased water infiltration rates resulting from the increase in readily decomposable organic matter added to the soil by legume covers (Song and Yap, 1976). In addition, the extensive root systems of legumes act as a permeable barrier to reduce the rate of run-off so that the soil particles are deposited and infiltration of water into the soil is increased.

Leaching losses under legume covers have been estimated to be 63 kg N ha^{-1} $year^{-1}$, less than losses under natural regrowth (Agamuthu and Broughton, 1985).

In summary, there is a consensus of opinion that cover crops are particularly beneficial in reducing soil erosion, adding organic matter to the soil and conserving soil humus,improving soil aeration and structure, improving the soil nutrient status, reducing leaching of minerals and conserving soil moisture.

Ochs and Danielson (1976), observed that, in drier climates, legume cover caused a decrease in yields of oil palm due probably to competition with the crop for water during the dry season. Kasasian (1971), also reported that shallow–rooted legumes competed with coffee for moisture and suggested the used of deep- rooted legumes for coffee.

2.2 Mucuna as a cover crop

2.2.1 Origin and distribution

Mucuna pruriens (L) (DC) *var utilis, known* in Akan as "Aduapia" is native to Southern Asia and Malaysia, but in recent times it is widely grown in the tropics. It belongs to the family Leguminosae and sub family Papilionaceae. It is prominent among the herbaceous legumes currently being introduced into the humid tropics or the moist savanna of West Africa, for use as green manure and cover crop for soil fertility improvement and weed control (Akobundu, 1987; Versteeg and Koudokpon, 1990; Buckles, 1995).

There are a dozen or so cultivated mucuna species found in the tropics and the most common species include *M. deeringiana, M. pruriens, M. cochichinensis, M. nivea, M. capitata, M. hassjoo, M. diabolica, and M. atterima* (Tanaka, 1976; Duke, 1981). However, Buckles (1995), ascertained that taxonomy of these species is confused and some designations may be

synonymous. *Mucuna pruriens* has several common names such as "Velvet bean" "Bengal bean," "cowhage" and "Koro benguk"(Hairiah, 1996).

2.2.2 Botany and growth characteristics of mucuna

The genus Mucuna includes many perennial climbers. The species of velvet bean commonly used are annual or perennial species with vigorously growing vines, which may extend up to 6 m in length (Hairiah, 1996), or 10-14 m under favourable conditions (Buckles, 1995).

Mucuna is a self-pollinating plant with out crossing being rare (Duke, 1981). It appears to be non-specific in its Rhizobium requirement (Hairiah, 1996). Like most legumes, Mucuna has the potential to fix atmospheric nitrogen through a symbiotic relationship with soil microorganisms. Inoculation of soil or seed with Rhizobia bacterial cultures may help stimulate nodulation, especially in the tropics (Burkill, 1966; Duke, 1981; Buckles, 1995).

The main differences among cultivated species are pubescence on the pod, seed colour and the number of days to pod maturity. Seed colours include shiny black, beige or grey, brown and mottled. Life cycle ranges from 100 to 290 days from sowing to harvest of the pod (Buckles, 1995).

Velvet bean is a vigorously growing plant, which climbs by twining in the anticlock-wise direction when provided a stake or spread profusely on the ground when there is no stake (Bennett–Lartey, 1994). The profuse spreading growth habit makes it a good cover crop and a useful weed control agent. The plant does not have a deep taproot but it produces an abundance of surface roots. It produces up to 23 t ha^{-1} of green forage and 9 t ha^{-1} of dry matter, including more than 1 t ha^{-1} of dried roots (Camas-Gomez, 1991; Chavez, 1993).

Bennett–Lartey (1992), characterised eight accessions of velvet beans and observed variability in the flowering and maturity dates, as well as growth habit.

Mucuna thrives best under warm and moist conditions, in areas with high total annual rainfall in a bimodal distribution (Buckles, 1995). Flowering is stimulated by cooler night temperatures (Duke, 1981). Duke (1981), also observed that mucuna species exhibit reasonable tolerance to drought and poor, sandy or laterite soils. Reports indicate that mucuna does not tolerate waterlogged or acidic soils, and very dry conditions or areas with altitudes above 2000 m (Anon., 1986). Mucuna can grow to cover extensive areas within a short time if left unchecked and is capable of controlling aggressive weeds and improving soil fertility. It is therefore, likely to be adopted in areas with serious problems of weed and/or soil fertility (Osei–Bonsu *et al.*, 1996).

2.2.3 Uses of mucuna

In the United States of America, India, South Asia and Latin America, the importance of mucuna for improving soils is well documented (Buckles, 1995). In West Africa, some work has been done in Benin, Nigeria and Ghana using mucuna as green manure in maize fields and as a source of food (Ezueh, 1977; Osei-Bonsu *et al.*, 1996; Versteeg *et al.*, 1996). In Ghana, Osei-Bonsu *et al.* (*1996*), suggested that mucuna is likely to be adopted in areas with predominantly monocropping systems especially of tall crops.

Versteeg *et al.*, (1996), observed 70% higher maize yields when mucuna was used as a fallow than on continuously cropped fields. Farmers who had opted for mucuna obtained more than double their grain yield, from 480 to 1140 kg ha^{-1}.

A survey of the use of legumes in tropical countries conducted by the International Institute of Agriculture in the 1930's (IIA, 1936), revealed that the crop is used for several

purposes. It is used as a cover crop in the Punjab region of India and as a soil improver preceding sugarcane, cassava and lemon grass. Mucuna was reportedly used in Zanzibar to prevent the growth of *Imperata cylindrica,* an obnoxious weed and as green manure.

Protein content of mucuna seed is reported to be about 26% and its quality is said to be comparable to that of soybean (Ravindran and Ravindran 1988). On the Island of Madagascar, it is used as fodder for cattle (IIA, 1936). Recent reports indicate, however, that mucuna species has been accepted among small scale farmers as a minor food crop in Nigeria (Ezueh, 1977), Mozambique (Infante *et al.,* 1990) and Ghana (Osei- Bonsu and Buckles, 1993). Osei-Bonsu *et al.* (1996), after a survey in Ghana, suggested that *Mucuna* and *Canavalia* have been grown extensively as minor food crops for at least a century. The legumes, according to them, are used frequently in stews and soups but in very small quantities during any one meal. Mucuna seeds produced in the Guatemalan lowlands are marketed as a coffee substitute among Indian groups in the highlands and in parts of Southern Mexico, where it is known as 'nescafe' (Buckles, 1995).

Mucuna seeds have been used as additional protein source, rather extensively, for farm animals like steer and pigs in Southern United States of America (Versteeg *et al.,* 1996) and were also used as feed for cattle and hogs (Buckles, 1995). Some species of mucuna have been used as ornamental, an aphrodisiac, an emetic and as poison (Buckles, 1995).

Mucuna seed contains a chemical substance, levodopa, which is used in the treatment of Parkinson's disease, but can produce a toxic confusional state in humans (Infante *et al.,* 1990). Levodopa contains antinutritional factors so that if the seeds are improperly prepared it can cause problems. Versteeg *et al.*(1996), have however suggested ways of preparation which can reduce the levodopa levels from about 6% to about 0.4%. Research in this area is however still needed to ensure that the seed is eaten without any adverse effects.

2.3 Pueraria as a cover crop

Pueraria phaseoloides is native to Malaysia, Indonesia or South East Asia, and is widely distributed in the wet tropics (Hairiah, 1996). It has some synonyms such as *Pueraria javanica* Benth and *Pueraria phaseoloides var javanica* (Benth) Hook. It is commonly called "Puero" in Australia, "Tropical Kudzu" in most of the tropics and "Kacang ruji" in Java and Indonesia (Hairiah, 1996). It is commonly grown as cover crop and green manure in coffee, oil palm, citrus and rubber plantations. It is palatable to animals and is also extensively used as pasture plant in many humid tropical areas. The plant has seed protein content of 19% (Anon., 1990).

It grows slowly at seedling stage but after it has established, it grows vigorously and forms a dense thick ground cover of length 7 m – 9 m. Its rapid and luxuriant growth helps to suppress weeds and protects the soils from rapid water run-off. It forms an abundance of root nodules and is a good green manure (Anon., 1990). The plant is a hairy perennial herb with long runners and considered to be one of the best tropical legumes for smothering weeds, hence its wide use as cover crop in sisal in Tanzania, and in smothering nut grass *(Cyperus rotundus)* in Venezuela (Hairiah, 1996; Skerman, 1977). When support is provided it will grow as a twining climber.

Pueraria has a deep and extensive root system, which binds the soil together, and helps minimise erosion. It also produces nodules on the roots, which helps in nitrogen fixation. Zaharah *et al.* (1986), using the isotope dilution method on *Pueraria phaseoloides* growing with grasses in a two year-old oil palm plantation, found N_2 fixed to be 151 kg $ha^{-1}year^{-1}$ The stems root at the nodes in contact with the ground and lateral and secondary stems are formed to produce a mass of vegetation 0.3 to 0.6 m in height within 8- 9 months from sowing (Anon., 1990). The plant is reported to tolerate a high water level in the soil and found to be best

suited to heavy soils in Singapore (Anon., 1990). In the drier part of a year however, the plant also grows well and produces many flowers and pods. The plant tolerates shade and is sometimes found in thickets or edge of forest (Anon., 1990).

2.4 Cowpea as a cover crop

Cowpea is the second most important food legume cultivated in Ghana after groundnut (*Arachis hypogea*) and is known to have originated from Africa (Doku, 1977). It forms a large part of the diet of the people of developing countries, being an inexpensive source of protein.

There are different types of growth habit, in the different varieties from erect to climbing types. The prostrate or spreading types are particularly good for use as cover crops. Oladokun (1980), used *Vigna unguiculata* as a cover crop under coffee together with *Pueraria phaseoloides* and *Calopogonium mucunoides.* He found *Pueraria phaseoloides* to be more effective in suppressing weeds than *Calopogonium mucunoides* and *Vigna unguiculata.*

The use of cowpea as a cover crop under eucalyptus has been evaluated. Cowpea was recommended for planting in eucalyptus stands for periods not exceeding 90 days after planting (Schumann, 1991). The use of cowpea as a cover crop to suppress weeds in oil palm has the added advantage of providing food for the farmer. Hairiah *et al.* (1986), working on different leguminous cover crops, observed that *Vigna unguiculata* and *Mucuna utilis* grew rapidly, aged early and had a relatively high nitrogen concentration and a low root: shoot ratio.

2.5 Cover crops in weed management of tree crop plantations

Weeds pose serious problems to plantation crops, especially at their nursery stages. Utulu (1986), observed that oil palm seedlings in polybags cannot tolerate weed interference beyond six weeks after planting. He also observed that uncontrolled weed growth caused significant reduction in seedling leaf area, leaf number, height and dry weight in the polybags.

Weeds are also a serious problem in tree crops during the early years of field establishment. This is because many of the trees require several months or even years to develop full canopy to shade weeds out (Akobundu, 1987).

Yield losses due to weeds alone have been estimated to be greater than 50% of the potential yield of cultivated crops in the tropics (Deat, 1982; Terry, 1983). Delayed weeding in an attempt to spread the labour load has often resulted in crop yield losses (Carson, 1979). Carson (1975), observed that in cotton a delay of more than 4 weeks in weeding caused a significant reduction in yield, while at least 6 weeks of weed-free conditions after planting were necessary to prevent a significant reduction in yield. Weed competition has also been reported to cause stunting of cocoa trees (Paviot, 1977).

Weed interference in established oil palm plantation has been found to adversely affect female flower production, number of leaves per palm and fresh fruit bunch yield (Ojuederie *et al.*, 1983). Weeds interfere with harvesting operations and increase cost of harvesting in both smallholder and large-scale oil palm plantations (Akobundu, 1987). In the oil palm plantation, uncontrolled weed growth also poses problems of accessibility. This leads to poor standards of field operations, especially the collection of loose fruits after harvesting and fertilizer application. In addition, these weeds may serve as hiding places for rodents, especially in the immature oil palm. Rajaratnam *et al.* (1977), observed that weeds competed very well with the oil palm for nutrients.

In Ghana, there is a shortage of farm labour and hence the need for more reliable and cost-effective methods of weed control, especially in plantation crops. Four main methods of weed control are practiced, namely manual, chemical, biological and integrated weed control.

Manual weed control has been the traditional weed control method in tropical Africa. In Ghana, initial establishment of most plantation crops is characterised by under-brushing

with a cutlass and felling of big trees with an axe. Majority of farmers in Africa spend more time weeding than any other farming activity (Flinn and Zuckerman, 1979; Akobundu, 1980). Manual weed control can be quite uneconomical where large areas are being cultivated (Lerch and Zemp, 1982; Akobundu, 1991).

Akobundu (1987), has observed that increasing scarcity and cost of farm labour is gradually making chemical weed control more appealing to farmers than in the past. Bonaparte (1981), showed that in cocoa, chemically-weeded plots out-yielded manually-weeded plots consistently for 3 years. A similar observation was made in coffee when chemical weed control was found to have consistently given better crop yield than hand slashing with a cutlass.

The major type of biological weed control in plantation crops is the use of plants to suppress weed growth. Shade trees such as *Gliricidia spp* and, *Musa spp* have been noted to play a role in weed control in cocoa. Oladokun (1980), observed marked differences in the weed suppression capacity of cover crops in coffee. The use of cover crops for weed control is very common in oil palm plantations. Cover crops, if established early, have been shown to be of immense help to oil palm especially at the early stages of growth. One of the problems in cover crop management is to prevent them from climbing onto the young palms. Clean weeding of about 2 m radius around each palm tree is therefore advisable.

Akobundu (1987), suggested that it is not economical to use any one weed control method repeatedly throughout the economic life of most plantation crops and advocated for an integrated approach. In the oil palm for instance, initial establishment could be done by manual clearing. The cover crop could then be established. Selective herbicides can be used in the maintenance of the covers. The rings around the palm could be maintained by the use of herbicides or hand weeding.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Pot experiment: Evaluation of the response of three cover crops to bradyrhizobial inoculation, in two soils

A pot experiment was conducted at the Sinna's garden of the Crop Science Department, University of Ghana, Legon, from March-July 1998. The experiment was aimed at evaluating nodulation, nitrogen accumulation and dry matter accumulation of three leguminous cover crops with and without bradyrhizobial inoculation.

3.1.1 Experimental treatments and layout

The legume cover crops used were *Pueraria phaseoloides*, two accessions of Mucuna, *Mucuna pruriens var utilis* Accession 1746 (early maturing mucuna designated – mucuna E) and *Mucuna pruriens var utilis* Accession 1745 (late maturing mucuna designated – mucuna L) and a prostrate variety of cowpea (1239).

Plastic pots of 10 litres capacity measuring 28 cm in diameter and 26 cm high were used. Three small holes were made at the base of each pot and also the base of the pots was lined with plain paper to prevent loss of soil, while allowing free drainage of excess water through the holes at the base of the pot. Each pot was filled with 10 kg of soil – sand mixture. The mixture was made by thoroughly mixing two parts of soil to one part of sand on weight to weight basis. The soils used in this study were Nzima (Orthi-ferric acrisol) and Kokofu (Eutric/Dystric nitisol). They were obtained from an area at the research fields of the Oil Palm Research Institute, previously planted with oil palm. The soils were taken from a depth of 0 – 20 cm, air-dried and sieved (< 5 mm).

The experiment consisted of a factorial combination of two soil series, four cover crops and inoculation versus no inoculation treatments. There were three harvesting times. The treatments were arranged in a randomised complete block design with four replications. This gave a total of 192 pots for the experiment. A total of 64 pots were selected for harvesting at each harvest time.

Four seeds were sown per pot and thinned to two plants per pot, a week after emergence. *Pueraria phaseoloides* seeds were mechanically scarified to promote germination. Seeds were first coated with 40% gum arabic and then inoculated with peat - based inoculant containing the local effective isolates of specified bradyrhizobia for the respective cover crops. Seeds were sown immediately after inoculation. All pots were supplied with 50 ml N-free nutrient solution (Hoagland and Aron, 1938) at three weeks after sowing and four weeks after sowing. Subsequently, an addition of 50 ml was done fortnightly. The pots were kept in the open and watered daily with tap water.

3.1.2 Data Collection and Statistical Analysis

The physical properties of soil analysed were percent sand, silt, and clay. The chemical properties analysed were pH (1:1 H_2O), organic matter, Total N, Available P (ppm), % Carbon, K, Ca, Mg, Na and CEC. Twenty core soil samples (0 – 20cm depth) were randomly collected from the sites where the soils were taken. The soils were mixed together, sieved (< 5 mm) and sub sample taken for soil analysis. The soil analysis was duplicated and the mean values recorded in Table 5.

Plants were harvested at 40, 80 and 120 days after planting (DAP) by cutting the stem of the two plants at soil level. The fresh weights of the shoots were taken and then oven dried at 70^0C to constant weight to obtain the shoot dry weight. The dry shoot samples were milled

for determination of plant nitrogen content. The plant roots were washed under gently flowing tap to free the roots of all soil particles. The nodules were carefully removed, counted and oven- dried at 70^0C till constant weight. Roots were also oven dried at 70^0C to constant weight to obtain root dry weight. Nitrogen content of shoots was determined by the Kjeldahl method.

Analysis of variance (ANOVA) for shoot dry weight, root dry weight, number of nodules, nodule dry weight and nitrogen content of shoots were carried out using Genstat statistical package (Genstat, 1997). Square root transformation was done on the number of nodules data before analysis. Simple correlation coefficients among the characters were also determined.

3.2 Field Experiments

Two field experiments were conducted at the Oil Palm Research Institute, Kade, on the Kokofu soil series (Eutric/Dystric nitisol).

3.2.1 Experiment 1: Evaluation of nodulation, dry matter and total nitrogen content of three leguminous cover crops.

The experiment was conducted between June and October 1998.
The objective of this experiment was to determine the rate of dry matter production, nodulation and nitrogen accumulated in the shoot of *Pueraria phaseoloides,* two accessions of *Mucuna pruriens var utilis* and *Vigna unguiculata*.

3.2.1.1 Land Preparation

The study area, which was previously planted with oil palm, had been left to fallow for about four years after the palms were felled. A general survey of weeds present on the plot

was made and recorded. The land was cleared by cutting and removing the above ground vegetation. The experiment was conducted close to the area where soil sample for the pot experiment was taken.

3.2.1.2 Experimental layout and planting

Each plot was 4.8 m x 4.8 m in size, with 2 m gap between plots. A randomised complete block design with four replications was employed. The treatments in the study were *Pueraria phaseoloides, Mucuna pruriens var utils* ACC 1745 (late maturing), *Mucuna pruriens var utilis* ACC 1746 (early maturing) and *Vigna unguiculata* (cowpea).

The mucuna and cowpea were planted at a spacing of 60 cm x 40 cm, at three seeds per hill and thinned to two, a week after emergence. The pueraria was seeded at 15 kg ha^{-1}, each plot requiring about 40 g of seed. Pueraria seed was drilled in rows 60 cm apart. There were seven rows per plot. The plots were weeded by hand picking, two weeks after planting.

3.2.1.3 Data collection and statistical Analysis

Same data was collected as was in the pot experiment. However, plants were harvested at 40, 60, 80 and 100 days after planting. At each harvest, five plants from each plot were cut at the soil level. The roots were carefully dug out and washed on a 1mm mesh sieve. Statistical analysis was same as in the pot experiment.

3.2.2 Experiment 2 : Evaluation of the effectiveness of leguminous cover crops for weed control.

This study aimed at evaluating the effectiveness of the three cover crops in controlling weeds.

3.2.2.1 Experimental layout and planting

Land preparation was same as in experiment 3.2.1. Each plot was 4.8 m x 4.8 m in size, with 2 m between plots. A randomised complete block design with four replications was employed. The treatments in this study were *Pueraria phaseoloides, Mucuna pruriens var utilis* ACC 1745 (late maturing), *Mucuna pruriens var utilis* ACC 1746 (early maturing) and *Vigna unguiculata* (cowpea). An unweeded plot was kept as control in each block.

Mucuna and cowpea were planted at a spacing of 60cm x 40cm, at three seeds per hill and thinned to two a week after emergence. Pueraria was seeded at 15 kg ha^{-1}, each plot requring about 40 g of seed. Pueraria seed was drilled in rows 60 cm apart. Weeds were removed by hand picking at two weeks after sowing.

3.2.2.2 Data collection and statistical analysis

The efficiency of the legumes in weed control was estimated with the beaded string method (Sarrantonio, 1991). A thin string measuring about 10 m long was used. Then starting from about 1 m from the end, the string was beaded at every 15 cm. The string was stretched diagonally across the plot and staked down at each end. The plot was leaned over and each dot was observed below. If the dot lay over or under a legume plant part, it was counted. When it lay over the ground, dead residue or weed it was not counted. Next, the string was crossed in the opposite direction and the dots in the other diagonal counted.

Percent ground cover was then determined by the following equation (Sarrantonio, 1991).

$$\% \text{ Ground cover} = \frac{\text{Dots with legumes}}{\text{Total dots counted}} \times 100$$

Total dots counted were given by the total number of dots in the two diagonals within a plot.

Percent weed coverage was also determined with the same method. That is if the dot lay over or under a weed, it was counted and when it lay over a legume or ground it was not counted. The equation for percent weed coverage is given below.

$$\% \text{ Weed cover} = \frac{\text{Dots with weeds}}{\text{Total dots counted}} \times 100$$

Measurements were made at 30, 60,90 and 120 days after planting.

Analysis of variance for the percentage ground cover of legumes and percent weed coverage were carried out using Genstat Statistical package (Genstat, 1997).

CHAPTER FOUR

4. RESULTS

4.1. Response of three cover crops to bradyrhizobial inoculation in two soils

4.1.1 Number of nodules and nodule dry weight

Only cowpea plants produced nodules at 40 days after planting (Table 1). Mean number of nodules for cowpea ranged from 35 per plant in uninoculated plants on Nzima soils, to 124 per plant in inoculated plants on Nzima soils. On Kokofu soil, uninoculated cowpea plants produced a higher number of nodules than when inoculated. However, on Nzima soil, nodulation more than trebled with inoculation of cowpea plants.

The inoculation x soil x legume interaction for nodule number at 80 days after planting was not significant. None of the first order interactions, namely, inoculation x soil type, inoculation x legume species and soil type x legume species was also significantly different. Mean number of nodules for the legumes ranged from 12 per plant in uninoculated pueraria plants on Kokofu soils to 78 per plant in inoculated late maturing mucuna on Nzima soil (Table 1). There were also no significant differences among the legumes for nodule number. For both varieties of mucuna, inoculation led to increased nodule number in the Nzima soil. With pueraria, nodule number was higher in Kokofu than Nzima under inoculation but the reverse was true without inoculation. For both inoculated and uninoculated treatments, the number of nodules was on average higher on Nzima than Kokofu soils (Table 1).

The inoculation x soil x legume interaction was not significant for nodule number at 120 days after planting. Significant differences (P=0.05) occurred among the legumes for nodule number. Cowpea had on the average less than five nodules per plant at 120 days after planting. Pueraria had the highest number of nodules at 120 days after planting.

Table 1: Effect of inoculation on number of nodules plant $^{-1}$ of three leguminous cover crops at different stages of growth on Nzima and Kokofu soils in pots

Legume type	Inoculated			Uninoculated		
	Nzima	Kokofu	Mean	Nzima	Kokofu	Mean
40 days after planting						
Cowpea	124	61	92	35	94	65
80 days after planting[b]						
Mucuna (Early)	26	22	24	15	15	15
Mucuna (Late)	78	16	47	23	28	26
Cowpea	37	17	27	45	25	35
Pueraria	25	57	41	26	12	19
Mean	41	28		27	20	
120 days after planting[c]						
Mucuna (Early)	32	58	45	78	32	55
Mucuna (Late)	76	47	62	47	60	54
Cowpea	6	4	5	5	4	4
Pueraria	99	70	84	159	76	117
Mean	53	45		76	40	

[b]LSD (P= 0.05): Inoculation (NS); soil type (NS); legume (NS); Inoculation x soil type (NS); Inoculation x legume (NS); soil type x legume (NS); Inoculation x soil type x legume (NS)

[c]LSD (P=0.05): Inoculation (N.S); soil type (N.S); legume (28); Inoculation x soil type (N.S); Inoculation x legume (N.S); soil x legume (N.S); Inoculation x soil type x legume (N.S)

The nodule dry weight at 40 days after planting ranged from 0.12 g per plant in the uninoculated control to 0.86 g per plant in the inoculated cowpea plants. The inoculated cowpea plants on Nzima produced the highest nodule dry weight whilst uninoculated cowpea plants on Kokofu soil produced higher nodule dry weight than those on Nzima soil (Table 2).

The inoculation x soil x legume interaction for nodule dry weight at 80 days after planting was not significant. There were also no significant differences among the legumes for nodule dry weight. For both inoculated and uninoculated treatments, nodule dry weight was on the average higher on Nzima than Kokofu soils (Table 2).

The inoculation x soil x legume interaction at 120 days after planting was significant (P=0.05) for nodule dry weight. There were significant (P=0.05) differences among the legume types for nodule dry weight with cowpea producing significantly lower nodule dry weight than the three other legumes (Table 2). Pueraria produced the highest nodule dry weight while cowpea produced the least nodule dry weight. On the average, the highest nodule dry weight was produced on Kokofu soils for the inoculated plants. However, for the uninoculated plants, average nodule dry weight was higher on Nzima soil. Uninoculated legumes on the average produced higher nodule dry weight than inoculated ones but the differences were not significant. The effect of inoculation on nodule dry weight in pueraria was consistent at both 80 and 120 days after planting.

4.1.2 Shoot dry matter yield

Shoot dry matter produced by mucuna, cowpea and pueraria plants in the two soils, with and without inoculation are shown in Table 3. The second order interaction, legume x soil x inoculation was not significant for shoot dry weight at 40 days after planting. Also, none of the first order interactions among the three factors was significant.

There were however, significant (P= 0.05) differences among the cover crops, with inoculated cowpea producing the highest average dry matter yield of 6.89 g per plant in the two soils. This represents about 90% increase over the average yield of pueraria, which produced the least shoot dry matter.

Table 2: Effect of inoculation on nodule dry weight (g plant $^{-1}$) of three leguminous cover crops at different stages of growth on Nzima and Kokofu soils in pots

Legume type	Inoculated			Uninoculated		
	Nzima	Kokofu	Mean	Nzima	Kokofu	Mean
40 days after planting						
Cowpea	0.86	0.25	0.56	0.12	0.34	0.23
80 days after planting[b]						
Mucuna (Early)	0.14	0.21	0.18	0.15	0.12	0.14
Mucuna (Late)	0.35	0.06	0.21	0.16	0.18	0.17
Cowpea	0.34	0.22	0.28	0.52	0.32	0.42
Pueraria	0.16	0.44	0.30	0.20	0.06	0.13
Mean	0.25	0.23		0.26	0.17	
120 days after planting[c]						
Mucuna (Early)	0.97	1.28	1.13	1.31	0.90	1.10
Mucuna (Late)	1.09	0.75	0.92	1.32	1.51	1.42
Cowpea	0.01	0.00	0.00	0.00	0.00	0.00
Pueraria	0.76	1.45	1.11	2.55	1.24	1.89
Mean	0.71	0.87		1.30	0.91	

[b]LSD (P= 0.05): Inoculation (NS); soil type (NS); legume (NS); Inoculation x soil type (NS); Inoculation x legume (NS); soil type x legume (NS); Inoculation x soil type x legume (NS)

[c]LSD (P= 0.05): Inoculation (N.S); soil type (N.S); legume (0.46); Inoculation x soil type (N.S); Inoculation x legume (N.S); soil type x legume (N.S); Inoculation x soil type x legume (0.91)

For the uninoculated plants, cowpea produced the highest average dry matter yield of 5.78 g in the two soils and this was about 75% higher than pueraria, which produced the least shoot dry matter yield.

When averaged for all the legumes, higher shoot dry weights were produced on Kokofu soil than Nzima for both the inoculated and uninoculated plants but the differences were not

significant. On the average, legume crops produced higher shoot dry weight with inoculation than without inoculation but these differences were not significant.

The two mucuna accessions had higher shoot dry weights on Kokofu than on Nzima soils for both inoculated and uninoculated plants. Inoculation increased shoot dry weight of the two mucuna species on Nzima soil but it reduced this parameter on Kokofu soil. On both soils, however, inoculation improved dry matter yield of cowpea.

At 80 days after planting, the inoculation x soil x legume interaction was significant (P= 0.05) for shoot dry weight. The inoculation x soil, inoculation x legume and soil x legume interactions were however, not significant (Table 3). There were significant (P=0.05) differences among the legume types. Cowpea produced significantly higher shoot dry weight than the other three legumes. The late maturing mucuna produced significantly higher shoot dry weight than the early maturing mucuna. When inoculated, both cowpea and late mucuna produced similar amounts of dry matter in Kokofu and Nzima soils. Without inoculation however, the two legumes produced higher amounts of dry matter on Kokofu than Nzima soil. Pueraria on the other hand produced higher dry matter on Nzima soil without inoculation than when inoculated. It however, responded to inoculation in the Kokofu soil.

Again the second order interaction of inoculation x soil x legume was significant (P= 0.05) for shoot dry weight at 120 days after planting. The cowpea produced significantly (P= 0.05) lower dry matter than all the other legumes both with and without inoculation. Dry matter production in pueraria was also significantly lower than in late mucuna only in inoculated plants on Nzima and in uninoculated plants in Kokofu.

4.1.3 Shoot Nitrogen (N) Content

Differences in shoot nitrogen (N) content for the inoculation x soil x legume interaction was not significant. There were however, significant (P= 0.05) differences among

the legumes for shoot N accumulated at 40 days after planting (Table 4). Soil type did not have a significant effect on shoot N but plants on Kokofu soil generally had higher shoot N than those on Nzima soil.

Cowpea accumulated the highest nitrogen content whilst pueraria accumulated the least nitrogen content for both the inoculated and uninoculated treatments at 40 days after planting. The shoot N content of pueraria was less than a third of that of mucuna and only about 13% of that of cowpea, under inoculation. The relative differences among the legumes without inoculation were different from under inoculation. The ranking among the legumes was however, the same with and without inoculation.

The legumes responded differently to inoculation in the two soils, thus leading to a significant (P= 0.05) inoculation x soil x legume interaction at 80 days after planting (Table 4). For example, the late maturing mucuna accumulated higher shoot N on Nzima soil than Kokofu soil in the inoculated treatments. However, on Kokofu soil, uninoculated late mucuna accumulated even higher N than the inoculated plants on both soils. There were also significant (P= 0.05) differences among the legumes for shoot N content. Cowpea had a significantly (P= 0.05) higher shoot N content than the three other legumes. The late maturing mucuna also had a significantly (P=0.05) higher shoot nitrogen content than the early maturing mucuna and pueraria. The early maturing mucuna and pueraria were however not significantly different from each other. For the early maturing mucuna, inoculation significantly (P=0.05) improved shoot dry weight, nodulation and shoot N content on Kokofu soil than Nzima soil. The uninoculated plants however had higher shoot dry weight, nodulation and shoot N content on Nzima soils.

The second order interaction, inoculation x soil x legume was significant (P=0.05) for shoot N content, at 120 days after planting.

Table 3: Effect of inoculation on shoot dry weight (g plant $^{-1}$) of three leguminous cover crops at different stages of growth on Nzima and Kokofu soils in pots

Legume type	Inoculated			Uninoculated		
	Nzima	Kokofu	Mean	Nzima	Kokofu	Mean
40 days after planting[a]						
Mucuna (Early)	2.12	2.33	2.23	1.78	2.92	2.35
Mucuna (Late)	3.79	3.96	3.88	3.37	4.23	3.80
Cowpea	6.98	6.80	6.89	5.20	5.78	5.49
Pueraria	0.55	0.90	0.73	2.14	0.56	1.35
Mean	3.36	3.50		3.12	3.37	
80 days after planting[b]						
Mucuna (Early)	8.39	9.56	8.98	8.47	9.10	8.79
Mucuna (Late)	14.17	14.89	14.53	11.68	16.71	14.20
Cowpea	20.65	20.54	20.60	12.45	22.69	17.57
Pueraria	4.86	9.82	7.34	16.44	4.64	10.54
Mean	12.02	13.70		12.26	13.29	
120 days after planting[c]						
Mucuna (Early)	31.10	33.50	32.30	26.00	23.40	24.70
Mucuna (Late)	43.80	28.70	36.25	26.10	41.00	33.60
Cowpea	17.60	9.80	13.70	10.20	13.60	11.90
Pueraria	19.10	31.90	25.50	33.24	21.20	33.20
Mean	27.9	25.98		23.89	24.8	

[a]LSD (P= 0.05): Inoculation (NS); Soil type ((N.S); legume (0.92); Inoculation x Soil type (NS);Inoculation x legume (NS); Soil type x legume (NS); Inoculation x Soil type x legume (NS)

[b]LSD (P= 0.05): Inoculation (NS); soil type (NS); legume (3.6); inoculation x soil type (NS); inoculation x legume (NS); soil type x legume(NS); inoculation x soil type x legume (7.12)

[c]LSD (P= 0.05): Inoculation (NS); Soil type (N.S); legume (7.41); Inoculation x Soil (NS); Inoculation x legume (NS); soil x legume (NS); Inoculation x Soil x legume (14.83)

Table 4: Effect of inoculation on shoot nitrogen content (mg plant $^{-1}$) of three leguminous cover crops at different stages of growth on Nzima and Kokofu soils in pots

Legume type	Inoculated			Uninoculated		
	Nzima	Kokofu	Mean	Nzima	Kokofu	Mean
40 days after planting[a]						
Mucuna (Early)	101.7	109.7	105.7	83.8	137.5	110.7
Mucuna (Late)	171.1	162.1	167.0	151.2	166.2	158.7
Cowpea	261.4	269.1	265.3	229.5	234.0	231.8
Pueraria	23.6	42.2	32.9	91.2	24.1	57.7
Mean	139.7	145.8		138.9	140.5	
80 days after planting[b]						
Mucuna (Early)	167.0	174.0	170.5	178.0	175.0	176.5
Mucuna (Late)	318.0	286.0	302.0	234.0	387.0	310.5
Cowpea	445.0	599.0	522.0	181.0	563.0	372.0
Pueraria	125.0	244.0	184.5	422.0	108.0	265.0
Mean	263.8	325.8		253.8	308.3	
120 days after planting[c]						
Mucuna (Early)	813.0	832.0	822.5	546.0	429.0	487.5
Mucuna (Late)	971.0	563.0	767.0	658.0	965.0	811.5
Cowpea	502.0	215.0	358.5	270.0	325.0	297.5
Pueraria	642.0	955.0	798.5	984.4	519.0	928.5
Mean	732.0	641.3		628.1	571.3	

[a]LSD (P= 0.05); Inoculation (NS); Soil type (NS); legume (40.18); Inoculation x Soil type (NS); Inoculation x legume (NS); soil type x legume (NS); Inoculation x Soil type x legume (NS).

[b]LSD (P= 0.05): Inoculation (NS); Soil type ((NS); legume (103.3); Inoculation x Soil type (NS); Inoculation x legume (NS); soil x legume (NS); Inoculation x Soil type x legume (206.6)

[c]LSD (P= 0.05): Inoculation (N.S); soil type (N.S); legume (249); Inoculation x soil type (N.S); Inoculation x legume (N.S); soil x legume (N.S); Inoculation x soil type x legume (497.9)

Thus differences in shoot N content depended on the combination of the three factors acting together. There were also significant (P= 0.05) differences among the legume species. In both soils, the shoot N of cowpea was significantly (P=0.05) lower than that of the other legume species. The late maturing mucuna and pueraria were also not significantly different from each other, but were significantly different from the early maturing mucuna and cowpea (Table 4).

On Nzima soil, uninoculated pueraria plants produced higher shoot nitrogen content than with inoculation at all three sampling dates. Cowpea had the lowest N content, while pueraria had the highest shoot N content. This was the exact reverse of N contents of the two legumes at 40 days after planting.

Table 5: Some chemical and physical properties of the top soil (0-20 cm) of the two soils used in the experiment

	Soil Series	
Soil Property	**Nzima**	**Kokofu**
Sand (%)	62.8	59.0
Silt (%)	22.2	21.4
Clay (%)	15.0	20.6
pH (1:1$H_2$0)	5.0	4.8
Org. Matter (%)	2.4	2.4
Total N (%)	0.13	0.11
Carbon (%)	1.04	0.84
Available P (ppm) Bray1	2.54	2.04
K (C mol/kg)	0.12	0.23
Ca (C mol/kg)	3.0	2.2
Mg (C mol/kg)	1.2	1.0
Na (C mol/kg)	0.14	0.14
CEC (cmol/Kg)	11.26	10.40

Table 6. Correlation coefficients (r) for relationships among nodulation, shoot dry weight and shoot N content of potted plants of mucuna, cowpea and pueraria.

	Nodule dry weight	Shoot N. content	Shoot dry weight
No. of Nodules			
a.	0.86**	0.50**	0.65**
b.	0.70**	0.58**	0.60**
c.	0.77**	-0.14 ns	-0.25 ns
d.	0.89**	0.72**	0.73**
Nodule dry weight			
a.		0.71**	0.82**
b.		0.72**	0.77**
c.		-0.04ns	-0.07 ns
d.		0.81**	0.82**
Shoot N. content			
a.			0.92**
b.			0.91**
c.			0.90**
d.			0.98**

**: Significant at 0.01 level; ns – not significant
a - Mucuna (early); b - Mucuna (late); c - Cowpea; d - Pueraria

4.1.4 Associations among characters

Number of nodules was significantly (p=0.01) correlated to nodule dry weight for all the legume cover crops. Nodule dry weight was also significantly (p=0.01) correlated to shoot N content and shoot dry weight for all the legume cover crops except cowpea, which was not significant. Shoot N content was significantly (p=0.01) correlated to shoot dry weight for all the legume cover crops (Table 6).

4.2 Field evaluation of nodulation, dry matter yield and nitrogen accumulation of three legume cover crops

4.2.1 Number of nodules and nodule dry weight

There were significant (P=0.05) differences in the number of nodules among the legumes at the different stages of harvesting (Table 7). Mean nodule number per plant was more than doubled from 40 to 100 days after planting for all the legumes except cowpea. At all the growth stages examined, pueraria produced the highest number of nodules whilst cowpea produced the least number of nodules (Table 7). Cowpea produced significantly lower number of nodules than the other legumes at all the growth stages examined. Cowpea recorded the highest number of nodules at 40 days after planting and then declined thereafter. No nodules were present at 100 days after planting. The late maturing mucuna produced significantly higher number of nodules than the early maturing mucuna at all stages of growth except at 40 DAP.

Table 7: Number of nodules plant^{-1} of three "field-grown" leguminous cover crops at different stages of growth

	Days after planting			
Legume type	**40**	**60**	**80**	**100**
Mucuna (Late)	7.2	15.0	19.8	22.7
Mucuna (Early)	6.5	9.5	11.6	13.7
Cowpea	5.2	4.5	2.1	0.0
Pueraria	13.5	18.9	25.0	28.3
L.S.D (P=0.05)	1.4	2.2	4.9	2.0

Significant (P=0.05) differences in nodule dry weight was observed among the legumes at various stages of growth except at 40 days after planting. Nodule dry weight increased from 0.027 g plant^{-1} at 40 days after planting to 0.083 g plant $^{-1}$ at 100 days after planting for

late maturing mucuna. Nodule dry weight of early maturing mucuna also increased from 0.043 g plant $^{-1}$ at 40 days after planting to 0.077 g plant^{-1} at 100 days after planting. Cowpea nodule dry weight however decreased from 0.016 g plant $^{-1}$ at 40 days after planting to zero at 100 days after planting (Table 8). There was no significant difference for nodule dry weight between the two mucuna accessions. On the average, pueraria produced the highest number of nodules and nodule dry weight.

Table 8 : Nodule dry weight (g plant $^{-1}$) of three "field-grown" leguminous cover crops at different stages of growth

	Days after planting			
Legume type	**40**	**60**	**80**	**100**
Mucuna (Late)	0.027	0.053	0.071	0.083
Mucuna (Early)	0.043	0.058	0.067	0.077
Cowpea	0.016	0.011	0.004	0.00
Pueraria	0.042	0.072	0.104	0.125
L.S.D(P=0.05)	NS	0.040	0.067	0.066

NS : Not significant

4.2.2 Dry matter yield and shoot nitrogen(N) content

There were significant (P=0.05) differences in shoot and root dry weights at all the growth stages examined. The two mucuna accessions were not significantly different from each other at all the growth stages examined except at 80 days after planting. Cowpea and early maturing mucuna were not significantly different from each other at 40 days after planting. Shoot dry weight yield increased steadily from 18.3 g plant $^{-1}$ at 40 days after planting to 92.6 g plant $^{-1}$ at 100 days after planting for late maturing mucuna. Shoot dry

weight for early maturing mucuna also increased steadily from 14.32 g plant $^{-1}$ at 40 days after planting to 80.5 g plant^{-1} at 100 days. Comparatively, pueraria had only 15.8 g plant $^{-1}$ of shoot dry weight at 100 days after planting (Table 9). Cowpea produced the highest shoot dry matter at 60 days after planting but this declined in subsequent harvests. At 100 days after planting, shoot dry weight of cowpea was only 5.7 g plant $^{-1}$.

The root dry weight of the two mucuna accessions were significantly (P=0.05) higher than those of the other two legumes (Table 10). The difference in root dry weight between the two mucuna accessions was not significant at 40 days after planting, but were significant (P=0.05) at 60, 80 and 100 days after planting. The highest root dry weight of 3.98 g plant $^{-1}$ was produced by early maturing mucuna at 100 days after planting while the lowest of 0.20 g plant $^{-1}$ was produced by pueraria at 40 days after planting (Table 10).

Table 9: Shoot dry weight (g plant $^{-1}$) of three "field-grown" leguminous cover crops at different stages of growth

	Days after planting			
Legume type	**40**	**60**	**80**	**100**
Mucuna (Late)	18.3	23.89	43.28	92.6
Mucuna (Early)	14.32	21.07	41.38	80.5
Cowpea	14.68	16.97	11.52	5.7
Pueraria	1.76	2.45	6.80	15.8
L.S.D(P=0.05)	2.74	2.56	4.40	7.35

Table 10: Root dry weight (g plant^{-1}) of three "field-grown" leguminous cover crops at different stages of growth

	Days after planting			
Legume type	**40**	**60**	**80**	**100**
Mucuna (Late)	0.94	1.05	1.72	3.09
Mucuna (Early)	0.93	1.65	2.14	3.98
Cowpea	0.59	0.76	0.52	0.49
Pueraria	0.20	0.23	0.84	0.92
L.S.D(P=0.05)	0.17	0.32	0.22	0.09

There were significant (P=0.05) differences at all the growth stages for shoot nitrogen content. Shoot nitrogen content was not significantly different between the two mucuna accessions at 60 and 80 days after planting. It was however significant at 40 and 100 days after planting. Shoot nitrogen content for cowpea was not significantly different from early maturing mucuna at 40 and 60 days after planting, but was significantly (P=0.05) different from the early maturing mucuna at 80 and 100 days after planting. Late maturing mucuna accumulated the highest shoot N at 100 days after planting (Table 11).

Table 11: Shoot nitrogen content (mg plant^{-1}) of three "field-grown" leguminous cover crops at different stages of growth

	Days after planting			
Legume type	**40**	**60**	**80**	**100**
Mucuna (Late)	726	793	1370	3277
Mucuna (Early)	513	649	1264	2589
Cowpea	596	498	359	215
Pueraria	56	80	207	521
LSD(P=0.05)	122.1	217.9	305.0	276.7

Table 12 . Correlation coefficients (r) for relationships among nodulation, shoot dry matter , root dry weight and shoot nitrogen content of "field–grown" plants of mucuna, cowpea and pueraria

	Nodule dry weight	Shoot N. content	Shoot dry weight	Root dry weight
No. of Nodules				
a.	0.52*	0.80**	0.86**	0.85**
b.	0.44 ns	0.75**	0.81**	0.82**
c.	0.84**	0.91**	0.90**	0.49 ns
d.	0.85**	0.80**	0.80**	0.84**
Nodule dry wt				
a.		0.26 ns	0.37 ns	0.41 ns
b.		0.29 ns	0.23 ns	0.38 ns
c.		0.76**	0.64**	0.22 ns
d.		0.78**	0.73*	0.81**
Shoot N. content				
a.			0.96**	0.92**
b.			0.98**	0.96**
c.			0.87**	0.52*
d.			0.97**	0.82**
Shoot dry wt				
a.				0.96**
b.				0.99**
c.				0.64**
d.				0.86**

*,**: Significant at 0.05 and 0.01 levels respectively.
a - Mucuna (early); b - Mucuna (late); c - Cowpea; d - Pueraria
Ns: not significant

4.2.3 Associations among characters

Number of nodules was significantly (p=0.01) correlated to shoot N content and shoot dry weight for all the legume cover crops. Nodule dry weight was however, significantly (p=0.01) correlated to shoot N and shoot dry weight of cowpea and pueraria but not the two mucuna species, (Table 12). Shoot N content was highly and significantly (p=0.01) correlated to shoot

dry weight for all the legume cover crops. Shoot dry weight was also significantly (p=0.01) correlated to root dry weight for all the legume cover crops, (Table12).

4.3 Ground cover of legume cover crops and weed growth

There were significant (P=0.05) differences among the legume species for percentage legume cover and percentage weed cover at all the growth periods (Figures 1 and 2).

The major weed species in the study area were *Chromolaena odorata, Paspalum congugatum, Aspillia africana* and *Panicum maximum*. These weeds constituted about 80% of the weedy areas in the experimental area. Marked differences were noted in the weed suppression capability of the cover crops. Late maturing mucuna gave faster ground coverage than all the other legumes over the period of study, effectively controlling the weeds present. Both cowpea and the late maturing mucuna grew rapidly covering about 65% of the plot in 30 days after planting compared to below 40% in the other treatments (Figure 1). Cowpea and early maturing mucuna matured early. Cowpea had its peak coverage at 60 days after planting and covered about 67% of the land at that time. The early maturing Mucuna however had its peak coverage at 90 days after planting, after which it declined. Pueraria was initially very slow but grew steadily, attaining about 70% coverage at 120 days after planting (Figure 1) and effectively suppressing the weeds under its coverage.

Weed coverage in the control plot was almost 100% from 60 days after planting (Figure 2). The cowpea plots had 32% weed coverage until at 90 days after planting, after which it increased to about 95%. Weed coverage in other legume plots was below 40% at the end of the experiment.

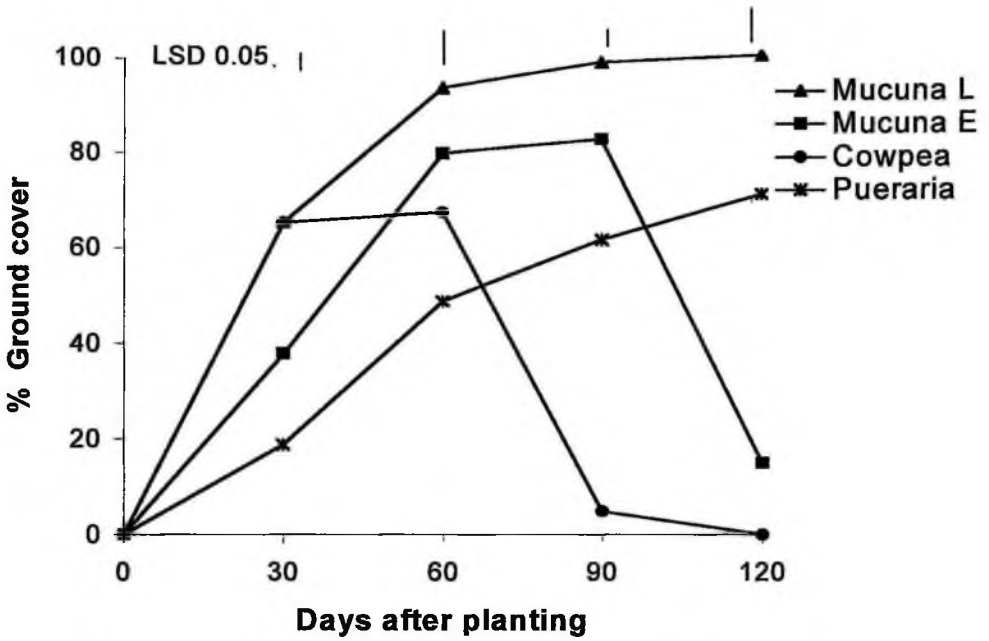

Figure 1: Ground cover of legume cover crops

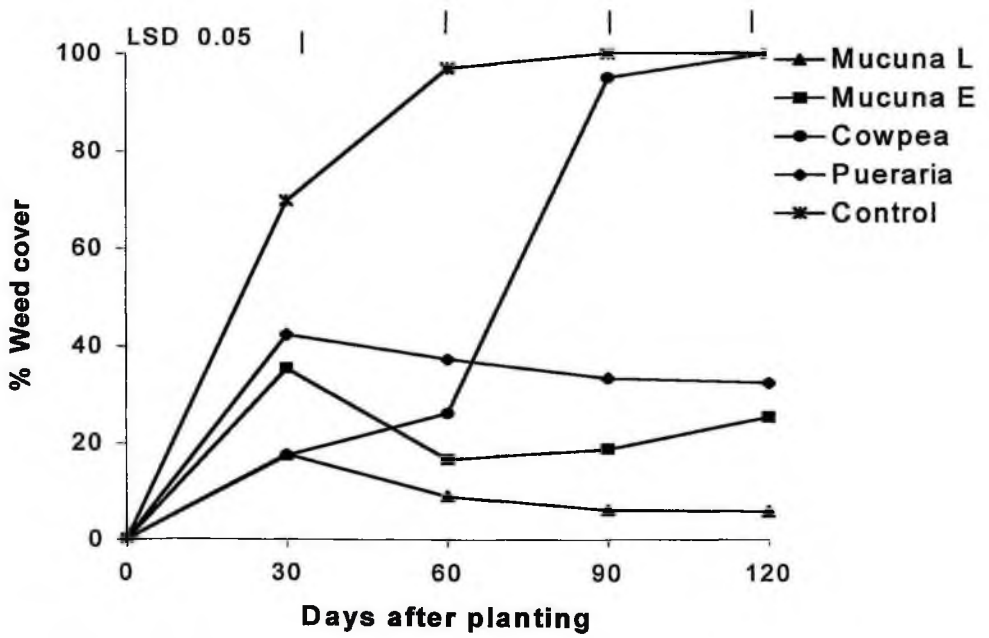

Figure 2: Percentage weed cover in different legume plots

CHAPTER FIVE

5. DISCUSSION

5.1 Effects of bradyrhizobial inoculation and soil type on nodulation, nitrogen accumulation and dry matter production of potted pueraria, cowpea and mucuna plants

Inoculation with rhizobia did not significantly increase dry matter production of the three legumes. Cowpea, and the two mucuna accessions however, generally produced higher shoot dry weight when inoculated while pueraria consistently produced higher shoot dry weight without inoculation. Faizah *et al.* (1989), on the other hand, observed that pueraria showed a small dry weight response to inoculation at 26 weeks but not at earlier or later harvests. The present observations may probably be due to the high and efficient population of the indigenous rhizobia in the soils and their compatibility with pueraria, compared with the inoculated rhizobia. Pueraria may therefore not require inoculation in these soils.

Inoculation did improve the shoot dry weight, nodulation and shoot N content of cowpea over their uninoculated control, but the differences were not significant. Some reports (Doku, 1969; Ezedinma, 1963; Kang *et al.,* 1977) have indicated little or no increase in cowpea nodulation and yield following bradyrhizobium inoculation in tropical soils. In this study, although there were increases in nodulation, shoot N content and shoot dry weight, the increases were not significant. Danso and Owiredu (1988), however, observed that inoculation of cowpea resulted in significant increases in nodule formation, total N and shoot dry weight in soils containing native bradyrhizobium especially at high cell densities of the strains used.

The two mucuna accessions produced on the average, higher shoot dry weight for the inoculated plants than uninoculated plants. The two mucuna accessions however, responded

differently to rhizobial inoculation in the different soils. Sanginga *et al.* (1996), in a pot experiment using *Mucuna pruriens var utilis and var cochinchinensis* observed that on the average uninoculated plants recorded higher number of nodules and nodule fresh weight than inoculated plants. *Mucuna pruriens var utilis* however had one out of the four rhizobia strains tested, increasing the nodule fresh weight of inoculated plants over the uninoculated control. They found that response to inoculation depended on variety, soil origin and the strain used, and concluded that it is difficult to identify strains that consistently give inoculation response.

When averaged over the harvesting periods, inoculation did not improve nodulation, dry matter production and shoot nitrogen content of pueraria and early maturing mucuna on the Nzima soil. In Kokofu soil however, nodulation, dry matter production and shoot nitrogen content of these legume cover crops were all increased by inoculation.

In the uninoculated control, pueraria and early maturing mucuna recorded higher number of nodules and nodule dry weight on Nzima soil than on Kokofu soil. This might have led to the higher dry matter production and shoot nitrogen content observed on Nzima soil. This observation could also be due to the native rhizobia in Nzima soil being more effective and compatible with pueraria and early maturing mucuna than the native rhizobia in the Kokofu soil. Inoculation did not improve dry matter production; shoot nitrogen content and nodulation of cowpea and late maturing mucuna on Kokofu soil. In Nzima soil however, the average dry matter yield, shoot nitrogen content and nodulation were increased by inoculation. The effect of inoculation was therefore influenced by soil types. Danso and Owiredu (1988), working with cowpea, observed that with the exception of one strain in the Tikobo soil, inoculation with rhizobia strains resulted in significantly ($P=0.05$) higher shoot dry matter yields in all soils compared to the uninoculated control. In this study, the increase in shoot dry matter yield of inoculated cowpea on Nzima soil was significant at 80 and 120 days after

sowing .The results of this study indicates that the legumes responded differently to inoculation in the two soils. Mwangi and Mwaura (1998), who studied inoculation response of *Leucaena leucocephala* on two soils, also concluded that soil factors were important in the effectiveness of this plant – bacteria association. Similarly, Sanginga *et al.* (1996) also observed that some rhizobia strains induced higher shoot dry weights of *Mucuna pruriens var utilis* in one type of soil but those strains were totally ineffective on *Mucuna pruriens var cochinchinensis* in that same soil. This is an indication that the host legume species x rhizobium strain interaction is quite important and a further study into these relationships is recommended. Allison (1992), observed that responses to inoculation is also a function of the rhizobia present in the soil which are suitable for nodulation. In this study however, rhizobia in both soils were not enumerated nor identified.

Apart from the indigenous rhizobia other soil factors could also have contributed to the observed results. The soils used were generally low in P (Table 5). Nzima soil was however higher in P than Kokofu and that could partly explain why nodulation and shoot dry matter were generally better on Nzima than Kokofu for both inoculated and the uninoculated control. Olufajo and Adu (1992), working with soybean, observed nodulation to be better in soils with higher P and exchangeable Ca.

5.2 Nodulation, nitrogen accumulation and dry matter production of pueraria, cowpea and mucuna cover crops under field conditions.

Nodules were present on all the legume crops at 40 DAP on the field (Table 7). It was however not clear why nodules were absent from the roots of the two mucuna accessions and pueraria at 40 days after planting in the pot experiment (Table 1). Pueraria produced the highest nodulation for both the pot and field experiments, yet it did not result in a higher shoot

dry matter. Although Peoples *et al.* (1995), cautioned that good nodulation does not necessarily ensure a good rate of N_2 fixation, shoot N content of pueraria was highly correlated (r=0.81, P=0.01) to nodule dry weight in this study (Table 6). Faizah *et al.* (1989) and Hairiah and van Noordwijk (1986), also observed that among the leguminous species tested, *Pueraria phaseoloides* produced the highest nodulation.

Number of nodules was higher in the pot experiment (uninoculated treatment) for all the legumes except pueraria at 80 DAP. Higher figures were recorded for nodule dry weight in the pot experiment (uninoculated treatment) than that in the field experiment for all the legumes. This is probably because in the pot, it is easy to recover all the nodules but on the field, it is difficult to recover all roots and hence the possibility of loss of some nodules.

The late maturing mucuna had a relatively higher shoot N content over the period and it was significantly (P=0.05) different from the other legumes (Table 11). This could have resulted in the higher shoot dry matter observed for late maturing mucuna when averaged across the harvesting periods. The relatively higher shoot N content of late maturing mucuna could also be an indication that higher amount of N is being fixed. N fixation was however, not studied in this work.

Shoot dry weight in this study, was highly and positively correlated with shoot N content for all legumes and this may be an indication that, for these legumes, the higher the shoot dry matter, the higher the N accumulated in the shoots. High biomass levels have also been shown to correlate positively with N_2 fixed. This has been reported in mucuna and pueraria (Sanginga *et al.*, 1996; Vesterager *et al.*, 1995). The early maturing mucuna flowered and set pods early and therefore produced less dry matter than the late maturing mucuna. The longer period of vegetative growth in late maturing mucuna accounts for its high biomass. Bennett-Lartey (1994), observed the late maturing mucuna (accession 1745) to have a thick

canopy and concluded that it will be suitable for use as cover crop. The soil and rainfall conditions at Bunso are similar to those at Kade where the experiment was conducted.

The two mucuna varieties produced higher shoot dry weight on the field compared to the pot experiment (uninoculated treatment). In deed at 40 and 80 DAP, shoot dry weight of mucuna in the field was more than three times that in the pot experiment. It is possible that the mucuna on the field exploited more nutrients in the soils around the plots compared to the pots where lack of space could limit their growth. Cowpea podded earlier on the field than in the pot and lost most of the leaves when the pods dried up and that explains why there was a reduction in shoot dry weight after 60 DAP. The lost of the leaves could be because all the nutrients in the leaves were mobilized for pod formation leading to senescence. Hence its number of nodules and nodule dry weight was similarly low after 40 DAP.

5.3 The efficiency of pueraria, cowpea and mucuna cover crops in controlling weeds.

The relatively fast growth of mucuna with its trammeling effect on everything in its way might have led to the effective control of weeds including *Chromolaena odorata*, which was predominant in the area. Similar results on weed suppression have been obtained elsewhere with *Mucuna pruriens* (L) DC and *Pueraria phaseoloides* (NAS, 1979; IITA, 1985; Anon, 1989). The area is not known for cowpea production probably due to high rainfall, which also induces high insect infestation. In this work, cowpea had to be sprayed every fortnight with Actellic and Dithane to reduce pest and disease infestation. Cowpea and the early maturing mucuna had early senescence and this immediately reduced the weed control ability of cowpea but the early maturing mucuna had accumulated a thick mulch free of weeds, hence, the low weed coverage even at 120 DAP. Hairiah and van Noordwijk (1986), made

similar observations when they compared six legumes including *Vigna unguiculata*, mucuna and pueraria.

The late maturing mucuna dried up during the dry season and formed a thick carpet of dry matter, which prevented weed re-growth. The late maturing mucuna exhibited the fastest growth covering almost 100% of the land in 90 DAP. Similarly, Ismail (1990), reported that mucuna covered 100% of the soil in three months. The late maturing mucuna had robust vegetative growth and formed a thick canopy, which enabled it to suppress weeds. The thick canopy was reflected in the higher shoot dry matter of late maturing mucuna compared to the others.

Pueraria had an initial slow growth and had to be maintained regularly in the first two months to avoid weed strangulation. It may therefore be advisable to establish pueraria early enough to suppress the weeds before planting of oil palm or other tree crops.

CHAPTER SIX

6. CONCLUSIONS AND RECOMMENDATION

From the results of this study, the following conclusions and recommendations can be drawn:

- Mucuna could be a useful weed control agent and can improve the physical and chemical properties of the soil, in view of its fast growth and high levels of biomass production. It covered about 100% of the land in 90 days. The late maturing mucuna is however, preferred to the early maturing mucuna.
- Pueraria has a slow initial growth and therefore does not achieve full canopy cover as quickly as Mucuna. It however has the potential to establish and persist better with time. It covered about 70% of the land in 120 days.
- Cowpea could be used to control weeds effectively for 65 days but can be replanted if moisture is available. Its use as cover crop should however be weighed against the back-ground that the plant is highly susceptible to insect attack especially in high rainfall areas where tree crops are mostly planted in Ghana.
- Mucuna was more effective in suppressing weeds followed by pueraria and then cowpea during the time of the experiment. Mucuna may therefore be used during early stages of plantation developments. It may be suitable as a cover crop in place of pueraria but may need re-seeding.
- Cowpea, even though nodulated earliest, its short life span would not make it a suitable cover crop in tree crop plantations. Its rate of biomass production was comparatively low.

- Pueraria produced a lot of nodules even without inoculation and can therefore be planted without inoculation on the soils used. The good nodulation makes it a potential nitrogen fixer. It could accumulate large amounts of shoot N with time.
- Mucuna nodulates quite well on the soils used even without inoculation and accumulated the highest amount of nitrogen in the shoot.
- For all the legumes studied, the higher the shoot dry matter, the higher the N accumulated. High biomass production of pueraria, mucuna and cowpea could result in high N accumulation.

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APPENDICES

Appendix 1

Pot experiment

Analysis of variance for shoot dry weight (g plant^{-1}) at 40 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB.
Replications	3	12.289	4.096	2.09	
Legume type	3	289.539	96.513	49.28	<0.001
Soil type	1	5.040	5.040	2.57	0.116
Inoculation	1	0.008	0.008	0.00	0.950
Legume type x Soil type	3	2.737	0.912	0.47	0.708
Legume type x Inoculation	3	4.108	1.369	0.70	0.557
Soil type x Inoculation	1	1.000	1.000	0.51	0.479
Legume type x Soil type x Inoculation	3	0.737	0.246	0.13	0.945
Residual	45	88.130	1.958		
Total	63	403.587			

Appendix 2

Pot experiment

Analysis of variance for shoot dry weight (g plant^{-1}) at 80 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB.
Replication	3	25.19	8.64	0.35	
Legume type	3	607.12	02.37	8.10	<.001
Soil type	1	29.32	29.32	1.17	0.284
Inoculation	1	0.12	0.12	0.00	0.945
Legume type x Soil type	3	156.13	52.04	2.08	0.116
Legume type x Inoculation	3	78.20	26.07	1.04	0.383
Soil type x Inoculation	1	1.73	1.73	0.07	0.794
Legume type x Soil type x Inocul.	3	404.69	134.90	5.40	0.003
Residual	45	1123.97	24.98		
Total	63	2427.19			

Appendix 3

Pot experiment

Analysis of variance for shoot dry weight (g plant^{-1}) at 120 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB.
Replication	3	367.0	122.3	1.13	
Legume type	3	4158.7	1386.2	12.79	<.001
Soil type	1	4.3	4.3	0.04	0.842
Inoculation	1	107.6	107.6	0.99	0.324
Legume type x Soil type	3	16.7	27.3	0.25	0.862
Legume type x Inoculation	3	178.3	164.7	1.50	0.227
legume type x Inoculation	1	32.2	32.2	0.30	0.588
Soil type x Soil type x Inocul.	3	1633.5	544.5	5.02	0.004
Residual	45	4877.5	108.4		
Total	63	11375.9			

Appendix 4

Pot experiment

Analysis of variance for shoot nitrogen content (mg plant^{-1}) at 40 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	4794	1598	0.50	
Legume type	3	356393	118798	37.31	<.001
Soil type	1	232	2.32	0.07	0.789
Inoculation	1	147	147	0.05	0.831
Legume type x Soil type	3	6107	2036	0.64	0.594
Legume type x Inoculation	3	7155	2385	0.75	0.529
Soil type x Inoculation	1	86	86	0.03	0.870
Legume type x Soil type x Inocul	3	9973	3324	1.04	0.382
Residual	45	143274	3184		
Total	63	528163			

Appendix 5

Pot experiment

Analysis of variance for shoot nitrogen content (mg plant^{-1}) at 80 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replications	3	24017	8006	2.44	
Legume type	3	684825	228275	10.85	<.001
Soil type	1	54310	54310	2.58	0.115
Inoculation	1	2948	2948	0.14	0.710
Legume type x Soil type	3	285584	95195	4.53	0.007
Legume type x Inoculation	3	113505	37835	1.80	0.161
legume type x Inoculation	1	247	247	0.01	0.914
Legume type x Soil type x Inocul	3	273727	91242	4.34	0.009
Residual	45	946671	21037		
Total	63	2385834			

Appendix 6

Pot experiment

Analysis of variance for shoot nitrogen content (mg plant^{-1}) at 120 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replications	3	885200	295067	2.41	
Legume type	3	2205266	735089	6.01	0.002
Soil type	1	227554	85207	0.70	0.408
Inoculation	1	49293	158759	1.30	0.260
Legume type x Soil type	3	110706	3963	0.03	0.992
Legume type x Inoculation	3	489049	106772	0.87	0.462
legume type x Inoculation	1	10870	5086	0.04	0.839
Legume type x Soil type x Inocul	3	1922465	4.6434	3.41	0.025
Residual	45	5560644	122239		
Total	63	10421793			

Appendix 7

Pot experiment

Analysis of variance for nodule number plant^{-1} at 40 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replications	3	370.7	123.6	0.82	
Legume type	3	73770.5	24590.2	162.56	< 0.001
Soil type	1	3.8	3.8	0.02	0.876
Inoculation	1	773.5	773.5	5.11	0.029
Legume type x Soil type	3	11.3	3.8	0.02	0.995
Legume type x Inoculation	3	2320.6	773.5	5.11	0.004
Soil type x Inoculation	1	37.43.9	3743.9	24.75	<.001
Legume type x Soil type x Inocul	3	11231.7	3743.9	24.75	<.001
Residual	45	6807.1	151.3		
Total	63	99033.1			

Appendix 8

Pot experiment

Analysis of variance for nodule number plant^{-1} at 80 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	2107	702	0.55	
Legume type	3	2441	813	0.64	0.595
Soil type	1	1722	1722	1.35	0.252
Inoculation	1	1991	1991	1.56	0.219
Legume type x Soil type	3	3500	1167	0.91	0.443
Legume type x Inoculation	3	2538	846	0.66	0.580
Soil type x Inoculation	1	138	138	0.11	0.744
Legume type x Soil type x Inocul	3	6355	2118	1.66	0.190
Residual	45	57541	1279		
Total	63	78333			

Appendix 9

Pot experiment

Analysis of variance for nodule number plant^{-1} at 120 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	3580	1193	0.78	
Legume type	3	74694	24898	16.34	<.001
Soil type	1	7744	7744	5.08	0.029
Inoculation	1	1199	1199	0.79	0.380
Legume type x Soil type	3	6806	2269	1.49	0.230
Legume type x Inoculation	3	3719	1240	0.81	0.493
legume type x Inoculation	1	3094	3094	2.03	0.161
Legume type x Soil type x Inocul	3	5366	1789	1.17	0.330
Residual	45	68559	1524		
Total	63	174760			

Appendix 10

Pot experiment

Analysis of variance for nodule dry weight (g plant^{-1}) at 40 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	0.0325	0.0108	2.90	
Legume type	3	1.8252	0.6084	162.45	< 0.001
Soil type	1	0.0395	0.0395	10.55	0.002
Inoculation	1	0.1073	0.1073	28.64	< 0.001
Legume type x Soil type	3	0.1185	0.0395	10.55	< 0.001
Legume type x Inoculation	3	0.3218	0.1073	28.64	< 0.001
Soil type x Inoculation	1	0.1733	0.1733	46.26	< 0.001
Legume type x Soil type x Inocul	3	0.5198	0.1733	46.26	< 0.001
Residual	45	0.1685	0.0038		
Total	63	3.3064			

Appendix 11

Pot experiment

Analysis of variance for nodule dry weight (g plant^{-1}) at 80 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	0.15992	0.05331	1.16	
Legume type	3	0.34497	0.11499	2.51	0.071
Soil type	1	0.04463	0.04463	0.97	0.329
Inoculation	1	0.01000	0.01000	0.22	0.643
Legume type x Soil type	3	0.14854	0.04951	1.08	0.367
Legume type x Inoculation	3	0.19918	0.06639	1.45	0.241
Soil type x Inoculation	1	0.02364	0.02364	0.52	0.476
Legume type x Soil type x Inocul	3	0.27376	0.09125	1.99	0.129
Residual	45	2.06175	0.04582		
Total	63	3.26639			

Appendix 12

Pot experiment

Analysis of variance for nodule dry weight (g plant^{-1}) at 120 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replications	3	2.5802	0.8601	2.09	
Legume type	3	20.3292	6.7764	16.47	<.001
Soil type	1	0.1986	0.1986	0.48	0.491
Inoculation	1	1.5923	1.5923	3.87	0.055
Legume type x Soil type	3	0.2261	0.0754	0.18	0.907
Legume type x Inoculation	3	1.8843	0.6281	1.53	0.221
Soil type x Inoculation	1	1.2114	1.2114	2.94	0.093
Legume type x Soil type x Inocul	3	3.6048	1.2016	2.92	0.44
Residual	45	18.5170	0.4115		
Total	63	50.1438			

Appendix 13

Field experiment

Analysis of variance for shoot dry weight (g plant^{-1}) at 40 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replications	3	3.727	1.242	0.42	
Legume type	3	627.147	209.049	71.11	<.001
Residual	9	26.458	2.940		
Total	15	657.333			

Appendix 14

Field experiment

Analysis of variance for shoot dry weight (g plant^{-1}) at 60 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replications	3	7.862	2.621	1.03	
Legume type	3	1089.623	363.78	142.33	<.001
Residual	9	22.967	2.552		
Total	15	1120.453			

Appendix 15

Field experiment

Analysis of variance for shoot dry weight (g plant^{-1}) at 80 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replications	3	29.258	9.753	1.29	
Legume type	3	4452.365	1484.122	196.45	<.001
Residual	9	67.992	7.555		
Total	15	4549.615			

Appendix 16

Field experiment

Analysis of variance for shoot dry weight (g plant^{-1}) at 100 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replications	3	24.89	8.30	0.39	
Legume type	3	23461.62	7820.54	142.33	<.001
Residual	9	189.83	21.09	370.78	
Total	15	23676.34			

Appendix 17

Field experiment

Analysis of variance for root dry weight (g plant^{-1}) at 40 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	0.00450	0.00150	0.13	
Legume type	3	1.44930	0.48310	42.92	<.001
Residual	9	0.10130	0.01126		
Total	15	1.55510			

Appendix 18

Analysis of variance for root dry weight (g plant^{-1}) at 60 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	0.30729	0.10243	2.55	
Legume type	3	4.20313	1.40104	34.94	<.001
Residual	9	0.36093	0.04010		
Total	15	4.87135			

Appendix 19

Analysis of variance for root dry weight (g plant^{-1}) at 80 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	0.10047	0.03349	1.82	
Legume type	3	6.77427	2.25809	122.85	<.001
Residual	9	0.16542	0.01838		
Total	15	7.04018			

Appendix 20

Analysis of variance for root dry weight (g plant^{-1}) at 100 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	0.070207	0.023402	7.40	
Legume type	3	34.1087	11.36958	3595.43	<.001
Residual	9	0.028460	0.003162		
Total	15	34.2074			

Appendix 21

Field experiment

Analysis of variance for nodule number plant^{-1} at 40 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	2.94	0.98	1.23	
Legume type	3	163.76	54.59	68.42	<.001
Residual	9	7.18	0.7978		
Total	15	173.88			

Appendix 22

Field experiment

Analysis of variance for nodule number plant^{-1} at 60 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	3.487	1.162	0.64	
Legume type	3	477.548	159.182	87.77	<.001
Residual	9	16.323	1.814		
Total	15	497.357			

Appendix 23

Field experiment

Analysis of variance for nodule number plant^{-1} at 80 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	30.303	10.101	1.09	
Legume type	3	1201.287	400.430	43.12	<.001
Residual	9	83.573	9.286		
Total	15	1315.165			

Appendix 24

Field experiment

Analysis of variance for nodule number plant^{-1} at 100 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	1.075	0.358	0.22	
Legume type	3	1825.540	608.513	373.96	<.001
Residual	9	14.645	1.627		
Total	15	1841.260			

Appendix 25

Field experiment

Analysis of variance for nodule dry weight (mg plant^{-1}) at 40 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	0.0000337	0.00001112	0.03	
Legume type	3	0.0020827	0.0006942	1.75	0.226
Residual	9	0.0035701	0.0003967		
Total	15	0.0056864			

Appendix 26

Field experiment

Analysis of variance for nodule dry weight (mg plant^{-1}) at 60 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	0.0012717	0.0004239	0.67	
Legume type	3	0.0082397	0.0027466	4.31	0.038
Residual	9	0.0057291	0.0006366		
Total	15	0.0152404			

Appendix 27

Field experiment

Analysis of variance for nodule dry weight (mg plant^{-1}) at 80 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	0.003295	0.001098	0.63	
Legume type	3	0.020589	0.006863	3.96	0.047
Residual	9	0.015599	0.01733		
Total	15	0.039482			

Appendix 28

Field experiment

Analysis of variance for nodule dry weight (mg plant^{-1}) at 100 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	0.001464	0.000488	0.29	
Legume type	3	0.032310	0.010770	6.29	0.014
Residual	9	0.015410	0.001712		
Total	15	0.049184			

Appendix 29

Field experiment

Analysis of variance for shoot N content (mg plant^{-1}) at 40 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	27383	9128	1.57	
Legume type	3	1019635	339878	58.29	<.001
Residual	9	52479	5831		
Total	15	1099497			

Appendix 30

Field experiment

Analysis of variance for shoot N content (mg plant^{-1}) at 60 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	131340	43780	2.36	
Legume type	3	1138262	379421	20.44	<.001
Residual	9	167043	18560		
Total	15	1436646			

Appendix 31

Field experiment

Analysis of variance for shoot N content (mg plant^{-1}) at 80 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	303994	101331	2.79	
Legume type	3	4344396	1448132	39.84	<.001
Residual	9	327153	36350		
Total	15	4975544			

Appendix 32

Field experiment

Analysis of variance for shoot N content (mg plant^{-1}) at 100 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	377377	125792	4.20	
Legume type	3	27445782	9148594	305.75	<.001
Residual	9	269295	29922		
Total	15	28092454			

Appendix 33

Analysis of variance for legume ground cover at 30 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	0.97	0.32	0.10	
Legume type	3	6304.39	2101.46	641.08	<.001
Residual	9	29.50	3.28		
Total	15	6334.86			

Appendix 34

Analysis of variance for legume ground cover at 60 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	148.69	49.56	1.12	
Legume type	3	4451.86	1483.95	33.43	<.001
Residual	9	399.48	44.39		
Total	15	5000.03			

Appendix 35

Analysis of variance for legume ground cover at 90 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	27.79	9.26	1.80	
Legume type	3	19917.80	6639.27	1290.66	<.001
Residual	9	46.30	5.10		
Total	15	19991.88			

Appendix 36

Analysis of variance for legume ground cover at 120 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	57.77	19.26	1.13	
Legume type	3	15003.66	7501.83	438.83	<.001
Residual	9	102.57	17.10		
Total	15	15149.59			

Appendix 37

Analysis of variance for weed cover in different legume plots at 30 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	7.47	2.49	0.47	
Legume type	4	7458.49	1864.62	349.29	<.001
Residual	12	64.06	5.34		
Total	19	7530.02			

Appendix 38

Analysis of variance for weed cover in different legume plots at 60 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	4.92	1.64	0.53	
Legume type	4	19723.83	4930.96	1598.00	<.001
Residual	12	37.03	3.09		
Total	19	19765.77			

Appendix 39

Analysis of variance for weed cover in different legume plots at 90 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	16.22	5.41	3.32	
Legume type	4	30956.36	7739.09	4747.01	<.001
Residual	12	19.56	1.63		
Total	19	30992.14			

Appendix 40

Analysis of variance for weed cover in different legume plots at 120 days after planting

Source of variation	D.F	S.S	M.S	VR	PROB
Replication	3	2.33	0.78	0.87	
Legume type	4	30326.58	7581.65	8471.13	<.001
Residual	12	10.74	0.90		
Total	19	30339.65			