EFFECTS OF COTTON-COWPEA INTERCROPPING ON CROP YIELDS AND SOIL NUTRIENT STATUS UNDER ZIMBABWEAN RAIN-FED CONDITIONS.

BY

LEONARD RUSINAMHODZI

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DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL ENGINEERING
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DEDICATION

IN MEMORY OF MY LATE FATHER
MR.L.P. RISINAMHODZI.

“DAD THIS WAS ALWAYS YOUR DREAM”

NO SCIENTIFIC INVESTIGATION IS COMPLETE UNTIL ITS RESULTS CAN BE QUANTITATIVELY EXPRESSED. ONLY WHEN THIS IS DONE CAN THE INVESTIGATORS FEEL REASONABLY CERTAIN THAT THEY HAVE GAINED THE RIGHT PERSPECTIVE AND THAT THEY KNOW HOW NEARLY THEIR HYPOTHESES APPROXIMATE TO THE TRUTH.

Sir E.J. Russell, (1926).

ABSTRACT

Intercropping of cotton and cowpea is one of the ways to improve food security and soil fertility while generating and maintaining cash income of the rural poor. A study was carried out to find out the effects of cotton-cowpea intercropping strategies on crop yields and soil nutrient status under rain-fed conditions. The study was carried out at Kadoma Cotton Research Institute (CRI), Ntini and Mukosi sites which are all in Kadoma District. The treatments were sole cotton, sole cowpea, and 2 rows of cotton alternating with 1 row of cowpea (2:1), 1 row of cotton alternating with 1 row of cowpea (1:1). The intercrops were either planted at the same time (simultaneously), or cowpea was planted 4 weeks after cotton (4WAC). Results showed that cowpea suppressed cotton yields but the reduction in yield was compensated for by the yield of cowpea and also the residual fertility from cowpea residues. The reduction in cotton yield was less when cowpea was planted 4 weeks after cotton and when the row configuration was 2:1 (cotton: cowpea). Cowpea grain yield across the sites was as follows, sole cowpea (1.6 t ha^{-1}), 1:1 sim (1.1 t ha^{-1}), 2:1 (0.7 t ha^{-1}), 1:1 relay (0.8 t ha^{-1}) and 2:1 relay (0.3 t ha^{-1}). Cotton lint yield across the sites was as follows, sole cotton (2.0 t ha^{-1}), 1:1 sim (0.7 t ha^{-1}), 2:1 sim (1.2 t ha^{-1}), 1:1 relay (1.5 t ha^{-1}) and 2:1 relay (1.8 t ha^{-1}). Comparable intercrops had higher cowpea grain yields in the simultaneous than in the relay intercrops but cotton lint yields were higher in relay than simultaneously planted intercrops. All the intercrops were productive as compared to the sole crops with an average land equivalence ratio (LER) of 1.3 for both dry matter and grain yield across all the sites.

There was an increase in N_2-fixation by cowpea in intercrops as compared to sole crops though the amount fixed was lower due to reduced plant population. Sole cowpea had N_2-fixation of 73%, 2:1 simultaneous had 77% and 1:1 simultaneous had 85% while the total amount derived from N_2-fixation was, sole cowpea (104 kg ha^{-1}), 2:1 simultaneous (51 kg ha^{-1}) and 1:1 simultaneous (96 kg ha^{-1}). Sole cowpea and the intercrops contributed to positive N balances in the soil of 42.5 kg ha^{-1} for sole cowpea, 25.7 kg ha^{-1} for 2:1 simultaneous and 60.0 kg ha^{-1} for 1:1 simultaneous. Cowpea fixed N which was transferred to the companion cotton crop was very low with 1:1 simultaneous recording 3.6% and 2:1 simultaneous 0.9%. Soil mineral N and plant-available P generally increased after the intercrops with sole cowpea recording the highest and sole cotton the lowest and the intercrops recorded values were between those of sole cowpea and sole cotton. There was a slight change in pH and bases decreased but there was an increase in CEC. Microbial biomass C and N, and particulate organic matter C and N all increased especially after intercrops as compared to sole crops. Nitrogen release from sole crop residue and mixtures was in the order 36.4 mg kg^{-1} soil for cowpea residues, 33.4 mg kg^{-1} for 30:70 mixture, 27.1 mg kg^{-1} for 50:50 mixture, 21.6 mg kg^{-1} for 70:30 mixture and 19.2 mg kg^{-1} for cotton residues. The ratios given are for cotton: cowpea dry matter proportions obtained in the intercrop. The trend for C mineralization was the reverse of N mineralization and there was more C release from cotton residues. Grain yield after intercrops was substantial even without fertilizer (N) and was as follows, after sole cotton (1.1 t ha^{-1}), sole cowpea (3.0 t ha^{-1}), 1:1 intercrops (2.8 t ha^{-1}) and 2:1 intercrops (2.5 t ha^{-1}).

Relay intercropping of cotton and cowpea is a good strategy to address issues of food security, income and soil fertility depletion. However issues of cotton pesticides effect on humans and livestock need to be understood in order to provide the correct recommendations. Markets and marketing infrastructure for cowpea also need to be improved in order to increase adoption of this strategy by farmers.

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CHAPTER 1

1.0 INTRODUCTION

1.1 Background

Legume intercrops are potential sources of plant nutrients especially N that compliment or supplement inorganic fertilizers. Legume intercrops are included in cropping systems due to their ability to reduce soil erosion (Giller and Cadisch, 1995), suppress weeds and fix N (Giller *et al.,* 1994). Intercropping is widely practiced as a means to increase efficiency of land use through more complete utilization of solar radiation (Keating and Carberry, 1993), water (Morris and Garrity, 1993a) and nutrients (Morris and Garrity, 1993b).

When growing more than one crop simultaneously, a habitat different from a monocrop is created and the increased crop diversity is likely to influence insect distribution and abundance in the crops (Alteri, 1993). A decrease in pest numbers can be attributed to hampered pest movements, difficulty in identifying the host and also the companion crop may attract natural enemies (Kareiva, 1983). Intercropping cotton leads to reduction of insect pests for example, Fukai and Trenbath (1993), found that cotton (*Gossypium hirsutum* L.) grown without insecticides in an intercrop with sorghum yielded 25% higher than sole-crop cotton with insecticides.

Research on cotton intercropping with various crops is well documented, but most of this work has mainly been confined to countries outside Africa. In Brazil for example annual cotton is commonly intercropped with food crops such as cowpea and maize (Bezzerra Neto and Robichaux, 1997). In India, cotton and maize intercropping used to be dominant but the introduction of short season cotton varieties has led to cotton and wheat intercropping (Babu *et al.,* 1995). In Africa, some research has been carried out in Tanzania (Myaka and Kabissa, 1996) while one study was carried out in Zimbabwe by Natarajan and Naik (1992). The study in Zimbabwe was centred on the competitive effects of short duration cowpea when intercropped with cotton, by assessing yield and any benefits of cotton pesticides to cowpea. In these intercropping studies, cotton yield decreased because of competition but the loss was compensated to varying degrees by the yield of the legume intercrops. Some work by Rochester *et al.* (2001), also focused on the contribution of legumes such as faba bean (*Vicia faba*), field pea (*Pisum sativum*) and lablab (*Lablab purpureus)* on N fertility of cotton cropping systems in Australia.

1.2 Overview of cotton production in Zimbabwe

Cotton (*Gossypium hirsutum* L.) is an important cash crop for smallholder farmers in Zimbabwe where 80% of national production occurs and it is the second largest foreign currency earner among agricultural products in Zimbabwe (CRI Report, 1993-94). In 2003 cotton exports earned the country US$150 million and production stood at 250 tonnes rising by 25% to 300 tonnes the following year (CSO, 2004). Cotton seed oil accounts for more than 50% of the local oil requirements and the seed cake forms a major part of the ruminant stock feed (CRI Report, 1993-94).

The most suitable cotton growing areas in Zimbabwe are below an altitude of 1 200 m having deep, fertile, medium to heavy soils (Cotton Training Center, 2000). The crop develops fully in about 180 days but this period is shorter at lower altitudes and longer at higher altitudes. The cotton growing areas are shown in Fig.1.2. The yields in smallholder areas average about 500 kg ha^{-1} whereas the overall commercial farm average yield is around 1800 kg ha^{-1} (CRI Report, 1993-94). Cotton fields in smallholder areas are mainly cultivated by draught animals while commercial farms are highly mechanized and combine high input levels with high management expertise (CRI Report, 1993-94).

Cotton production follows a closed season; there is a period every year depending on location where no cotton crop should be growing in the field. This period is called "dead season" and operates from 15 August to 5 October in the Lowveld and between 10 September and 20 October in the remainder of the country. This is considered as the only solution to control the menacing pink bollworm (*Pectinophora gossypiella).*

Zimbabwean cotton is entirely hand picked and this has assured high quality on the world market since hand picked cotton has no crop residue impurities. Although machine picking has been introduced in recent years, the financial implications and physical distribution of small scale producers have remained as notable impediments to this initiative. A variety of buyers now exist since the Cotton Marketing Board was transformed into the Cotton Company of Zimbabwe, and allowing competitors to come in. Growers sell their crop as seed cotton which companies buy on a five-grade system based on colour, insect and soil stain, immaturity and trash content.

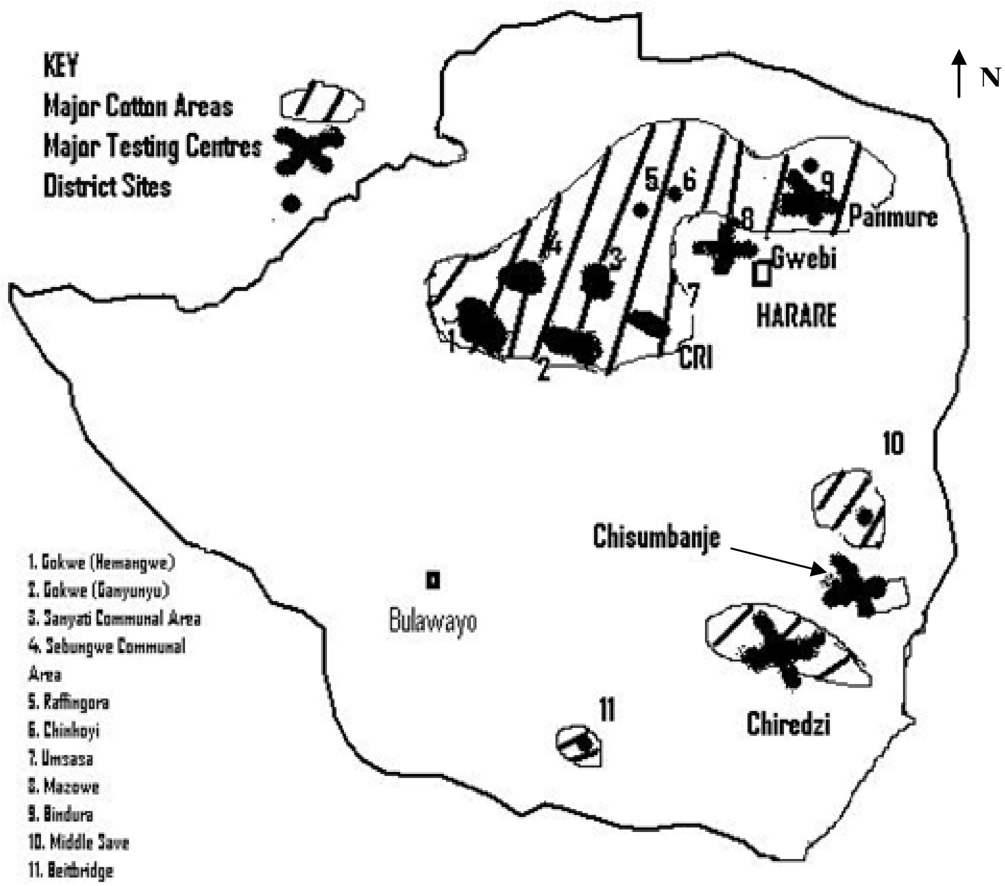

Fig.1.2. The distribution of cotton farming areas in Zimbabwe (CRI Report, 1993-94)

1.3 Overview of cowpea production in Zimbabwe

Cowpea (*Vigna unguiculata* (L.) Walp) is a grain legume grown in savanna regions of the tropics and it has a long history of cultivation in Zimbabwe (Reid, 1977), where spreading types are predominant and their leaves as well as seeds are consumed as supplement to the staple diet of maize. Its value lies in, high protein content, ability to tolerate drought, and the capacity to fix atmospheric N. Cowpea grain contains about

22% protein and constitutes a major source of protein for resource-poor rural and urban people and, the crop residues from cowpea constitute an important source of livestock feed especially for the dry savannah regions (Hussain and Basahy, 1998). Jeranyama *et al*. (2000) reported that cowpea has a low N harvest index, implying it has a low N removal from the field through grain. Cowpea can be used at all stages of growth as a vegetable crop. In many areas of the world, cowpea is the only available high quality legume hay for livestock feed (Tirawali *et al.,* 2002).

Cowpea together with pigeonpea (Cajanaus cajan (L.) Millsp.) are two promising legumes for semi-arid areas (Mapfumo and Giller, 2001) and both nodulate freely in Zimbabwean soils without inoculation (Mpepereki and Makonese, 1995). Cowpea yields however have failed to respond consistently to inoculation with commercial rhizobial strains (Mpereki and Pompi, 2003). These legumes are tolerant to drought and poor soil fertility environments, and have a good combining ability in intercropping systems (Mafongoya and Nair, 1997). Long-duration cowpea varieties that have high regeneration capacities after cutting and grazing, and short-duration erect varieties that can accumulate relatively high biomass yields over short periods, are suitable for semi-arid areas (McDonagh, 1988).

Cowpea is often intercropped with the most important cereals such as maize, sorghum and pearl millet (Steiner, 1984). However in mixed farming systems cowpea yields may be low due to low soil fertility and low plant densities (Reddy *et al.* 1992). Cowpea grain yield varies between 50 kg ha^{-1} and 300 kg ha^{-1} in farmers' fields contrasting sharply with yields from commercial enterprises and research stations of 2 t ha^{-1} (Bationo *et al.* 2002).

Current cowpea price is pegged at Z$800 000.00 (1USD = Z$6 400.00) per tonne for the highest quality category (Grain Marketing Board, 2004).

1.4 Rationale of the study

Smallholder rain-fed crop production in Zimbabwe is characterized by poor productivity caused by poor soil fertility leading to low household income. A recent survey by ICRISAT has shown that up to 30% of all smallholder farmers in Zimbabwe always face food deficit due to low productivity caused by poor soil fertility. The soils of these areas are highly weathered and subject to intensive cultivation but with low levels of fertilizer application. Long-term production of cotton in the same field often leads to low yields, even with large amounts of nitrogen (N) and phosphorus (P) fertilizer. This is mainly due to soil compaction and poor soil structure, which is a result of low organic matter content of the soils. Low organic matter content is caused by non-addition of crop residues to the soil since cotton crop residues are burnt at the end of the season as a pest control strategy (Cotton Training Center, 2000). Under these circumstances profitability of mineral fertilizer use becomes poor. The solution therefore is to combine high remunerative cash crops such as cotton with legume based technologies (cowpea) to make the cropping system more sustainable and attractive to the farmer. Benefits include improved soil productivity and pest management and enhanced risk management with greater enterprise diversity. Rotation can provide more plant residue to soil than monocropping systems, thus improving tilth and water-holding capacity. By alternating between the different types of root systems of the various crops, more of the soil profile is used for crop production. In addition, rotating crops aids integrated pest management strategies.

Rotation may disrupt life cycles of many insect pests and pathogens. Increasing plant diversity also may encourage beneficial insects, nematodes, fungi and bacteria to flourish. Moreover, rotation provides growers with an opportunity to alternate herbicides

Labour and land constraints to carry out rotation coupled with lack of enough N fertilizer inputs makes it possible to integrate more legumes in existing cropping systems as intercrops because growing sole legume crops or green manures in fallow has faced immense resistance from smallholder farmers (Kumwenda *et al.,* 1996). Legume cotton intercropping offers a potential method to reduce inputs such as N fertilizers. Though the nutrient management of these crops (sole crops) has been worked out, it is not fully understood how these crops when grown as intercrops exert influence on the changes in soil fertility and crop productivity. Cotton being a fibre crop requires high amounts of N and K, while its requirement for P is very low. It is grown in widely spaced rows, about one metre apart and initial growth is slow. Therefore it is possible to use the space between the cotton rows to produce a grain crop of cowpea for food and biomass for soil fertility replenishment on small-scale farms. Cowpea might also benefit from the pesticides applied to the cotton (Endondo and Samatana, 1999).

Although this practice is not popular in Zimbabwe, incorporating cowpea into cotton based cropping systems offers potential benefits. There are no extra costs in terms of fertilizer inputs, the succeeding cotton crop can benefit from incorporated cowpea residues. The companion cowpea can access sparingly soluble P, can be harvested earlier than cotton and is likely to benefit from cotton pesticides since insect pests also limit its productivity. Cowpea also has extrafloral nectaries on petioles and leaflets that may attract natural enemies to feed on cotton pests (Koptur, 1992).

1.5 Research Questions

The research seeks to answer the following questions: To what extent does cotton-cowpea intercropping affect the soil chemical properties such as pH, POM, N, P, Ca, Mg, K and microbial biomass N and C?, Which plant arrangement and population optimises yield in cotton-cowpea intercropping? And, are cowpea residues beneficial to succeeding maize crop in rotation and to what extent do cotton-cowpea intercropping affect N_2 fixation and how much of the fixed N is transferred to the associated cotton plant?

1.6 Hypotheses

The research work was designed to answer the following hypotheses:

(i) There is a more net decrease in the concentration of nutrients (N, P, Ca, Mg, and K) and properties such as POM, microbial biomass and pH in the soil with cotton followed by maize compared to intercropping cotton and cowpea.

(ii) The total yield achieved in an intercrop is higher than achieved by sole crops on the same size of land.

(iii) Cotton performance is positively affected by the time of planting of the cowpea companion crop.

(iv) The residual effects from the preceding cowpea crop are beneficial to the succeeding maize crop.

(v) Biological nitrogen fixation in cowpea is positively affected by the companion cotton crop in intercropping.

(vi) Some of the N fixed in the intercrop can be transferred from cowpea to cotton crop during the season.

(vii) Residue mixtures produced under cotton-cowpea intercrops improves N release and soil N mineralization potential.

1.7 OBJECTIVES

To evaluate cotton-cowpea intercropping including the effects of relay intercropping on individual crop and total yield and on soil nutrient status under rain fed conditions.

Specific objectives

3.1 To determine changes in soil properties and nutrient status (pH, OM, N, P, Ca, Mg, and K) due to the effects of cotton and cowpea intercropping.

3.2 To determine the yield of cowpea and cotton as intercrops and compare to sole crop.

3.3 To determine the effect of relative time of interplanting cowpea on its performance and that of the associated cotton crop.

3.4 To determine the response of a subsequent maize crop grown after cowpea and compare this with the response to fertilizer N.

3.5 To determine the amount of N_2 fixation in cowpea-cotton mixtures.

3.6 To determine the amount of N fixed and transferred from cowpea to cotton during the season.

3.7 To determine the C and N mineralization pattern of cotton and cowpea residue mixtures and of soil previously under cotton-cowpea intercrops.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Legumes and biological nitrogen fixation (BNF)

Biological nitrogen fixation (BNF) maintains soil fertility and hence sustainability of agro-ecosystems (Boddey *et al*., 1997). Legumes have the ability to convert atmospheric N to mineral N in symbiosis with the *Rhizobium* bacteria in their root nodules and this along with other symbiotic and non-symbiotic relationships is one of the major routes of N fixation in tropical soils (Webster and Wilson, 1998). The bacteria enter the root hairs and the cortical cells, causing the formation of root nodules. The nodules provide a habitat for the *Rhizobia* and the plant a source of carbohydrate for energy. The bacteria in turn supply the plant with mineral N after conversion from atmospheric N (Brady, 1990). Soyabean, a relatively new legume crop in Africa, responds well to rhizobial inoculation and fixes large amounts of N even in marginal soils (Kasasa, 2000; Musiyiwa, 2001).

The use of BNF may be the only means by which N supply to plants can be increased by resource poor farmers in less developed countries, especially considering the cost of importing N fertilizers and generally deteriorating terms of trade (Hungria & Vargas, 2000). Vance and Graham*,* (1995) estimated that 65% of N input in global agriculture comes from BNF and Dakora *et al*. (1997) suggested that BNF is a cheaper and most effective way for maintaining sustainable yields in African agriculture.

The potential quantity of N fixed and the contribution from leguminous crops are influenced by a number of environmental factors, including soil type, nutritional status of the soil, species and varieties, water availability and temperature as well as soil and crop management (Ledgard and Steele, 1992). Where conditions favour plant growth, the potential for N fixation is greater. Where conditions do not favour plant growth (except if N is limiting), the potential for N fixation is lower. Other causes of low N fixation may be a result of the addition of N to the soil by rain and the mineralization of organic matter already in the soil (Webster and Meyer, 1997). Uptake of N in intercrops is likely to be higher than in sole crops and it is likely that BNF will increase and therefore it needs to be quantified to understand this better. The other important reason for variation in the N_2 fixation estimates is however the method used and these also need to be reviewed. Dakora *et al*. (1997) suggested that a variety of legumes have the ability to fix between 15 and 581 kg N ha^{-1}.

2.2 Methods of measuring BNF

2.2.1 Determination of dry matter

Legumes meet up to 90% of their N requirements through BNF and biomass yield of crops is dependent on the N content. Dry matter accumulation by plants could be used as a measure to compare the efficiency of N_2 fixation of different cultivars. This method is simple and very easy to use and get a rough estimate of BNF. Reliable estimates of the fixed N are difficult to obtain because of the inherent differences in the cultivars for exploiting the native soil N. In addition, presence and absence of relevant rhizobia and the extent of effective nodulation will also significantly affect N_2 fixation and consequent dry matter accumulation by different plant types (Azam and Farooq, 2003).

2.2.2 Nodule number and mass

Nodule number and mass method makes use of the presence of effective and relevant rhizobia in good numbers in the plant rhizosphere. This method may also serve to reveal the presence of species- and cultivar- specific rhizobia in a particular soil. Nodule formation depends on the presence of effective and relevant rhizobia in good numbers in the plant rhizosphere. This method can conveniently be used to ascertain the effect of different agro-climatic conditions on nodulation and N_2 fixation of a particular plant type. It can also be used to reveal the presence of species- and cultivar- specific rhizobia in a particular plant type. Comparisons obtained may not be reliable because rhizobia are species and cultivar specific as far as the efficacy of nodulation and efficiency of N_2 fixation is concerned (Azam, 2001).

2.2.3 Acetylene reduction assay (ARA)

The assay gives an estimate of the activity of nitrogenase, an enzyme that is involved in the reduction of several compounds including N. Its ability to reduce acetylene to ethylene has found a good utility in indirectly measuring N_2 fixation at any point of time. The assay involves the incubation of detached nodules, nodulated root pieces, or detopped root system with 10% acetylene in a closed container of known volume (Hansen, 1994). Gas phase samples are analyzed by gas chromatography to measure the concentration of accumulated ethylene. The method is inexpensive, rapid, sensitive and accurate (Turner and Gibson, 1980) and has been used extensively for field measurements. It is also good for measuring instantaneous rates of nitrogenase activity in studies of crop physiology. The error arising from use of this method varies between 30 and 60%. Estimates of N_2 fixation on per plant basis are limited by incomplete recovery of nodules especially from deep-rooted plants or under low moisture (dry) situations. Washing and nodule detachment cause a reduction in nitrogenase activity (Wych and Rains, 1978).

2.2.4 Nitrogen Difference Method

The total N accumulated by a non-legume or reference plant, or legume isoline is used as an estimate for uptake of soil N by an adjacent symbiotically active legume. The amount of N fixed can thus be determined by using the expression: Fixed N= Total N (fixing crop)–total N (non-fixing crop), (Azam and Farooq, 2003). The real advantage of the N difference method is that N fertilizer addition is not required, because fertilizer N leads to enhanced uptake of soil N through priming effect or added nitrogen interaction (Azam, 2002) and this may give inaccurate results. The most notable weakness of the method is that when vigorous non-legumes such as wheat are used, they take up more N from the soil than most legumes such that when the N in wheat is subtracted from the N in legumes, it will give a negative value. The method also does not account for inherent differences in plant types in affecting the mineralization and availability of soil N because cereals are found to obtain higher amount of soil N as compared to legumes (Broadbent *et al.,* 1982).

2.2.5 Content of ureides (allantoin and allantoic acid) and other metabolites

Nodulated legumes export (from root to shoot) amides or ureides as products of BNF, while those depending mainly on the soil N have xylem sap rich in NO_3^- because of negligible NO_3^- reductase activity at the root level. Relative concentration of ureides and NO_3^- in the xylem sap has thus been used as a measure of N fixing ability of the legumes (Dakora *et al*., 1992). Although this method does not produce the most accurate estimate of time-integrated N_2 fixation because of the limited sampling frequency, it is very simple. The weakness of the method is that each field measurement reflects N_2 fixation by the crop at or shortly before the time of the assay and it is not recommended to extrapolate from such single measurements to predict fixation for the whole growth period (Hansen and Danso, 1993).

2.2.6 ^{15}N Natural abundance

The ^{15}N natural abundance technique exploits the difference in natural ^{15}N abundance of soil/fertilizer and atmospheric N (Broadbent *et al.,* 1982). It can be assumed that ^{15}N of the non-fixing system will be the same as that of readily mineralizable N in soil. Because of the difference in natural ^{15}N abundance, the N fixing plant that depends on soil N and BNF, will have low ^{15}N abundance than a non-fixing plant that obtains N from the soil alone (Danso *et al.,* 1993). The advantage is that there is no requirement to add N, making it applicable at the farm, or landscape level, rather than plot basis. This method has been successfully applied in grazed pastures to estimate N_2 fixation (Peoples *et al.,* 1995). The problem with this method is the requirement to calculate the concentration in legume of ^{15}N when the legume is completely dependent on N_2 fixation for growth.

Under fully symbiotic conditions legume shoot N is typically depleted in ^{15}N relative to the atmospheric N_2 and thus estimations of N_2 fixation based on $\partial^{15}N$ of legume above-ground biomass relative to a non-legume reference plant ^{15}N will overestimate %Ndfa unless $\partial^{15}N$ of the legume is considered (Shearer and Kohl, 1986).

2.2.7 ^{15}N isotope dilution

The ^{15}N isotope dilution involves the application of ^{15}N labeled fertilizer to the soil, subsequent harvest of the N_2 fixing species and appropriate reference non-N_2-fixing plants and analyses. Plant materials are analyzed for ^{15}N content and the dilution of the enriched fertilizer by ^{14}N derived from the atmospheric N_2 (99.6337 at % ^{14}N) relative to that of the non-fixing plant is then used to calculate the proportion of legume N coming from N_2 fixed from the atmosphere (Unkovich and Pate, 2000). Technique has been used for providing time integrated measurements of N_2 fixation in field settings. It is difficult to establish a stable ^{15}N enrichment of soil mineral N in space and in time and so differences in patterns of soil mineral N uptake between plant species make it difficult to get a reliable estimate of legume ^{15}N uptake from the soil using a non-N_2 fixing plant of the same or other species (Danso *et al.,* 1993). The addition of mineral N to the soil is likely to disturb the process under measurement as this added amount can constitute a significant fraction of the mineral N available to the legume *(*McNeill *et al., 1996).*

2.3 Grain legumes in intercrops

Grain legumes could be used either as sequential, relay or full intercrops. Intercrop technologies could be particularly valuable where main crop yields are increased as a result of reduced competition or facilitation, despite the presence of the grain legume (Vandermeer, 1989). Additionally, some of the fixed N may be transferred directly to the crop at least in relay and full intercropping. Leaf litter may also provide N for the main crop. The leaf abscission during the growth of a pigeon pea intercrop has been estimated to be equivalent to between 10 - 40 kg N ha^{-1} (Rao *et al*., 1987). The deep root system of pigeon pea may also be important in recycling N from deeper soil layers and various authors have noted the build-up of subsurface nitrates at about 1-3 m. A further N benefit of intercropping may be in the rate at which N is fixed from the atmosphere. Growing a non-legume with a legume reduces mineralized N in the soil, legumes respond by fixing more N than they might do in a pure stand, so long as the legumes dominate the mixture (Marschner, 1995).

There are limitations facing BNF technologies and these are in particular the issues concerning the quantity of N fixation and the quality of the biomass produced. The efficacy of grain legume intercrops is also hampered by deficiencies of other soil nutrients, particularly P (Marschner, 1995). This may be less of a problem with full and relay intercropping as the farmer by default will be applying fertilizer to the legume if he applies it to the main crop. In sequential intercropping however, the situation may be quite different and the farmer may be reluctant to provide fertilizers to reduce P deficiency in the soil.

Depending on the nature of the crops selected, the main crop may either reduce the growth of the legume intercrop, or the legume intercrop may reduce the growth of the main crop. The associated problem of reliability of establishment of both main and intercrop, particularly when environmental conditions are difficult, are of paramount importance to resource poor farmers. It is when conditions are most difficult that the technology may function least effectively. Intercropping technology is far less sustainable than rotation technology for typical African farming situations (Dakora & Keya, 1997).

Pigeon pea/cereal intercrop is one of the most common intercropping systems in Eastern and Southern Africa (Le Roi, 1997). Planting is generally done in rows at fairly low density, one row of pigeon pea alternating with several (from 2 to 10) rows of cereal (Le Roi, 1997). In Uganda, long and medium-duration pigeonpea varieties are generally broadcast with finger millet (Silim *et al*., 1995). Due to their low plant population they usually produce low yields, varying between 300 and 700 kg ha^{-1} (Le Roi, 1997). After harvest of the cereal, the pigeonpea crop is left in the field to finish its growth cycle during the second and less reliable annual rainy season. Due to its long season growth habits pigeon pea is a potential companion crop with cotton.

2.4 Relay intercropping

Relay intercropping is a technique in which different crops are planted at different times in the same field within the same rainy season (Snapp *et al*., 1998). Relay intercropping may go some way to reducing the effects of competition that can occur in full intercropping. In many circumstances it may be more appropriate to plant a late maturing grain legume intercrop such as pigeon pea, which does not compete with and reduce the yield of the main crop (Jeranyama *et al.,* 1998). This allows the grain legume to go on maturing after the main crop has been harvested with the possibility of high biomass yields. The benefits of this have been shown in areas of Africa with rainfall varying between 500-1000 mm (Snapp *et al*., 1998). However, the N fixed by grain legumes used as relay intercrops has generally not been sufficient to maintain yields in an on-farm situation because of increased competition from already grown companion crop. Effort should therefore be directed at how to reduce competition in intercrops.

A relay-intercropped legume is not likely to directly benefit the companion crop, but has potential to increase yields of a subsequent crop (Jeranyama *et al.,* 1998). Giller *et al*. (1998) reported that cowpea sown 28 days after the companion crop can produce large amounts of biomass without reducing the yield of companion crop. Jeranyama *et al*. (2000) reported that relay-intercropping of cowpea and sunnhemp into maize fertilized with zero or 60 kg N ha^{-1} was not associated with a significant maize grain yield reduction. Reductions of maize yields were observed when maize was fertilized with higher rates of N for example after applying 120 kg N ha^{-1} there was an average reduction in yield of 25% for the two seasons. They attributed this reduction to competition effects between fast-growing and well-fertilized legume crop and maize. The results obtained for zero and 60 kg N ha^{-1}, which are typical fertilizer rates for smallholder farmers in Zimbabwe, suggest that legumes could be relay intercropped with various crops without reduction in yield of the main crop (Jeranyama *et al*., 2000).

In Malawi, Kanyama-Phiri *et al*. (1997) suggested that a green manure relay intercrop with potential was *Sesbania sesban* and results showed that it was capable of fixing 30 - 60 kg N $ha^{-1}yr^{-1}$. In Zimbabwe, Rattray & Ellis (1952), showed that maize, which has relatively high N requirements, could be grown for over 20 years without dramatic declines in maize yield, if grown in alternate years following a green manure crop, such as velvet bean (*Mucuna utilis*) or sunn hemp (*Crotalaria juncea*). This was in contrast to the yields from continuous cropping, which declined dramatically.

2.5 Nitrogen transfer in intercropping

Nitrogen (N) transfer from one species to another is important for the N cycling in low-input farming system. Nitrogen transfer is a facilitatory process where N moves from, for example, an N-rich legume to an N-starved non-legume. N-transfer can be (1) direct (through VAM); (2) indirect (mineralization of legume residues during the current growing season), or (3) residual (mineralization after the current growing season). For example, indirect transfer can occur when an early season legume is intercropped with longer duration non-legume (such as soybean-cassava) because dry matter from legumes will decompose and N released is taken up by the non-legume. The lower percentages of lignin and other fibrous materials in annual legumes such as cowpea result in faster decomposition rates (Schwendiman and Kaiser, 1960), which may provide more immediate N transfer to long season crops in intercropping. However in temperate zones, most N transfer is residual. Interspecific N transfer may for instance take place aboveground via grazing herbivores or belowground through direct or indirect pathways. The belowground mechanisms are mainly through root and nodule senescence and mineralization, rhizodeposition and transfer between roots by interconnected mycorrhizal hyphae. Above ground mechanisms are through mineralization of senesced plant material, consumption by grazing animals and return in excreta or as carcasses, foliar leachates and transfer of ammonia to associated plants (Ledgard and Giller, 1995). The belowground N transfer has received considerable scientific interest because of its importance for the N economy of legume-based pastures under low external input conditions (Laidlaw *et al*., 1996).

Transfer of N from legumes to non-legumes is favoured when the different species are grown in close association and by a high legume/non-legume ratio (Brophy *et al*., 1987). This agrees with the theory that legume roots and nodules must turnover and that the non-legume subsequently will compete successfully for the released N (Ledgard and Steele, 1992). In addition, direct transfer may occur through a common mycorrhiza mycelium or via the atmosphere through NH_3 exchange (Janzen and Gilbertson, 1994) although their agronomic importance has yet to be established. Morris *et al*. (1990) observed N transfer from arrow leaf clover to ryegrass and suggested that in mixed stands of legumes and non-legumes (e.g. grasses), direct transfer of N during the growing season is possible, for example via VA mycorrhizal hyphae, although the extent to which it occurs is small and most likely in the range of 10% or less of the total N fixed. Snoeck *et al.* (2000) reported that roughly 30% N effectively fixed by a legume (including biomass, roots and exudates) was transferred to the associated plant.

2.6 Methods used to measure N transfer and their limitations

The amount of N transferred in the overall N cycling was initially estimated by difference methods (Simpson, 1976). Later techniques based on dilution of soil ^{15}N were developed to get estimates with higher precision (Vallis *et al.,* 1967). The N difference method and the ^{15}N dilution techniques are sensitive to changes in soil biology and chemistry and also influenced by competitive traits like root distribution in the soil profile. Transfer of N from non-legume to legume cannot be detected and both methods are subject to errors because of a possible stimulation of N uptake by non-legume in mixture. The accuracy of the ^{15}N dilution technique depends on small differences in the spatial and temporal distribution of soil ^{15}N, which can lead to large errors in the estimates (Chalk and Ladha, 1999).

A direct labeling technique which uniformly incorporates ^{15}N in tissue and organs will therefore potentially be able to estimate N transfer with high precision. Direct labeling is done by enclosing the canopy with excess $^{15}N_2$ (Wood and McNeill, 1993) or $^{15}NH_3$ (Schmidt and Scrimgeour, 2001). This technique is difficult to employ under field conditions. The $^{15}N_2$ would label the legumes only and $^{15}NH_3$ would label all species in the plant community, and accurate determination of net transfer from one species to another can only be done by individual plant labeling.

Ledgard *et al.* (1985) leaf labeled white clover and lucerne in mixture under field conditions in order to estimate N transfer over a period of 36 days and observed a minimal transfer. Grass clover mixtures are managed as perennial crops and transfer normally increases with time. The leaf labeling technique should therefore be applied over a long-time scale. Under low-input conditions, transfer may contribute significantly to the total N economy of the agro-ecosystem (Hogh-Jensen, 1996).

Recently ^{15}N-urea has been fed to individual plants or leaves (McNeill *et al.,* 1997). The leaf-feeding techniques enable the labeling of individual plants grown in close association with other species and it is possible to detect transfer from the legume to the non-legume and vice-versa by cross-labeling the species (Russell and Fillery, 1996) and better estimates of N transfer can be obtained and this means the method is more reliable than those previously mentioned.

2.7 Grain legumes in rotation

Legume rotations are already an important practice for farmers with large enough holdings (above 1 ha) and the use of grain legumes in rotation with maize is already widely practiced in Southern Africa as a soil fertility sustaining measure (Snapp *et al*., 1998). Dakora and Keya (1997), found that grain legumes fix between 15 - 210 kg N ha^{-1} and that crop rotation involving legume and cereal monocultures is by far more sustainable than intercropping, the most dominant cultural practice on the continent. Snapp *et al*. (1998) cited unpublished data from Zimbabwe to show that the contribution of a groundnut (*Arachis hypgaea*), crop to soil N was equivalent to about 86 kg ha^{-1} of inorganic N fertilizer, on smallholder farms where inorganic fertilizers were already being used. Various research projects have shown that a grain legume may increase maize yields substantially in the year following a grain-legume, compared with the continuous cropping of maize (MacColl, 1989).

Self nodulating promiscuous types of indeterminate soybean (*Glycine max*), pigeon pea (*Cajanus cajan*), groundnuts, dolichos bean (*Dolichos lablab*) and cowpea are amongst the most promising in southern Africa for the double roles of food provision and fertility enhancement (Snapp *et al*., 1998)

It has been found that the addition of N to the soil might be minimal where there is a high harvest index and the edible parts are required for consumption or sale. There are also issues of reliability of legume establishment and growth, during the fallow, particularly in adverse weather conditions (Snapp *et al*., 1998). Growing crops in rotation may also be impossible if the farmer has very little land available for agriculture. Although legume crops grown in rotation may supply their own N needs and add to it if incorporated as a green manure, legume growth, and therefore N fixation, may still be limited by deficiencies of other nutrients, in particular P. This is particularly problematic for legumes grown in rotation as a farmer may be unwilling to invest money in fertilizer for a crop of secondary importance, or for a crop that is to be incorporated into the soil as a green manure. It is possible that the farmer may be unwilling to use a grain legume in rotation with a main crop, as the total production of the main crop is in any case usually higher under continuous cropping, despite poor annual yields (Snapp *et al*., 1998).

Where climatic conditions are periodically or inherently difficult, grain and biomass yields (and therefore BNF) are very low and that the impact of the grain legume on the following maize crop very small (Snapp *et al*., 1998). Ironically, it is during these adverse periods that the farmer may most need the best results from the technology.

2.8 Effect of crop rotation soil nutrients

Soil nutrient depletion is an increasing constraint to sustainable development for smallholder farmers in developing countries, where much grain-legume production occurs and many farmers cannot afford to use fertilizers (Graham and Vance, 2003). Currently N fertilizer inputs for this region average only 5-10 N kg ha^{-1}, with many soils being progressively mined of their nutrients (Giller and Cadisch, 1995). The depletion of N, P and K in Zimbabwe's agricultural soils has been estimated at 20-40, 3.5-6.6 and 17-33 kg ha^{-1} yr^{-1}, respectively (Smaling *et al*., 1997)

Grain legumes make substantial net contributions of nitrogen to soil fertility, but sometimes there is net removal of N from the field if legume stover is removed at harvest. Giller *et al.* (1994) reported that to obtain a net contribution of N to the system, the proportion of N in the legume derived from N_2-fixation should exceed the proportion of N removed at harvest. The construction of nutrient budgets, which quantify nutrient inputs to crops and / cropping systems, and their removals in the form of harvested grain or biomass is important in efficient nutrient management in agro-ecosystems (Lanyon and Beegle, 1989). When used together with nutrient concentrations in soil and plant samples, nutrient budgets give a good indication of the sustainability of a system in relation to nutrient management. Kennedy and Cocking (1997) suggested that N_2-fixation-based systems are most promising and potentially profitable in extensive rather than intensive agricultural systems, where erratic or historically low rainfall and market changes can seriously impact the economics and efficiency of fertilizer use.

Besides being valuable cash crops, Hearn (1986) was able to show that legumes could enhance the yield of the following crop. Self-nodulating types of cowpea are among the most promising for the role of providing grain and leaf for food and maintaining soil fertility through net N contributions (Kumwenda *et al*., 1997). Legumes grown within cotton cropping systems can fix quantities of atmospheric N_2, and have the potential to return more than 200 kg N ha^{-1} to the soil N pool in the vegetative residues after grain harvest (Rochester *et al*., 1998). Substantial amounts of this residual legume-N can be mineralized during the period prior to sowing cotton (Rochester *et al*., 2001).

Crop yields and some soil properties are influenced by crop sequence due to changes in availability of nutrients and water, soil physical properties, and incidence of diseases, weeds, or insects (Alteri, 1993). Measures of soil quality in agricultural land include soil tilth (described by porosity, aggregation and other structural measures) as an index of soil physical quality, and pH, N, exchangeable cations, salinity, toxic chemicals and soil organic carbon as indicators of soil chemical quality (Walker and Reuter, 1996). Among these, soil organic carbon has been proposed as a primary indicator of soil quality (Lal, 1997). Soil organic matter declines rapidly with cultivation, especially in the tropics, where inputs are limited, and changes in SOM following cultivation quickly lead to lower fertility and to diminished soil structure, water holding capacity and biological activity.

Even where NPK fertilizer is supplied, there are demands on the soil to supply other essential elements.

The frequency and amounts of C and N inputs needed to replenish soil carbon and N reserves have been suggested as good indicators of long-term sustainability of many cropping systems, and has been incorporated into predictive models of sustainability (Lal, 1997). Indicators are simple ways and means of verification. Predictive models derived for dryland clay soils suggest that the first indicators of a system run-down under commercial cropping are increased requirements of fertilizer N (and other nutrients such as P and S) and water to maintain yields. In the longer-term, yield and profitability losses also occur (Freebairn *et al*., 1998).

Legume crops provide several advantages such as soil erosion control, improved soil water conservation and greater soil organic matter content (Hargrove, 1986). Moreover, legume cover crops can supply a considerable amount of biologically fixed N to the summer row crops. Estimates of N fertilizer equivalence of legume crops vary considerably (Smith *et al*., 1987). Ladd *et al*. (1981) concluded that the main benefit of legumes was in maintenance of soil organic N.

2.9 Short term indicators of soil quality.

2.9.1 Microbial biomass

Microbial biomass is living component of soil organic matter and is normally estimated as microbial carbon. It typically comprises 1-4% of total organic carbon in soil (Gregorich *et al.,* 1994). Microbial biomass serves as a store of labile organic matter, is responsible for the decomposition, mineralization, and nutrient cycling through decomposition of organic matter. In addition, microbial biomass reacts to change more quickly, shows a greater proportional change, and is a more sensitive indicator of organic matter dynamics than total organic matter (Swift and Woomer, 1993). Gupta and Germida (1988) found out that soil microbial biomass measurements were useful in studying soil organic matter changes in aggregate size classes resulting from cultivation. Insam *et al.* (1991) used microbial biomass to demonstrate changes in soil fertility caused by the addition of various organic and nitrogen fertilizer amendments resulting in increased soil organic matter content. Ocio *et al.* (1991) reported that microbial biomass is useful as an early indicator of small changes in soil organic matter. Sparling (1992) found microbial biomass C and ratio to soil organic C useful measures to monitor soil organic matter. Both also provided a more sensitive index than organic carbon measured alone in soil under pasture, native soils, exotic forests and arable cropping. Gregorich *et al.* (1994) reported that microbial biomass has to be compared to a related soil parameter to indicate whether soil organic matter is increasing or decreasing. For example, the ratio of microbial biomass C to total organic carbon or the ratio of CO_2-C respired to microbial biomass C provides a measure of organic matter dynamics. Rice *et al.* (1996) suggested expressing microbial biomass C to total soil organic C to provide a measure of soil organic matter dynamics.

2.9.2 Particulate Organic Matter (POM)

Cultivation is usually accompanied by a decline in soil organic carbon (SOC) and nutrients, and deterioration of soil structure (Ashagrie *et al*. 2004). This is usually a combination of chemical and biological soil processes including reduced inputs of plant residues and increased soil disturbance, but the nature of changes depend on the agronomic practices adopted and on the properties of the soil (Christensen, 1992). The magnitude of management-induced changes are important to select appropriate management options (Ashagrie *et al*., 2004).

Short-term changes in soil C in response to changes in management are small relative to the amount of total soil C and may be difficult to detect by measuring bulk changes in soil C. Therefore, physical, chemical, and biological soil C pools have been isolated in an attempt to identify those soil C fractions likely to respond more rapidly than total C to changes in management (Haynes, 2000). It has been shown that particulate organic matter (POM) C and N provide an early indication of changes in C dynamics and total soil C under different agricultural management practices (Wander and Bollero, 1999). The amount of non-POM, or mineral-associated (silt plus clay) C is largely inhibited by soil mineral surface area (Hassink and Whitmore, 1997). Thus, POM C may serve as a sensitive indicator of changes in soil C that may not be detectable due to inherent soil C variability and relatively small changes relative to total C pool size.

2.10 Importance of N in cotton growth

Adequate levels of N are essential for proper plant growth, as it is needed for chlorophyll, enzymes as well as for the amino acids and proteins used for building plant tissues and cell organelles (Brady, 1990). In many tropical agricultural systems, the importance of N is second only to water (Webster & Wilson, 1998). The N content of most surface mineral soils is about 0.02 - 0.5%. However, most of the soil N is in organic form associated with humus and silicate clays and only about 2-3% of this is mineralized each year (Brady, 1990). Thus, the amount of readily available N in the form of nitrate and ammonium compounds is generally only about 1-2% of the total soil N in the soil, excluding areas where large amounts of fertilizer have been added. In many developing countries, there is an increasing deficit of N. Putting the problem very broadly, Giller (2001) estimated that between 20 and 70 kg N ha^{-1} yr^{-1} may be exported through harvests every year from developing countries particularly in sub-Saharan Africa.

Nitrogen nutrition is an important single determinant of growth and yield of cotton. N deficiency causes small stalks, pale green leaves, small bolls, fruit shed and ultimately low yields. Excessive and inappropriate applications of N fertilizer delays crop maturity because there is increase in vegetative growth at the expense of reproductive organs (Hearn, 1986). High levels of N input than necessary also lead to reduction in fibre quality and increase the incidence of cotton pathogens such as boll rot (Boquet *et al.,* 1991). Much of this excess N is usually lost from the system, mainly through denitrification and also by volatilization and leaching (Chen *et al.,* 1994).

2.11 Decomposition of plant residue mixtures and N mineralization.

When crops are grown as intercrops, residues of different crops become mixed so that residues of different quality decompose simultaneously within the same soil volume. Interactions between decomposing residues can be complex and may result in mineralization patterns which are not readily predicted from the N mineralization of separate components of the mixture (Handayanto *et al.,* 1997). Mixing residues of different species often leads to complex, non-linear interactions and decomposition patterns (Asquith and Butler, 1986) therefore a mineralization study of cotton-cowpea residues mixture is desirable to understand fully the N and C release patterns of these.

Short-term benefits of crop residues depend on the rate of decomposition and nutrient release (Jensen *et al.,* 1997). The challenge resides in sustaining crop production while maintaining soil fertility through supply and efficient management of organic residues (Isaac *et al.,* 2000). Biederbeck *et al.* (1994) suggested that it may be possible to manipulate the timing and quality of litter input through appropriate management of mixed stands to improve the synchrony of nutrient release with crop requirements.

Residues rich in N, but with low lignin and polyphenol concentrations decompose rapidly and supply a large amount of N during the early periods of crop growth, but may not contribute much to the maintenance of soil organic matter (Handayanto *et al.,* 1997). On the other hand, plant residues poor in N, but with large concentrations of lignin and active polyphenols decompose and release N slowly, so that little of the plant N applied is available for the succeeding crop although it remains in the soil (Cornforth and Davis, 1968).

In mixed residues, there are significantly greater initial releases of N and lower subsequent N immobilization than predicted because of differences in the decomposer community originating from the mixtures of varied litter resource quality (Blair *et al.* 1990, Handayanto *et al.* 1997). In contrast with incubation techniques, decomposition under field conditions is affected by climate (Vanlauwe *et al.,* 1995) and faunal activity (Tian *et al.,* 1992) and addresses several aspects of interaction between residue quality and decomposition more realistically for example N mineralized from residues may be lost beyond the reach of the decomposer community due to leaching.

2.12 Cotton pesticides and pesticide residues

Cotton has become an important part of the Zimbabwean agricultural economy due to significant yield increases obtained by careful timing of insecticide application based on crop monitoring. Some of the most commonly used pesticides in Zimbabwe are carbaryl (*1-naphthyl methylcarbamate*), Dimethoate (*2- dimethoxyphosphinothioylthio-N-methylacetamide*) and Fenvalerate EC (*RS)-α-cyano-3-phenoxybenyl-(RS)-2-(4-chlorophenyl)-3-methylbutyrate*, chemicals which synthetic pyrethroids that are relatively safe to humans (Myaka and Kabissa, 1996).

Pesticide residues are closely regulated in foods in most countries using Maximum Residue Limits (MRL's) or lethal dose where 50% of test animals are killed by this dose

(LD_{50}), the MRL are based on recognized safe and reasonable use patterns. Acute toxicity is a measure of how toxic a pesticide is after a single exposure. Chronic toxicity is a measure of how toxic a pesticide is over a period of time and after repeated exposure and represents the dangers associated with chemical accumulation in the body (e.g. chlorinated hydrocarbons). The lower the LD_{50} number of a pesticide, the more toxic it is.

In Zimbabwe pesticides are classified according to how poisonous the active ingredient is. Most cotton pesticides such as carbaryl 85WP range from poison (amber label) through dangerous poison (red) to extremely poisonous (purple label). The LD_{50} values that have been used to classify these chemicals are, green (> 2000mgkg^{-1} Body Weight), amber (501-2000mgkg^{-1} Body Weight), red (101-500mgkg^{-1} Body Weight) and purple (0-100 mgkg^{-1} Body Weight) (Zimbabwe Crop Chemical Handbook, 2002). Of concern in this study is the effect of these pesticides on the edibility of cowpea, both grain and leaves as fodder.

CHAPTER 3

3.0 GENERAL MATERIALS AND METHODS

3.1 Site and climate

This study was carried out at three sites, namely Kadoma Cotton Research Station (CRI) (29º 53'E, 18º 19'S, Altitude 1156 m), Ntini (28º 45'E, 18º 19'S, Altitude 1152 m) and Mukosi (29º 42'E, 17º 50'S, Altitude 1155 m) villages, all of which are in Kadoma district, Zimbabwe. All on-station experiments, except the ^{15}N trial, were repeated on-farm as researcher managed trials. This was a way of introducing cotton-cowpea intercropping to smallholder farmers. The area has an average rainfall, calculated over 69 seasons of 741 mm with a range of 389 mm to 1205 mm (CRI Report 1994). Rain normally falls from October to April although sufficient rain for sowing does not normally occur before mid-November. The CRI site was previously under soyabean then left unplanted for the whole season before being put under cotton and cowpea intercrops. At both Ntini and Mukosi, the sites were under maize before being put under cotton and cowpea intercrops.

3.2 Soil Characteristics

The soils in Kadoma are the well-drained, reddish brown of the fersiallitic group (Nyamapfene, 1991). They have also been classified as Ferralic Cambisol (FAO) and Oxic Ustropept, USDA (Thompson and Purves, 1978). Agriculturally, they are regarded as the most important soils in the country because of their widespread occurrence and the diverse uses to which they are put. Most of Zimbabwe's early commercial farming activities were concentrated around these areas of red clays partly because of the good quality of the soils and partly because of the many gold mines which provided a major market for the agricultural produce from these early farms. The soils mainly occur on the central plateau, regions of relatively high and reliable annual rainfall of between 700 to 950 mm.

3.3 Soil pH analysis

Soil (20 g) was mixed with 50 ml of 0.01M $CaCl_2$ in a 100 ml beaker. The mixture was stirred for 10 minutes and left to stand for 30 minutes after which it was stirred again for 2 minutes. The mixture was allowed to settle and pH of the supernatant liquid was measured using a pH meter (Anderson and Ingram, 1993).

3.4 Total C analysis

Soil (0.5 g) was weighed into labelled 100 ml conical flask and 10 ml of 5% $K_2Cr_2O_7$ added and allowed to completely wet the soil. In the fume cupboard 20 ml of conc. H_2SO_4 were added and the mixture thoroughly mixed and allowed to stand overnight. The clear sub-sample was transferred into a colorimeter cuvette, and absorbance recorded at 600 nm for each of the sample and standard (Nelson and Sommers, 1982).

$C\% = \frac{(K * 0.1)}{(W * 0.74)}$ where, w is weight of sample and k is corrected concentration value

3.5 Total N: Kjeldahl digestion method

Samples (0.1 g plant, 0.5 g soil) were weighed into labelled digestion tubes and 4.4ml of digestion mixture added. The digestion mixture was made up of selenium powder as catalyst, lithium sulphate, hydrogen peroxide and concentrated H_2SO_4. Samples were heated in the digester at 360^oC until the solution was colourless and then removed from the block and allowed to cool. Distilled water (25.0 ml) was added and mixed with a vortex mixer and allowed to cool. The volume was made up to the 100 ml mark with distilled water. The solution was allowed to settle and a clear solution was taken from the top for N colorimetric determination. An automatic pipette was used to transfer 0.1 ml of each of standard / sample into a suitably marked test tube. Five millilitres of N1 reagent (34 g sodium salicylate, 25 g tri-sodium citrate, 25 g sodium tartrate, and 0.12 g sodium nitroprusside dissolved in 1000ml distilled water) was added to each tube, vortexed and left for 15 minutes after which 5 ml of N2 (30 g sodium hydroxide and 10 ml of 15% sodium hypochlorite in 1000 ml distilled water) was also added and vortexed again. The tubes were left for 1 hour for full colour development and each sample and standard's absorbance was read at 655 nm wavelength (Anderson and Ingram, 1993).

$N\% = \frac{(C * 0.01)}{W}$ where, W is weight of sample, and C is corrected concentration.

3.6 Soil mineral N ($NH_4^+ + NO_3^-$) analysis

Wet samples were taken and kept in a refrigerator to avoid N transformations. Mineral N was extracted by 1 M KCl and the extract was analysed for NH_4^+ and NO_3^-. Nitrate (NO_3^-) was determined by reduction of nitrite to nitrate using spongy cadmium. The nitrate so formed was then determined colorimetrically by the diazonation reaction. A pipette was used to transfer 10 ml of soil extract/ standard into a vial with a clip on top followed by the addition of 3 ml of NH_4Cl. This was followed by the addition of 1 ml Borax solution and about 0.5 g of granular cadmium and the contents swirled end-over-end for 30 minutes. After 30 minutes, 7 ml of the contents were transferred into a 50 ml volumetric flask while taking care not to transfer the cadmium granules. Sulfanilamide solution 1 ml was added followed by 1 ml of Napthlethyelene-Diamine-Dyhyrochloride Solution (NED) and the contents thoroughly mixed. Volume was made up to 50 ml using deionized water and after 10 minutes absorbance was read at 543 nm wavelength.

Ammonium (NH_4^+) was determined by pipetting leachate / standard (10 ml) into a 100 ml Erlenmeyer flask and mixed with 40 ml of deionized water followed by 2 ml of phenol solution and the contents were swirled. Sodium Nitroprusside solution (2 ml) was also added and the contents swirled again. Using a pipette 5 ml of oxidizing solution was added and the contents were swirled. After an hour, absorbance was read at 640 nm wavelength (Anderson and Ingram, 1993).

3.7 Total P analysis

The sample digestion was the same as in determination of total N. Sample / standard (5 ml) was pipetted into a 50 ml volumetric flask and 20 ml of distilled water added to each flask. Ascorbic acid reducing agent (10 ml) was added to each flask and mixed. Distilled water was used to make up to the mark and the solution was left for full colour development. The samples and standard absorbance were read at 880 nm wavelength (Anderson and Ingram, 1993).

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$P\% = \frac{(C * 0.025)}{W}$ where, W is weight of sample and C is concentration.

3.8 Plant available P analysis

Soil (2.5 g) was weighed into a polyethylene bottle and 50 ml extracting solution (sodium bicarbonate mixed with 10 % NaOH, pH 8.5) added. The mixture was stirred for 30 minutes before being filtered through Whatman No. 42 filter paper. The filtrate (1 ml) was pipetted into a test tube and 4 ml of ascorbic acid solution and 3 ml of molybdate reagent were added and mixed well. Colour was allowed to develop fully and absorbance was read at 880 nm wavelength after 1 hour (Watanabe and Olsen, 1965)

3.9 Exchangeable bases

Soil (5 g) was added to a 60 mm diameter long funnel (plugged at the bottom with cotton wool) with a capacity of 25 ml. The soil was leached with 10 successive 20 ml aliquots of 1M ammonium acetate (pH 7) over a 2 hour period and the leachate was collected in a 250 ml volumetric flask. The volumetric flask was made up to the 250 ml mark with ammonium acetate solution and thoroughly mixed. Leachate (20 ml) was pipetted into a 100 ml volumetric flask and 20 ml of lanthanum chloride solution, the volumetric flask was filled up to the mark with distilled water. The K^+ content was determined by flame emission spectroscopy, and Ca^{2+} and Mg^{2+} by atomic absorption spectroscopy (Anderson and Ingram, 1993).

3.10 Soil Texture analysis

Air-dried soil (40 g) was weighed into a 600 ml beaker and 100 ml of sodium hexametaphosphate solution added. The beaker was filled to the 500 ml line with deionized water and the mixture was put on an automatic shaker overnight then left to stand for at least 10 minutes. The mixture was mixed well for five minutes with an electric mixer. The solution was then transferred into sedimentation cylinder, and using deionized water to bring the volume to the 1000 ml mark. The suspension was inverted 10 times. The hydrometer was carefully inserted and readings taken after 40 seconds and 5 hours, and temperature noted (Gee and Bauder, 1986).

Calculations

40 sec (corr) = 2(40 sec reading – 40 sec blank +T)

5 hr (corr) = 2(5hr reading- 5hr blank +T)

Where T=temperature corrections: For every ^{o}C above 20 ^{o}C (d), T= 0.3 x d; for every ^{o}C below 20 ^{o}C (d) T=-0.3 x d.

% Sand =100 -40 sec (corr)

% Silt = 40 sec (corr)- 5 hr (corr) % clay = 5 hr (corr).

CHAPTER 4

4.0 EFFECTS OF PLANT POPULATION UNDER DIFFERENT COTTON-COWPEA INTERCROPPING PATTERNS ON EFFICIENCY AND YIELD.

4.1 Introduction

The most important reason for growing two or more crops together is the increase in productivity per unit of land through more complete utilization of solar radiation (Keating and Carberry, 1993). Intercropping can also spread labour needs and reduce pest problems (Van der Pol, 1992). Spatial arrangements, planting rates and maturity dates may be exploited to make intercrops more productive than growing pure stands. Sullivan (1998) explains that there are four ways by which spatial arrangement can be varied to increase productivity. Row intercropping is the growing of two or more crops at the same time with at least one crop planted in rows. Strip intercropping is growing two or more crops in strips wide enough to permit separate crop production using machines but close enough for crops to interact. Mixed intercropping is growing two or more crops in no distinct row arrangement and relay intercropping is planting a second crop into a standing crop at a time when the standing crop is at its reproductive stage but before harvesting. Maturity dates are important because planting intercrops that feature staggered maturity dates takes advantage of variations in peak resource demand for nutrients, water and sunlight. If one crop matures before its companion crop the competition between the two crops is lessened due to reduced nutrient demands by the senescing plant (Sullivan, 198).

When growing more than one crop simultaneously, a habitat different from a monocrop is created. This increased crop diversity is likely to influence insect distribution and abundance in the crops (Alteri, 1993). A decrease in pest numbers can be attributed to hampered pest movements, decreased immigration or increased emigration (Kareiva, 1983). This can occur due to greater biological control and because host plants are difficult to find (less apparent) in intercrops. Intercropping cotton leads to reduction of insect pests, e.g. Fukai and Trenbath (1993) cites a study which found that cotton grown without insecticides in an intercrop with sorghum yielded 25% higher than sole-crop cotton with insecticides.

The efficiency or productivity of intercrops is usually expressed in terms of land equivalent ratio (LER). To calculate LER, the intercrop yields are divided by the pure stand yields for each component crop in the intercrop. Then, these two figures are added together. This is usually affected by the relative density of the companion crops and the level of N fertilizer application (Siame *et al*., 1998).

This study was carried out to determine the effects of cowpea plant population and time of planting on dry matter production, grain and lint yield and efficiency of cotton-cowpea intercrop system. It was hypothesized that the total yield achieved in an intercrop is higher than achieved by sole crops on the same size of land**.** An additive model was used for this study i.e. in the intercrops the plant population and spacing of the main crop (cotton) was maintained while that of cowpea was varied.

4.2. Materials and methods

The high yielding variety Albar SZ9134 was planted at a standard spacing of 1.0 m between rows and 0.3 m within row. Basal fertilizer, Compound L (12.5 kg N: 45 kg P: 25 kg K ha^{-1}) was applied at a rate of 250 kg^{-1}. Top dressing was at rate of 25 kg N ha^{-1} of ammonium nitrate. The normal chemical pest control measures were employed. Chemicals such as carbaryl, dimethoate, fenvelerate and marshal were applied after thorough scouting. The short season erect type CBC2 variety was planted at a spacing of 0.5 m between rows and 0.15 m within rows. Cowpea received only the basal fertilizer, the fertilizer rates of 250 kg ha^{-1} of Compound L were based on cotton fertilizer requirements since it was the main crop and also because Compound L contained sufficient amounts of P that is required for N_2 fixation. Ammonium was applied to cotton rows only. Cowpea benefited from insecticide application to cotton.

The additive model was used where the cotton plant population and spacing was maintained in sole and intercropping systems. The plots used measured 10 m x 6 m. A strip (1 m) separated the plots from each other all the sides. Border strips of 5 m were left on the edges of the fields. The experiment was a factorial experiment and laid out in a randomized block design with four replicates with the following treatments; (a) Sole cotton, (b) Sole cowpea, (c) 2 rows cotton alternating with 1 row cowpea, both planted the same time, (d) 2 rows cotton alternating with 1 row cowpea, cowpea planted 4 weeks after cotton, (e) 1 row cotton alternating with 1 row cowpea, both planted at the same time and (f) 1 row cotton alternating with 1 row cowpea, cowpea planted 4 weeks after cotton (1:1 Rel). The differences in plant growth parameters and yield attributed to treatment effect were analyzed using the analysis of variance (ANOVA) procedure of

Genstat 8.0 statistical package. The least significance difference (95 %) and standard error of difference of mean (SED) were used to compare means of the different treatments.

4.2.1 Cotton crop height measurement

Plant height was recorded on randomly selected six plants per plot and an average was taken to indicate plant growth for the different intercropping treatments. The measurements started at four weeks after planting and continued up to physiological maturity. A measuring tape and a graduated stick were used to record plant height. The normal method for determining cotton height is to measure from the soil surface to the terminal which is the growing point in the plant apex (Ball, 1998). The graduated stick had markings of 1 cm apart and precise measurements were obtained using the measuring tape.

4.2.2 Soil moisture content measurement

Soil moisture content was measured by the gravimetric method (Black, 1965)**.** Soil samples were collected at cowpea harvest using an auger within the 0-0.2 m depth. Sub-samples of about 100 g of soil were put in a pre-weighed (mass of container) metal can and closed tightly to prevent or minimize evaporation. The samples were weighed (mass of wet soil + container). In the laboratory, the samples were placed in the oven with the lid off. The temperature was adjusted to 105^{o}C and dried over night. Samples were taken from the oven and allowed to cool and weighed as weight of (dry soil + container). The moisture content on dry weight basis was calculated using the following formula:

$$Moisture\ content\ \% = \frac{(\text{mass of wet soil} + \text{container}) - (\text{mass of dry soil} + \text{container})}{(\text{mass of dry soil} + \text{container}) - (\text{container})}\ x\ 100$$

4.2.3 Yield assessment

Sub-plots of 4 m x 2 m were marked out for all the treatments as the net plots. The crop within this area was harvested, grain and lint yield was weighed and moisture from grain measured. The yield was calculated at 12% grain moisture. Stover yield was measured by cutting three plants at physiological maturity, these were dried at 60^{o}C until there was no change in mass, and this was given as dry matter.

Grain or lint was calculated as:

$$Grain / l\text{int}\ (t\ ha^{-1}) = \frac{10000\ m^2}{Area\ harvested\ (m^2)}\ x\ Mass\ of\ yield\ (t)$$

The dry matter was calculated as:

$$Dry\ matter\ (t\ ha^{-1})\ =\ \frac{Plant\ population\ (ha^{-1})}{Number\ plants\ harvested}\ x\ Mass\ of\ harvested\ plants\ (t\ ha^{-1})$$

To calculate the land equivalency ratio (LER), the intercrop yields were divided by the pure stand yields for each component crop in the intercrop. These two figures are then added together to get the LER. Cotton lint yield and cowpea grain yield as well as the dry matter yields of these crops were used in the calculations. This can be expressed mathematically thus;

$$LER = \left[\frac{Cotton_{intercrop}}{Cotton_{solecrop}} + \frac{Cowpea_{intercrop}}{Cowpea_{solecrop}} \right]$$

The grain can also be substituted by dry matter yields.

4.2.4 Gross Margin Analysis

Gross Margin was calculated as the average returns above variable costs (RAVC). The assumptions behind this analysis were that land is fixed and that labour has been valued at the price of its best alternative use (opportunity cost). The measurements were all expressed using the standard unit of per hectare. Variable costs were itemized for inputs used such as cowpea seed, cotton seed, Compound L, ammonium nitrate and insecticides (carbaryl, fenvalerate, and dimethoate). Other information used was the amount of cowpea grain and cotton lint sold and the price per unit received. The gross margin was given by the following equation:

$$GM = GTVP - VC$$

where NR is net return or gross margin, GTVP is the gross total value product and VC is the variable cost.

4.3 RESULTS

4.3.1 Soil moisture content

The mean soil moisture content was highest under the sole cowpea treatment and soil from the sole cotton treatment had the lowest moisture content. The moisture content among the treatments ranged from 23% to 31% (Table 4.1).

Table 4.1. The average total soil moisture content under sole crops and under different cotton-cowpea intercropping treatments at cowpea harvest.

Treatment	Mean Soil Moisture Content (%)
Sole Cowpea	31
Sole Cotton	23
Cotton/cowpea 1:1 simultaneous	27
Cotton/cowpea 2:1 simultaneous	26
Cotton/cowpea 1:1 relay	27
Cotton/cowpea 2:1 relay	25
$LSD_{0.05}$	1.2

The treatment effect on soil moisture content was highly significant ($p<0.001$). Time of planting of cowpea had no significant effect on soil moisture content as the simultaneously planted and relay planted intercrops were not significantly different from each other ($LSD_{0.005}$=1.2).

4.3.2. Cotton plant height as affected by intercropping.

Cotton height was suppressed by intercropping; the sole cotton treatment recorded the highest plant height (122 cm) while simultaneously planted cotton/cowpea 1:1 had the lowest plant height of 67 cm (Table 4.2). Cotton plant growth as indicated by height was similar for all the treatments during the first 8 weeks. Rate peaked from week 8 through week 17, with sole cotton recording the fastest growth rate (Fig. 4.1), at week 25, sole cotton had an average height of 109 m across the 3 sites. There was a significant ($p<0.001$) treatment and site effect on final cotton plant height.

Table 4.2. The cotton plant height for each treatment recorded at harvest.

Treatment	Plant Height (cm)		
	CRI	Ntini	Mukosi
Sole Cotton	102	102	122
Cotton/cowpea 1:1 simultaneous	68	68	95
Cotton/cowpea 2:1 simultaneous	88	89	104
Cotton/cowpea 1:1 relay	82	81	125
Cotton/cowpea 2:1 relay	98	98	126
$LSD_{0.05}$		12	

The data showed that sole cotton plant height was not significantly different from the relay planted cotton/cowpea 2:1 configuration (Fig.4.1).

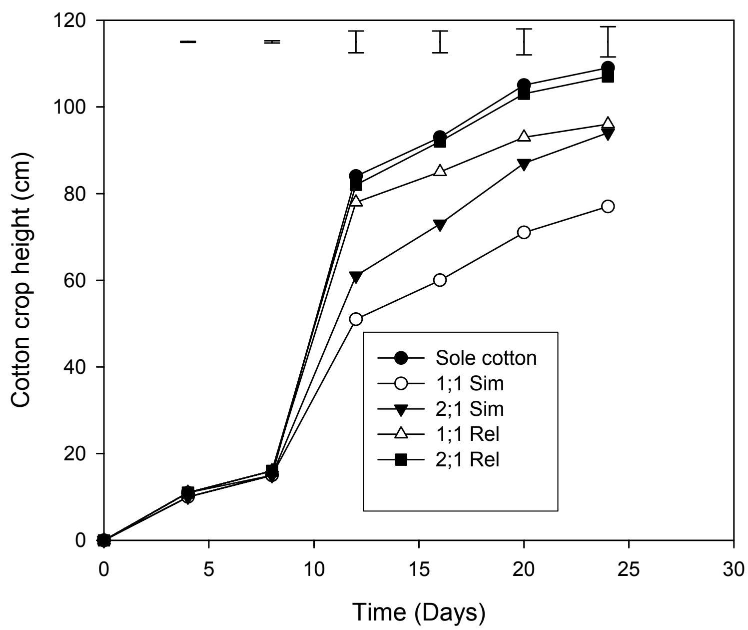


Figure 4.1. Cotton growth as affected by intercropping and progress of the season. The data points are averages for the three sites (CRI, Mukosi and Ntini).

4.3.3. Cowpea grain yield.

Cowpea grain yield values ranged from 0.3 t ha^{-1} for the relay 2:1 cotton-cowpea treatment to 1.9 t ha^{-1} for the sole cowpea crop (Table 4.3). The effects of treatment and site were highly significant ($p<0.001$) on cowpea grain yield.

Table 4.3. Cowpea grain yield as affected by intercropping treatment

Treatment	Grain Yield (t ha^{-1})		
	CRI	Ntini	Mukosi
Sole Cowpea	1.4	1.9	1.4
Cotton/cowpea 1:1 simultaneous	1.1	1.2	1.2
Cotton/cowpea 2:1 simultaneous	0.6	0.7	0.7
Cotton/cowpea 1:1 relay	0.6	1.1	0.7
Cotton/cowpea 2:1 relay	0.3	0.4	0.3
$LSD_{0.05}$		0.25	

The box-plot (Fig. 4.2) shows that the grain yield do not overlap much because of differences in cowpea plant population in the different intercrop treatments that ultimately gave different yields. Plant density had a significant effect on yield of cowpea.

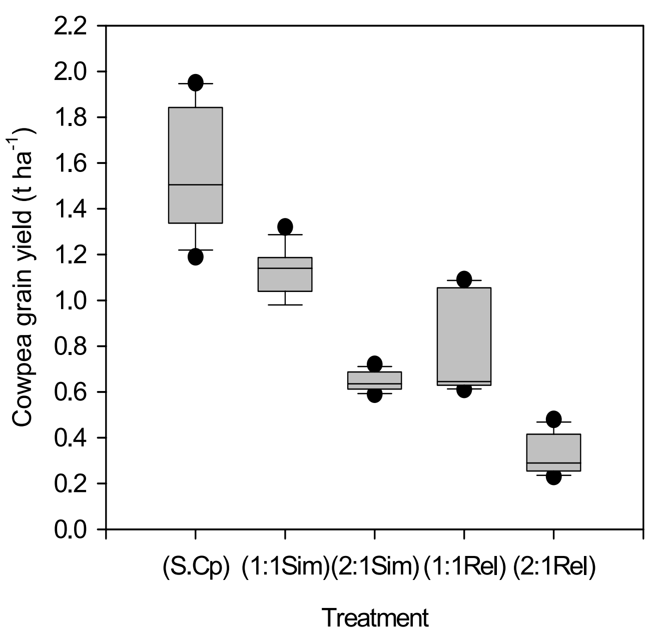


Fig. 4.2. Effect of cotton-cowpea intercropping on cowpea grain yield .The data points are averages for the three sites (CRI, Mukosi and Ntini).

4.3.4 Cowpea dry matter yield

The sole cowpea treatment recorded the highest dry matter yield of 5.0 t ha^{-1}. The simultaneously planted 1:1 cotton/cowpea treatment was second with 3.8 t ha^{-1}(Table 4.4). The effect of treatment, site and treatment and site interaction were highly significant ($p<0.001$) in all cases.

Table 4.4. Cowpea plant population and dry matter yields under different intercropping treatments.

Treatment	Plant Population (000 ha^{-1})	Total dry matter yield (t ha^{-1})		
		CRI	Ntini	Mukosi
Sole Cowpea	133.3	4.7	5.0	4.7
1:1 simultaneous	66.7	3.8	3.6	3.8
2:1 simultaneous	33.3	2.2	1.8	2.2
1:1 relay	66.7	3.2	3.4	3.3
2:1 relay	33.3	1.5	1.6	2.9
SED			0.4	

4.3.5 Cotton lint yield

The effects of treatment, site and, site and treatment interaction on cotton lint yield were significant ($p<0.001$). Lint yield ranged from 0.5 to 2.4 t ha^{-1} (Table 4.5). The highest lint yield was recorded at CRI site while the least was recorded at Mukosi site. Sole cotton recorded the highest yield followed by the relay planted 2:1 cotton-cowpea treatment and for all the sites; the simultaneously planted 1:1 cotton-cowpea treatment gave the lowest.

Table 4.5. Cotton lint yield as affected by different cotton-cowpea intercropping strategies.

Treatment	Cotton lint yield (t ha^{-1})		
	CRI	Ntini	Mukosi
Sole Cotton	2.4	1.6	2.1
Cotton/cowpea 1:1 simultaneous	0.9	0.8	0.5
Cotton/cowpea 2:1 simultaneous	1.5	1.0	1.2
Cotton/cowpea 1:1 relay	2.0	0.8	1.9
Cotton/cowpea 2:1 relay	2.4	1.1	1.8
$LSD_{0.05}$		0.6	

There 1:1 simultaneous treatment significantly reduced cotton lint yield as there was no overlap with the sole cotton treatment (Fig. 4.3). The spread of cotton lint yields showed that relay intercrops were similar to sole cotton. There was reduced competition in relay intercrops than simultaneous intercrops.

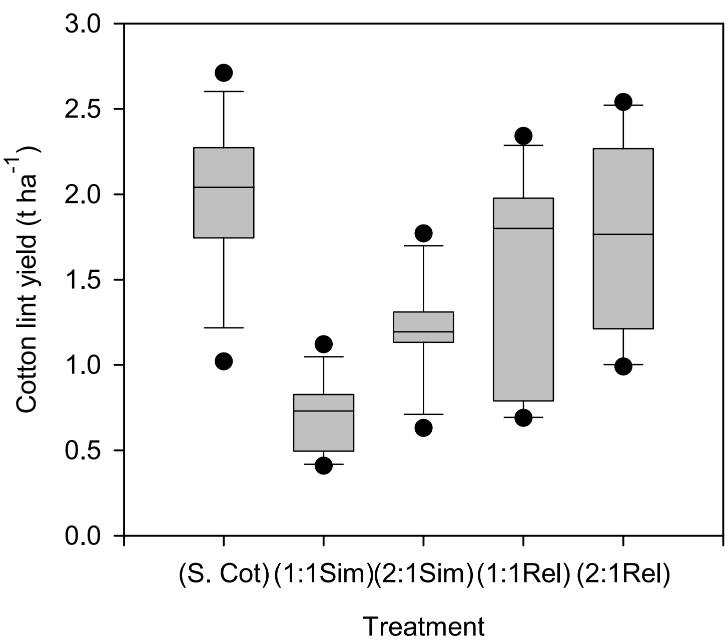


Fig. 4.3. Cotton lint yield as affected by different cotton-cowpea intercropping, average of three areas.

4.3.6. Cotton dry matter yield

The sole cotton treatment recorded the highest dry matter yield of 9.8 t ha^{-1} and the relay planted 2:1 cotton/cowpea treatment had the second highest of 8.7 t ha^{-1} (Table 4.6). The effect of treatment and site on cotton total above-ground dry matter yield was significant ($p<0.001$). Generally, high values were recorded at CRI site and Mukosi site whereas Ntini site recorded low values of dry matter yield for all the treatments. All the treatments were significantly different from each other ($LSD_{0.05}$=0.2), meaning that intercropping affected total aboveground dry matter yield from cotton.

Table 4.6. Cotton dry matter yield under different intercropping treatments.

Treatment	Dry matter (t ha^{-1})		
	CRI	Ntini	Mukosi
Sole Cotton	9.8	7.5	9.6
Cotton/cowpea 1:1 simultaneous	5.6	4.3	5.2
Cotton/cowpea 2:1 simultaneous	8.0	6.8	8.3
Cotton/cowpea 1:1 relay	8.7	7.1	8.6
Cotton/cowpea 2:1 relay	9.2	7.4	9.3
$LSD_{0.05}$	0.3	0.2	0.2

4.3.7 Total dry matter yield

Dry matter production in intercropping was much greater than in sole crops, relay intercrops had significantly higher total dry matter yield than sole cotton. The effect of site was significant with Ntini recording significantly lower yields for all treatments except sole cowpea (Table 4.7). There were significant differences between sole cowpea and sole cotton treatments.

Table 4.7. Total dry matter yield under sole cropping and intercropping treatments.

Treatment	Total Dry matter (t ha^{-1})		
	CRI	Ntini	Mukosi
Sole cowpea	4.7	5.0	4.7
Sole cotton	9.8	7.5	9.6
Cotton/cowpea 1:1 simultaneous	9.4	7.9	9.0
Cotton/cowpea 2:1 simultaneous	10.2	8.6	10.5
Cotton/cowpea 1:1 relay	11.9	10.5	11.9
Cotton/cowpea 2:1 relay	10.7	9.0	12.2
$LSD_{0.05}$		1.2	

4.3.8 Land Equivalence Ratios

Both dry matter and grain yields showed that there was an advantage of intercropping cotton and cowpea because all the land equivalence ratio (LER) values were greater than 1.0. Using dry matter yield, the relay planted 1:1 cotton/cowpea treatment had the highest LER value of 1.7 and the simultaneously planted 2:1 cotton/cowpea treatment had the lowest LER of 1.3 (Table 4.8). Using grain yields, the LERs ranged from 1.1 for the simultaneously planted cotton-cowpea (2:1) treatment to 1.3 or the relay planted cotton-cowpea (1:1) treatment. The average values of LER indicate an advantage of intercropping to sole cropping of at least 30% (Table 4.8).

Table 4.8. The land equivalence ratios (LER) for the different cotton-cowpea intercrop treatments using both dry matter and grain/lint yield.

Treatment	Land Equivalence Ratios (LER)		
	Dry matter	Grain/Lint	Mean
Cotton/cowpea 1:1 simultaneous	1.4	1.1	1.3
Cotton/cowpea 2:1 simultaneous	1.3	1.2	1.3
Cotton/cowpea 1:1 relay	1.7	1.3	1.5
Cotton/cowpea 2:1 relay	1.5	1.1	1.3

4.3.9. Gross Margins

The 1:1 simultaneous treatment had the highest GM of $3.7 million (USD1028) while sole cotton and 2:1 relay intercrop were at par at $3.6 million (USD1000) (Table 4.9). The marginal returns showeds that growing sole cowpea was least profitable while growing a 2:1 simultaneous intercrop gave a GM of $3.0 million (USD833).

Table 4.9. The gross margins (GM) for the different cotton-cowpea intercrops and sole crops. 1USD = $3, 600.00.

Treatment	Cowpea grain yield (t ha^{-1})	Cotton lint yield (t ha^{-1})	Marginal Returns ($ ‘000 000)
Sole cowpea	1.6		1.9
Sole cotton		2.0	3.6
Cotton/cowpea 1:1 simultaneous	1.1	0.7	2.6
Cotton/cowpea 2:1 simultaneous	0.7	1.2	3.0
Cotton/cowpea 1:1 relay	0.8	1.5	3.7
Cotton/cowpea 2:1 relay	0.3	1.8	3.6
SED	0.2	0.3	0.5

4.3.9 Effect of non-application of insecticide on cotton lint and cowpea grain yield in intercrops

Cotton yield was substantially reduced when cotton did not receive the normal insecticide application. The 2:1 simultaneous intercrop treatment had the highest reduction from 1.2 t ha^{-1} with insecticide application to 0.1 t ha^{-1} with no insecticide application (Table 4.9). Cowpea recorded a reduction in yield as well when there was no pesticide application but the margin of reduction was low as compared to cotton. Cowpea grain yield was 1.1 t ha^{-1}

in 1:1 simultaneous intercrop with pesticide application but fell to 0.8 t ha^{-1} without insecticide application (Table 4.10).

Table 4.10. Effect of insecticide application on cotton lint and cowpea grain yield in intercrops, an average of the three sites.

Treament	Cotton lint yield (t ha^{-1})	Cowpea grain yield (t ha^{-1})
Sole cowpea	-	1.6
Sole cotton (insecticide application)	2.0	-
1:1 Simultaneous (insecticide application)	0.7	1.1
2:1 Simultaneous (insecticide application)	1.2	0.7
1:1 Simultaneous (No insecticide)	0.2	0.8
2:1 Simultaneous (No insecticide)	0.1	0.3
Mean	0.8	0.9
SED	0.2	0.2

4.4 Discussion

Reduced competition between cotton and cowpea is important in order to get maximum benefits from cotton-cowpea intercropping. To maximize benefits, the insecticide sprays applied to cotton should coincide with the time the pest incidence in cowpea is high (Myaka and Kabissa, 1996). The difference in cowpea grain yield in treatments of the same row configurations but different planting times can be explained by the difference in competition between the intercrops. Relay planted cowpea was adversely affected by shading from the already tall cotton crop leading to more vegetative growth at the expense of consolidated yield, however the decrease in cowpea yield was compensated for by high cotton yields as compared to the other treatments. De Beltrao *et al.* (1986) also reported a reduction in cotton yield as a result of intercropping with cowpea.

Moisture stress in the early stages of growth increased the competitiveness of cowpea, thus adversely affecting the cotton especially the simultaneously planted 1:1 cotton-cowpea treatment. Soil moisture content results showed that there was a benefit of intercropping in terms of soil moisture conservation. Planting cowpea between the wide (at least 1.0m) cotton rows improved soil cover and ultimately reduced moisture loss from the soil. Though the high plant density in the intercrop meant increased water uptake, evaporation from the soil surface was greatly reduced (Turner, 1997).

The land equivalence ratios (LER) using total above-ground dry matter yield indicated that the relay planted 1:1 cotton-cowpea (1.7) treatment was more productive. This indicated that it would require 70% more land of the planted area in order to yield the same amount of biomass with sole crops. These results were also confirmed by LER values using cowpea grain and cotton lint yield, the relay 1:1 planted had a ratio of 1.3 and the 2:1 relay planted had 1.1, this underlined the importance of competition on intercrop performance. Schulz and Janssens, (2001) found in a similar study of cotton and pigeon intercrop that intercrop treatments gave yields higher than the corresponding monocrop, as measured by LER. They also found that increasing plant density increased pigeonpea yield but reduced cotton yield. Results were also closely related to an earlier evaluation study of cotton-cowpea intercropping (Rusinamhodzi *et al.,* Unpublished), which identified the relay planted 2:1 cotton-cowpea treatment as the best intercropping treatment because of reduced competition.

The significant difference in cotton biomass yields of sole and intercropped cotton was a result of plant density. Cotton growth was suppressed in the simultaneously planted 1:1 treatment, reducing biomass yield by 44% and the relay planted 2:1 cotton-cowpea treatment had the least reduction of cotton dry matter yield of 3%. Planting cowpea 4 weeks after cotton gave cotton a competitive advantage over cowpea in the intercrop hence biomass yield was not significantly suppressed in the relay treatments. Results clearly showed that competition during the early stages of growth affected yield more as compared to competition in mid-season or later stages of crop growth.

The marginal returns (MR) which did not include the soil fertility contribution of cowpea showed that the relay intercropping treatments were more profitable. This could be explained by the fact that there was little competition to cotton during the early stages of growth and hence yielded higher than that from simultaneous intercrops. The significant difference in height between cotton and the bushy cowpea variety meant that pests' movements in the intercrop were not hampered and they could easily find their target. Both crops though showed losses of yield with no insecticide application of more than 50% and it was therefore necessary to apply pesticides to the intercrops for economic gain.

4.5 Conclusion

There was suppression of cotton yield in intercropping, but this was compensated by the additional yield of cowpea. Intercropping cotton and cowpea improved land productivity as shown by the LER values greater than 1.0. However the marginal returns showed that income did not substantially increase through intercropping and this was one of the limitations of the strategies that were studied. Relay planted intercrops yielded better than simultaneously planted intercrops because of reduced competition; therefore for highly productive cotton-cowpea intercropping relay intercrops are promising. Cotton-cowpea intercropping also conserved soil moisture. It is desirable to apply pesticides in intercrops when pests' numbers are high following the normal IPM to realize the substantial benefits of cotton/cowpea intercrops.

CHAPTER 5

5.0 EFFECTS OF COTTON-COWPEA INTERCROPPING ON COWPEA N_2 FIXATION CAPACITY AND NITROGEN BALANCE UNDER ZIMBABWEAN RAIN-FED CONDITIONS

5.1 Introduction

Biological nitrogen fixation (BNF) in legumes is a fundamental process for maintaining soil fertility and the continued productivity of low-input cropping systems. Legumes are self sufficient with N; their N_2-fixation can cover the N demand of several subsequent non-N_2- fixing crops (van Kessel and Hartley, 2000). Biological nitrogen fixation therefore can be used in agricultural systems for replenishing nitrogen which is the most limiting growth factor in soils of the tropics**.** The amount of N_2 fixed and the N contribution from leguminous crops are influenced by a number of environmental factors, including soil type, nutritional status of soil, species and varieties, water availability and temperature as well as soil and crop management (Jensen *et al.,* 1997).

There are several methods for measuring N_2 fixed by legumes (Bergersen, 1988). The ^{15}N enrichment and the nitrogen difference methods are now preferred especially the ^{15}N dilution method. The ^{15}N isotope dilution principle stipulates that changes in ^{15}N enrichment result when two sources that differ in N isotopic composition are uniformly mixed. The extent of change that results will depend on the magnitude of the differences in the initial enrichments of the individual sources, as well the relative amounts of each. The ^{15}N isotope dilution technique was chosen because of its ability to give an integrated estimate of N fixation over a growing season or longer. It is the only method that can distinguish between soil, fertilizer and fixed N in field grown crops. Recent published literature (Azam and Farooq, 2003) reported an increasing use of the technique to quantify N-fixation in legumes. The method involves the application of ^{15}N labeled fertilizer to the soil, subsequent harvest of the N_2 fixing species and appropriate reference non-N_2-fixing plants and analysis. Plant materials are analyzed ^{15}N content and the dilution of the enriched fertilizer by ^{14}N derived from the atmospheric N_2 (99.6337 at % ^{14}N) relative to that of the non-fixing plant is then used to calculate the proportion of legume N coming from N_2 fixed from the atmosphere (Unkovich and Pate, 2000).

Inaccuracies in ^{15}N isotope dilution estimates arise from poor matching of reference and legume crop, coupled with the decline in ^{15}N enrichments of plant available soil N (Giller and Witty, 1987). Stabilizing the ^{15}N enrichment of the plant available N over time could potentially contribute to improved estimates of fixation.

Legumes are often a component of intercropped systems in tropical agriculture, and the possibility of direct benefit to the non-legume as the result of nitrogen excretion by the legume has been a contentious issue. Legumes grown within cotton cropping systems have the capacity to fix large quantities of atmospheric N_2, and have the potential to return more than 200 kg N ha^{-1} to the soil-plant system in the vegetative residues after grain harvest (Rochester *et al.,* 1998). Substantial amounts of this residual legume-N are therefore available for the next crop (Rochester *et al.,* 2001). Measurement of the amount of N_2 and hence N returned the system becomes important when planning the fertilizer regimes for the following crop after legumes. Nitrogen management is important because excessive N rates delays cotton maturity and hamper crop defoliation as there is more vegetative growth at the expense of reproductive organs (Hearn, 1986). Over-fertilization also reduces fibre quality and increases incidence of cotton pathogens such as boll rot (Boquet *et al.,* 1991).

Data in literature show that nitrogen exchange does occur in certain circumstances, but it can be detected only under conditions of very low availability of soil nitrogen because it occurs only in small amounts. There is evidence that mycorrhizal connections between the intercropped components may provide a route of nitrogen transfer. Such N benefit to an intercropped non-legume would be significant only under low-yielding conditions (Rao and Mathuva, 2000).

Although measurements of N_2-fixation capability of cowpea as a sole crop are well documented, it is not known whether its capacity to fix N is enhanced or suppressed under cotton-cowpea intercropping systems. The aim of this study was therefore to measure the N_2-fixation in cowpea grown either as a sole crop or in intercrop with cotton and quantify possible N transfer from cowpea to cotton. It was hypothesized that biological N_2 fixation by cowpea is positively affected by the companion cotton crop in intercropping. This information is necessary to find out the net N addition to the soil by sole cowpea and cotton/cowpea intercrops and hence evaluate the productivity of the different cropping systems in terms of N requirements of subsequent crops.

5.2 Materials and Methods

The field experiment was conducted during 2003/2004 season at Kadoma Cotton Research Institute (CRI). The area was under soyabean during 2001/2002 but was left fallow during 2002/2003 season. The land was ploughed during the dry season and then disked just before the rain season. The plots were laid out in a completely randomized block design with 4 replicates. Cotton was used as a reference plant for measuring N_2-fixation. Main plot sizes were 6 m x 9 m and cowpea was sown at a spacing of 50 cm between rows and 15 cm between plants within the rows in sole crops. Row spacing for cowpea was 100 cm for the 1:1 (cotton: cowpea) treatment and 200 cm for the 2:1 (cotton: cowpea) treatment but in-row spacing remained 15 cm. Cotton was sown at a spacing of 100 cm between rows and 30 cm within rows in both sole and intercrops. Analysis of variance (ANOVA) using Genstat 8.0 was used to identify treatment effects.

Within each main plot two microplots were marked out measuring 2 m x 1 m. Each microplot received 25 kg N ha^{-1} of $(^{15}NH_4)_2SO_4$ with an enrichment of 10.38 % ^{15}N atom excess. The N-fertilizer was mixed with sufficient sucrose as carbon source to give a C: N ratio of 10:1 in solution, and dissolved in water to allow even application to the microplots. Cowpea was not inoculated in all treatments. Recommended rates for phosphorus (45 kg P ha^{-1} as single superphosphate) and potassium (25 kg K ha^{-1} as Muriate of Potash) and boron (0.5 kg B ha^{-1} as borax) were applied (Cotton Training Center, 2000). The fertilizer applications were based on the main crop which is cotton.

Plants were harvested at the same time i.e. when cowpea was at physiological maturity and cotton at ball forming stage.

5.2.1 Ndfa (%) and N balance

Plants were sampled (cut at 1 cm above the ground) when cowpea had reached physiological maturity (at that time cotton was between flowering and ball forming) and cowpea pods separated from the leaves and stems. Plant samples were first dried at 72°C, ground in a Wiley mill to pass through a 0.5 mm sieve and then ball-milled to <150 microns. The ^{15}N abundance in the ground plant material was measured on an ANCA 20-20 GSL isotope ratio mass spectrometer (PDZ Europa Ltd., Cheshire, UK) following dry combustion. ^{15}N-labelled Plant Reference Material supplied by the International Atomic Energy Agency (IAEA) was used as standard. The analyses were done at Mauritius Sugar Industry Research Institute Laboratory (MSIRI).

The % N from N_2-fixation was calculated by the isotope dilution (ID) method:

$$\%N_{fixation} = \left[1 - \frac{\text{\% atom excess of legume}}{\text{\% atom excess of reference}}\right] \text{x} 100\%$$

and the total amount of N from N_2-fixation was calculated as:

$$N_{fixed} = \frac{\text{Total legume N x \% } N_{fixation}}{100}$$

Nitrogen contribution of the cowpea to the soil (N balance) was calculated as:

$$N_{balance} = N_{residue\ returned} - N_{uptake\ from\ soil}$$

5.2.2 N transfer

It has been shown that, when a non-N fixing plant was cultivated in association with an N-fixing plant, nitrogen taken up by the non N-fixing plant in the soil is derived from two sources: A% coming from the N_2 fixation by the legume and B% coming directly from the soil N (Kurdali *et al.*, 1990). This can be expressed by a system of two equations with two unknown quantities

$$A\% * {}^{15}N_{\text{fixation}} + B\% * {}^{15}N_{ref.Pl} = 100\% * {}^{15}N_{association}$$

$$A\% + B\% = 100\%$$

where ${}^{15}N_{\text{fixation}}$ was obtained from the N-fixing plant, ${}^{15}N_{\text{ref.pl}}$ was obtained from the cotton plant far from legume (sole crop) while ${}^{15}N_{\text{assoc}}$ was obtained from cotton in intercrops. The resolution of this system gives the percentage of N (A%) provided to the association by N fixation. The formula obtained is thus:

$$A\% = \frac{\sigma^{15}N_{ref.pl} - \sigma^{15}N_{assoc}}{\sigma^{15}N_{ref.pl} - \sigma^{15}N_{\text{fixation}}}$$

Some cotton crops were planted close to the cowpea crops (1:1 and 2:1 intercrop patterns) on either side. As a consequence, they received their litter and had their root systems mixed with those of the legumes. While other cotton crops were planted far from the legume (sole crop) and there was no interaction. Due to this planting design, it was possible to calculate the percentage of nitrogen introduced by N_2 transfer in the system by means of the ${}^{15}N$ excess measured in plants sampled on each of the two associated plants and on the distant cotton crop.

5.3 Results

Cowpea total dry matter yields were: 4.7 t ha^{-1} for sole cowpea, 2.2 t ha^{-1} for 2:1 cotton/cowpea intercrop treatment and 3.8 t ha^{-1} for 1:1 cotton/cowpea intercrop treatment (Table 5.3a). The highest percentage (85.2%) for N_2 fixation was recorded for 1:1 cotton/cowpea intercrop while 2:1 cotton/cowpea intercrop treatment had 77.4% and the lowest percentage (73.1%) was recorded for the sole cowpea treatment. The highest amount of N_2 fixation (103.5 kg N ha^{-1}) was however obtained from the sole cowpea crop, the 1:1 cotton/cowpea intercrop had 96.1 kg N ha^{-1} and the 2:1 cotton/cowpea treatment had the lowest amount of 50.9 kg N ha^{-1}. The amounts of N fixation were significantly different from each other ($p<0.05$) and $LSD_{0.05}$ (Table 5.3a). The productivity of the intercrop treatments was higher than for the sole crop as shown by land equivalence values (LER) which were greater than 1.0 in both cases (Table 5.3a).

Table 5.3a. Dry matter yield, percentage N_2 fixation and total amount of N_2 fixed by two cotton cowpea intercrop treatments as compared to sole cowpea treatment.

Treatment	Dry Matter of cowpea (t ha^{-1})	Land Equivalence ratio (LER)	% N_2 fixation	Total N_2 fixation (kg N ha^{-1})
Sole cowpea	4.7	1.0	73	104
2:1 cotton/cowpea intercrop	2.2	1.3	77	51
1:1 cotton/cowpea intercrop	3.8	1.4	85	96
Mean	3.6	1.2	79	83
$LSD_{0.05}$	1	0.01	7	6

The N balance calculated for these treatments was an estimate of the N accrual to the soil–plant system and indicated the amount of N contributed to the succeeding crop. The N balances of all the treatments were positive 25.7- 60 kg N ha^{-1} (Table 5.3b). Approximately 70 to 90% (Table 5.3a) of N was derived from the atmosphere (not the soil) and the N exported in the grain ranged between 15 and 21 %. The 1:1 cotton/ cowpea intercrop treatment had the highest N balance of all the treatments. The direct contribution to the soil was the amount of N in the legume residue crop (incorporated into the soil) derived from the atmosphere (Ndfa). The rest of the N content of the cowpea plant was absorbed from the soil. The N uptake from the soil was calculated as the difference between Ndfa and the total N in cowpea. Uptake from the soil ranged between 10 and 40 kg N ha^{-1} (Table 5.3b).

Table 5.3b. N uptake from soil, above ground N fixation, N removed in grain, above ground N in residues and N balance in soil of the two cotton/cowpea intercrop treatments as compared to sole cowpea treatment.

Treatment	Uptake from soil (kg ha^{-1})	Above ground Ndfa (kg ha^{-1})	Grain N removed (kg ha^{-1})	Above ground N in residue (kg ha^{-1})	N balance in soil (kg ha^{-1})
Sole Cowpea	38	104	23	81	43
2:1 cotton/cowpea	15	51	10	41	26
1:1 cotton/cowpea	17	96	19	77	60
Mean	23	84	18	66	43
$LSD_{0.05}$	4	6	3	4	3

The amount of N transferred was insignificant with 1:1 simultaneous having the highest amount of 3.1% (3.5 kg N ha^{-1}) as shown in Table 5.3c. The percentage of N in the associated cotton crop coming from N_2–fixation by cowpea was directly proportional to the intercrop system's fixation capability.

Table 5.3c. The percentage of Ndfa in cowpea and percentage transferred (A%) to cotton crops for the two intercropping systems.

Treatment	Ndfa (%)	A %	% N transferred (in % from Ndfa)	Amount transferred (kg N ha^{-1})
1:1 simultaneous	85.2	3.1	3.6	3.5
2:1 simultaneous	77.4	0.7	0.9	0.5

5.4 Discussion

The percentage N_2 fixation by cowpea was higher in intercrop treatments than in sole crop indicating a higher productivity of the cotton/cowpea intercropping system. Similar studies have shown that pigeon pea when intercropped with sorghum derived 59% of its N from fixation, and 78% when intercropped with pear millet, compared with 30% when grown as sole crop (Adu-Gyamfi *et al.,* 1996). The total amount of N_2 fixed was however lower in intercrop treatments than in sole crop due to the lower density of the fixing plant in intercrop than in sole crop. The greater density in cowpea sole crop increased the dry matter yield per unit area and hence the total amount of N fixed. Intercropping increased the proportion of N derived from fixation (Ndfa); this was due to increased competition for soil N which led to better nodulation. Marschner (1995) reported that growing a non-legume with a legume reduced mineralized N in the soil; legumes respond by fixing more N than they might do in a pure stand, so long as the legumes dominate the mixture. Fixation of N is stimulated by a high C/N ratio of the plant and the absence of nitrogen in combined form, as from fertilizer. In N-deficient soils more than 80% of total plant N may be derived from symbiotic fixation (Giller, 2001).

The results of Ndfa however could have been affected by the reference crop, wrong choice of reference crop can either underestimated or overestimate the N_2 fixed (Giller and Witty, 1987). Due to its deep rooted nature and slow initial growth, cotton could have accessed N from beyond the cowpea rooting zone and therefore result in lower $^{15}N_2$ enrichment. The reference crop may not necessarily behave the way it is assumed to and isolines have been proposed to be better reference crops though differences in uptake of N from fertilizer and soil have been reported (Boddey *et al.,* 1997). For accurate measurements or better estimates, multiple reference crops have been suggested and are recommended for future N_2 fixation measurements (Doughton *et al.,* 1995).

The land equivalence ratios obtained for cotton and cowpea intercrops were all greater than one. This meant that the land requirement for monocropping is higher than that for intercropping. Intercropped legumes and cotton used plant growth resources more efficiently than did pure stands, thus supporting results of Fukai and Trenbath (1993) and Rao *et al.* (1987) about intercropping systems with legumes and non-legumes. They attributed the advantage of intercropping to different above-ground and below-ground growth habits and morphological characteristics of the crops and the higher efficiency in the utilization of water and radiation energy. The cowpea density was reduced by 50% in the 1:1 cotton/cowpea intercrop from that of sole cowpea but the reduction in dry matter yield was only 20 %. Therefore in terms of dry matter yield the intercrop treatment performed better than the sole crop. The corresponding reduction in amount of N-fixation was 7% from 104 kg N ha^{-1} to 96 kg N ha^{-1}.

Although N_2-fixation was high (>75 %) in the intercrop systems, the associated cotton crops did not get much of the N fixed by cowpea. Little transfer was observed in both cases although it was a little higher for 1:1 intercrop than for 2:1. The amounts of N transferred were not significant to nutrition of the cotton crop. This could be explained by the fact that in 1:1 intercrop, the cotton crops were surrounded by two rows of cowpea crops whereas in 2:1, two rows of cotton shared a row of cowpea.

The available estimates of N balance reported took only the aboveground cowpea crop into consideration. The higher N balance (60.0 kg N ha^{-1}) for the 1:1 cotton/cowpea intercrop could be explained by a higher amount of N fixation almost equal to that of sole cowpea but far much lower removal of N in the grain (20 kg N ha^{-1}). The roots also contained some N derived from the soil and some N derived from the atmosphere and thus, accounting for root N would increase N balance and make it more positive. The belowground cowpea biomass may be an important source of N for a subsequent cereal crop where the above-ground biomass is eaten by livestock. Estimates of cowpea root dry matter are extremely variable ranging from 0.3 t ha^{-1} (Carsky, 2000) to 2.9 t ha^{-1} (Groot *et al.,* 1995). Root N concentration has been reported to range between 1.5 and 2.5% after a study by Nnadi and Balasubramanian (1978). Root N, if measured, may help to explain the full beneficial effect of cowpea rotation when aboveground N balance does not appear sufficient.

Franzluebbers *et al.* (1994) estimated the contribution of the cowpea roots to the following sorghum crop to be in the range of one-fifth of the whole cowpea plant used as green manure. However, in a field study conducted by John *et al.* (1992), the aboveground cowpea material was removed and cowpea below-ground residues only accounted for an increase in soil mineral N content, but did not increase the yield of the subsequent rice crop. When the aboveground cowpea biomass was included, however, the rice yield increased significantly. All or part of the cowpea residue may be exported as animal feed or burned off during the dry season. In such cases, the recycled cowpea residue consists only of leaves fallen before harvest (i.e., the litter) and the roots. Estimates of cowpea litter in the literature are rare and extremely variable results are reported in different trials, ranging from less than 0.1 to more than 1.0 t ha^{-1} and from less than 5% to more than 60% of total aboveground residue (Carsky, 2000). The rotational benefit consists of N derived from the atmosphere (the aboveground and below ground cowpea crop), the N-sparing effect (crop uptake of N decreases because of N from N_2 fixation) of the cowpea crop and other non-N benefits, and therefore, rotational experiments may overestimate the N contribution of the rotation (Wani *et al.,* 1995). The N-sparing effect may result in more N in the soil for a subsequent crop if the N is not lost from the soil profile before the subsequent cereal crop (e.g. by denitrification). Although it is an apparent benefit to the subsequent cereal crop, it is not a contribution to the soil–plant system. While N supply is the major benefit of cowpea rotation with cereals, non-N benefits are possible (Rao and Mathuva, 2000). In order to ascertain whether there are non-N benefits, there should be a full range of N levels after both preceding crops (cowpea and control) and this form the basis for the next chapter.

5.5 Conclusions

The intercropping of cotton with a short season cowpea variety is a potentially productive system. For the different cropping systems the largest amount of N_2 was fixed by sole cropped cowpea. However taking into account that cowpea grown in the intercrop was sown at half (1:1 cotton/cowpea) and a third (2:1 cotton/cowpea) of the sole crop density, it is apparent that the greatest relative amount of N_2 fixed was measured for the 1:1 cotton/cowpea intercrop. The method for measuring N_2 fixation could be improved especially with the choice of reference crops, cereals have been regarded as better reference crops. Nitrogen transfer occurred in cotton/cowpea intercropping but it was of little significance to the nutrition of the companion crop. Therefore the regard of N transfer during the season as a possible benefit of cotton/cowpea intercrop should be minimized. The positive N balance showed that cotton-cowpea intercrops will contribute to the nutrition of the successive crop more than sole cotton if losses of N during the dry season are minimized. The benefits mentioned in this study provide a starting point for resource poor farmers who want to improve their production systems through integration of legume.

CHAPTER 6

6.0 EFFECTS OF COTTON-COWPEA INTERCROPPING ON SOIL NUTRIENT LEVELS AND YIELD OF SUCCESSIVE CROPS.

6.1 Introduction

Soil nutrient depletion is an increasing constraint to sustainable development for smallholder farmers in developing countries, where much grain-legume production occurs and where many farmers cannot afford to use fertilizers (Graham and Vance, 2003). Currently fertilizer inputs for Southern Africa region average only 5-10 N kg ha^{-1}, with many soils being progressively mined of their nutrients (Giller and Cadisch, 1995). Sanchez (2002) suggests average annual nutrient depletion rates across 37 African countries of 22 kg N ha^{-1}, 2.5 kg P ha^{-1}, and 15 kg K ha^{-1}.

Maintenance of soil nutrient and biological status is a very important aspect of sustainability. Although there is widespread belief and acceptance that grain legumes make substantial net contributions of N to soil fertility, sometimes there is net removal of N from the field if legume stover is removed at harvest. Giller *et al.* (1994) found out that the proportion of N in the legume derived from N_2-fixation should exceed the proportion of N removed at harvest for there to be a net contribution of N to the system.

Besides being valuable cash crops, legumes enhance the yield of the following crop mainly through fallen leaves and belowground residues (Kasasa *et al.,* 1999). Self-nodulating promiscuous types of cowpea are among the most promising for the role of providing grain and leaf for food (promoting farmer adoption) and maintaining soil fertility through net N contributions (Kumwenda *et al*., 1997). Legumes grown within cotton cropping systems can fix large quantities of atmospheric N_2, and have the potential to return more than 200 kg fixed N ha^{-1} to the soil N pool in the vegetative residues after grain harvest (Rochester et al., 1998). Substantial amounts of this residual legume-N can be mineralized during the fallow prior to sowing cotton (Rochester *et al*., 2001).

Crop yields and some soil properties are influenced by crop sequence due to changes in availability of nutrients and water, soil physical properties, and incidence of diseases, weeds, or insects. Sustainability in any farming system is dependent upon a number of interacting factors, which include climate, soil quality, plant nutrition, management, weed and disease incidence, and economic factors (Greenland and Szabolcs, 1994). Measures of soil quality in agricultural land include soil tilth (described by porosity, aggregation and other structural measures) as an index of soil physical quality, and pH, N, exchangeable cations, salinity, toxic chemicals and soil organic carbon as indicators of soil chemical quality (Walker and Reuter, 1996).

Intercropping effects on soil nutrient levels are largely dependent on the quantity of nutrients removed in harvested grain and stover (Dalal, 1974), and camp or shading effects on BNF by legumes (Reddy *et al.*, 1994). If the legumes are intercropped in a timely manner, competition with the cotton companion crop for light, water, and nutrients can be minimized while legume herbage N can be accumulated and production increased. The objectives of this study was therefore to quantify changes in soil properties and nutrient status (pH, POM, microbial biomass C and N, N, P, Ca, Mg, K and CEC) due to the effects of cotton and cowpea intercropping, and to determine the response of subsequent maize crop grown after cowpea and compare this with the response to fertilizer N. It was hypothesized that there is a net decrease in the concentration of nutrients (N, P, Ca, Mg, and K) and properties such as POM, microbial biomass C and N and pH in the soil after cotton than when intercropping cotton and cowpea, and that the residual effects from the preceding cotton-cowpea intercrops are beneficial to the succeeding maize crop.

6.2 Materials and methods

Maize was grown at three sites i.e. CRI, Ntini and Mukosi in the plots that previously had sole cowpea, sole cotton, and 1:1 cotton: cowpea simultaneous/ relay and 2:1 cotton cowpea simultaneous/ relay the previous season. Cowpea residues were incorporated at CRI only not in farmers' fields (Ntini and Mukosi); this was done so as to follow current farmer practice. Aboveground cotton residues except litter fallen before harvest were not returned to the soil because cotton plants were cut dried and burned at the end of each season to control the pink bollworm. The yields from these plots were then compared to the yields obtained from plots where fertilizer was applied at three levels of N i.e. 0, 30, 60 kg N ha^{-1}, the typical application rates for smallholder farmers (Jeranyama *et al.,* 2000).

All the plots received a basal application of 45 kg P ha^{-1} as single super phosphate (SSP). Potassium was not added because it is seldom deficient in soils except under advanced stages of soil fertility depletion (Mugwira and Nyamangara, 1998). The cowpea residue yields obtained in the first season after removing grain were sole cowpea (3.5t ha^{-1}), 1:1 simultaneous/relay (2.5t ha^{-1}) and the 2:1 simultaneous/relay (1.5t ha^{-1}). The experiment was a factorial experiment and laid out in a randomized block design with four replicates. The factors under consideration were residue rate and fertilizer rate. The differences in plant growth parameters and yield attributed to treatment effect were analyzed using the analysis of variance (ANOVA) procedure of Genstat 8.0 statistical package. The least significance difference (95 %) was used to compare means of the different treatments.

6.2.1 Yield Assessment

Sub-plots of 4 m x 2 m were marked out for all the treatments as the net plots. The crop within this area was harvested, grain was weighed and moisture measured. The yield was calculated at 12% grain moisture. Stover yield was measured by cutting three plants at physiological maturity, these were dried at 60^{o}C until there was no change in mass, and this was given as dry matter.

Grain or lint was calculated as:

$$Grain\ \ (t\ ha^{-1}) = \frac{10000\ m^2}{Area\ harvested\ (m^2)}\ x\ Mass\ of\ \ yield\ (t)$$

The dry matter was calculated as:

$$Dry\ matter\ (t\ ha^{-1})\ \ =\ \ \frac{Plant\ \ population\ (ha^{-1})}{Number\ \ plants\ harvested}\ x\ Mass\ of\ \ harvested\ \ plants\ (t\ ha^{-1})$$

The residual benefits were expressed as grain increase percent. Grain increase percent was calculated as the difference between the yields of maize from absolute control to yield obtained from the residual plots. It can be expressed mathematically as;

$$\text{Grain Increase Percent} = \left(\frac{\text{Yield}_{\text{control}} - \text{Yield}_{\text{treatment}}}{\text{Yield}_{\text{control}}} \right) \text{X } 100\%$$

6.2.2 Soil sampling

Soil samples for chemical analysis were taken before and after cotton-cowpea intercrops. Soil samples (0–0.2 m depth) were collected with an auger at 12 random locations in a plot, mixed in a 20 L bucket and a sub-sample of about 1 kg was taken for air drying. Air-dried samples were ground and sieved (2 mm) before analysis.

6.2.3 Soil analysis

Soils were analyzed for pH (Section 3.3), total C (Section 3.4), Total N (Section 3.5), mineral N (Section 3.6), total P (Section 3.7), plant available P (Section 3.8), exchangeable bases (Section 3.9) and texture (Section 3.10).

6.2.4 Microbial Biomass C and N: Fumigation extraction method

Two sub-samples of fresh soil, 10 g each were weighed into 50 ml plastic containers. One sub-sample was extracted using 50 ml of 0.5 M K_2SO_4 without fumigation. The other sub-sample was fumigated using chloroform in a dessicator and left to stand in the dark at 25^{o}C for 24 hours. The samples were extracted in 50 ml of 0.5 M K_2SO_4. The extracts were analyzed for dissolved organic C and N as described in sections 3.7.2 and 3.7.3 respectively (Anderson and Ingram, 1993).

6.2.5 Particulate Organic Matter (POM) analysis

The separation of particulate organic matter (POM) was done following the procedure of Six *et al.* (1998). Soil (50 g) was weighed into a container and 200 ml of water were added and left to stand overnight in a refrigerator to reduce microbial activity. A dispersing agent was regenerated in 3M trisodium citrate and added to the soil and put on an automatic shaker overnight (18 hours). Soil was wet sieved through a series of sieves and separated into three fractions, POM 250 (>250 µm), POM (53-250 µm) and non-POM (<53 µm). Organic C and N concentrations in the fractions were determined as described in the sections 3.7.2 and 3.7.3 respectively.

6.3 Results

6.3.1 Soil mineral N

There was an increase in concentration of mineral N available to plants at the end of the first season for most treatments except under sole cotton and relay intercrops. Sole cowpea showed the highest increase in mineral N for all the sites with highest being 33 mg kg^{-1} recorded at Ntini site (Table 6.1). The general trend was that mineral N increased with increase in the proportion of cowpea in the system. Simultaneously planted intercrops had higher mineral N as compared to relay planted intercrops.

When the cotton-cowpea intercrops were rotated with maize (high nutrient requirements), there was a decrease in the levels of mineral N for all previous cropping system though the magnitude of decline differed. Plots that had sole cotton before maize had the lowest mineral N levels for all the sites, e.g. at Mukosi, N concentration was 14.6 mg kg^{-1} and at Ntini it was 15 mg kg^{-1} compared to fallow with 18 mg kg^{-1} and 24 mg kg^{-1} respectively.

Table 6.1. Soil mineral N ($NH4^+$ + NO_3^-) in mg kg^{-1} after cotton-cowpea intercrops (2004) and after maize (2005) as compared to a fallow.

Treatment	CRI		NTINI		MUKOSI	
	2004	2005	2004	2005	2004	2005
Sole Cotton	18	16	20	15	17	115
Sole Cowpea	26	20	33	21	30	17
1:1 Sim	22	18	23	18	23	16
2:1 Sim	23	19	25	18	25	15
1:1 Rel	21	17	20	17	25	18
2:1 Rel	21	18	21	19	20	16
Fallow	21	21	24	24	19	18
$LSD_{0.05}$	2		3		4	

6.3.2 Soil pH and plant available P

There was no treatment effect on pH for all the three sites. Available P generally increased after cropping and was directly proportional to the proportion of cowpea in the intercropping system. Sole cowpea caused the greatest increase from an average of 2.1 mg g^{-1} to 2.5 mg g^{-1} P representing a change of 14% (Table 6.2). Sole cotton showed a decrease in P levels at all sites recording the lowest of 1.4 mg g^{-1} at CRI. There was a significant treatment effect on available P and the values were significantly different ($LSD_{0.05}$) within site but not across sites.

Table 6.2. Phosphorus and pH levels before (2003) and after (2004) cotton-cowpea intercrops as compared to a fallow.

Treatment	pH			Available P (mg g^{-1})		
	CRI	Ntini	Mukosi	CRI	Ntini	Mukosi
Sole Cotton	6.5	5.9	5.8	1.4	1.6	1.8
Sole Cowpea	6.5	5.8	5.7	2.4	2.4	2.6
1:1Sim	6.5	5.9	5.7	1.8	1.9	1.8
2:1 Sim	6.5	5.9	5.7	2.2	2.2	2.1
1:1 Rel	6.5	5.9	5.7	2.1	1.8	2.0
2:1 Rel	6.5	5.9	5.8	2.3	2.3	2.2
Fallow	6.5	5.8	5.7	2.2	2.1	2.0
$LSD_{0.05}$		0.3			0.2	

6.3.3 Exchangeable bases and CEC

Intercrops and sole crops did not cause significant differences on exchangeable bases and CEC. Sole cotton caused a decrease in CEC while the other treatments caused an increase as compared to the fallow. The greatest CEC increase was under sole cowpea which recorded 24.6 $cmol^{+}kg^{-1}$ which represents an increase of 9% (Table 6.3). There were no significant treatment differences on exchangeable bases and CEC.

Table 6.3. Exchangeable bases and CEC ($cmol^{+}kg^{-1}$) after cotton and cowpea intercrops as compared to a fallow, an average for three sites (CRI, Ntini and Mukosi).

Treatment	Ca	Mg	K	CEC
Sole Cotton	8.1	8.5	0.28	21.6
Sole Cowpea	7.2	6.5	0.27	24.6
1:1 Sim	8.4	6.5	0.28	23.4
2:1 Sim	7.8	4.6	0.26	22.8
1:1 Rel	8.8	6.2	0.26	23.1
2:1 Rel	7.1	6.5	0.28	22.6
Fallow	8.6	7.4	0.29	22.4
$LSD_{0.05}$	0.02	NS	0.05	3.3

6.3.4 Soil microbial biomass C and N

Microbial biomass C and N increased with increase in proportion of cowpea in the intercrops. Sole cowpea had the highest microbial biomass C and N of 421 $\mu g\ g^{-1}$ and 42 $\mu g\ g^{-1}$ respectively (Table 6.4). Sole cowpea and simultaneously planted 1:1 cotton-cowpea intercrop gave significantly higher microbial biomass N values while sole cotton gave values significantly lower than that of fallow (Table 6.4).

Sole cowpea and 1:1 cotton-cowpea intercrop gave microbial C/N ratio of 10 and 11 respectively, both of which were less than that of fallow. Generally cotton-cowpea intercropping lowered the microbial C/N ratio while sole cotton gave a wide ratio. There were no significant treatment differences on microbial biomass C as a percentage of total C but all treatments were higher than that of fallow and sole cowpea gave the highest value of 1.3%.

Table 6.4. Microbial biomass C and N after cotton-cowpea intercrops as compared to fallow. Values shown are averages for the three sites (CRI, Ntini and Mukosi).

Treatment	C_{mic} ($\mu g\ g^{-1}$)	N_{mic} ($\mu g\ g^{-1}$)	$\%C_{mic}$: C_{tot}	Microbial C/N ratio
Sole cotton	354	19	1.1	18
Sole cowpea	421	42	1.3	10
1:1 Sim	396	35	1.2	11
2:1 Sim	367	27	1.1	14
1:1 Rel	382	31	1.2	11
2:1 Rel	359	24	1.1	15
Fallow	345	26	1.0	13
$LSD_{0.05}$	45	6		

6.5 Particulate organic matter C and N

There was an increase in both POM-C and POM-N after cotton-cowpea intercrops but the magnitude of increase was greatly reduced after sole cowpea than after sole cotton. In most cases in the non-POM fraction more N was lost than C under the cropping systems under review especially cotton. Sole cotton and 2:1 relay increased C content in the bigger particle size fraction (POM 250) but there was a decrease in the non-POM fraction compared to fallow. The same treatments recorded lower values of N content in the different fractions as compared to the other treatments (Table 6.5). There was a general increase in organic C and decline in total N in the particle size fractions with cropping system except under sole cowpea. Sole cotton and 2:1 simultaneous intercrop significantly increased organic C in the fractions. Sole cotton caused an increase of organic C and total N of almost 50 % from 419 $\mu g\ g^{-1}$ to 618 $\mu g\ g^{-1}$ and from 33 $\mu g\ g^{-1}$ to 18 $\mu g\ g^{-1}$ respectively for the coarse fraction (Table 6.5). The C/N ratios were variable especially in the POM 250 (range from 12 to 34) but constant in the POM 53 (mean 14) and very stable in the non-POM fraction (Table 6.5)

Table 6.5. Particulate organic matter C and N after cotton-cowpea intercrops as compared to fallow. Values shown are averages for the three sites (CRI, Ntini and Mukosi).

Treatment	C ($\mu g\ g^{-1}$)			N ($\mu g\ g^{-1}$)			C/N ratio		
	POM250	POM53	non-POM	POM250	POM53	non-POM	POM250	POM53	non-POM
Cowpea	420	748	1200	35	55	137	12	14	9
Cotton	618	390	974	18	24	83	34	16	12
1:1 Sim	452	641	1103	30	44	128	15	15	9
2:1 Sim	496	618	1050	28	42	124	18	15	9
1:1 Rel	420	658	1120	29	46	126	15	14	9
2:1 Rel	556	429	983	22	34	115	26	13	9
Fallow	419	691	1150	33	50	132	13	14	9
$LSD_{0.05}$	74	82	136	5	6	24			

*POM250=particulate organic matter > 250µm, POM53=particulate organic matter 53-250µm and Non-POM=organic matter <53 µm.

6.6 Maize grain and stover yields

The highest yield obtained was 6.2 t ha^{-1} for the plots that received 60 kg N ha^{-1} followed by 4.6 t ha^{-1} for maize after sole cowpea, for the CRI site (Table 6.6). The highest yield for Ntini was 3.3 t ha^{-1} for 60 kg N ha^{-1} and maize after sole cowpea had its yield (1.8 t ha^{-1}) lower than that of 30 kg N ha^{-1} which had a grain yield of 2.0 t ha^{-1}. Treatment, site and site x treatment interaction were highly significant ($p<0.001$) for both grain and stove yield.

T able 6.6. Effect of residual fertility (N) on maize stover and grain yield after growing cotton and cowpea intercrops as well as sole crops as compared to three mineral fertilizer levels for the three sites, CRI, Ntini and Mukosi.

Fertilizer / Previous crop	**Grain yield (t ha^{-1})**		
	CRI	Ntini	Mukosi
0 kg N ha^{-1}	2.3	1.1	1.9
30 kg N ha^{-1}	2.9 (26)	3.6 (227)	2.7 (42)
60 kg N ha^{-1}	6.2 (170)	4.0 (264)	3.3 (74)
Cotton	1.4 (-39)	0.9 (-18)	0.9 (-53)
Cowpea	4.6 (100)	1.8 (64)	2.5 (32)
1:1 Intercrop	4.4 (91)	1.6 (45)	2.3 (21)
2:1 Intercrop	3.9 (70)	1.3 (18)	2.2 (16)
$LSD_{0.05}$		0.3	
Fertilizer / Previous crop		**Stover yield (t ha^{-1})**	
0 kg N ha^{-1}	5.9	3.4	3.5
30 kg N ha^{-1}	9.2	6.2	6.7
60 kg N ha^{-1}	11.7	8.8	8.3
Cotton	4.3	3.5	3.3
Cowpea	8.6	5.5	5.8
1:1 Intercrop	8.1	4.9	5.3
2:1 Intercrop	7.3	4.3	4.6
$LSD_{0.05}$		0.4	

§ Figures in bracket depict grain increase percent (%) as described in section 6.2.1

There were significant treatment effect at each site ($LSD_{0.05}$=0.3). The average results show that the farmers fields (Ntini and Mukosi), yielded about half of the yields from the research site (CRI). The CRI site had a mean grain yield across the treatments of 3.2 t ha^{-1}, Ntini had 1.5 t ha^{-1} and Mukosi had a mean of 2.0 t ha^{-1} (Table 6.6). Mukosi site had the lowest yield of maize after sole cotton of 0.9 t ha^{-1} and the highest yield of 3.3 t ha^{-1} for 60 kg N ha^{-1} was almost half of CRI for the same treatment. The results show a positive increase in yield of maize for both stover and grain in plots that had cowpea residues. Maize grown after sole cowpea yielded the highest amounts of both grain and stover and showed a grain increase of 100% compared to yield to plots where there were no addition of mineral fertilizers of crop residues. Plots that had sole cotton had lower yields, with Mukosi site recording the largest reduction in yield of -53% while CRI had -39% and Ntini site had the least reduction of -18%.

6.6.7 Effect of interaction of fertilizer and previous crop residues on maize yield

Results show that maize yield (both grain and stover) was high where the quantity of cowpea residues was high. The highest grain yield (6.2 t ha^{-1}) and stover yield (11.7t ha^{-1}) were obtained in plots that had sole cowpea the previous season and received 60 kg N ha^{-1} (Table 6.7a and 6.7b respectively). Maize after sole cotton showed reduced yields under all levels of fertilizer N as compared to the control. The lowest maize grain yield of 1.1 t ha^{-1} was obtained from plots that had sole cotton the previous season (Table 6.7a). Previous cropping and fertilizer interaction were highly significant ($p<0.001$) in yield.

Table 6.7a. Average maize grain yield (t ha^{-1}) as influenced by mineral N fertilizer and N from previous crop(s) residues for the three sites.

Fertilizer-N rate kg N ha^{-1}	**Previous crop**					Mean
	Cotton	Cowpea	1:1 cotton/cowpea	2:1 cotton/cowpea	Control	
0	1.1	3.0	2.8	2.5	1.9	2.3
30	2.5	4.1	3.8	3.5	3.2	3.4
60	3.4	5.8	5.0	4.6	4.3	4.7
Mean	2.3	4.3	3.9	3.5	3.2	
$LSD_{0.05}$			0.3			

Table 6.7b. Average maize stover yield (t ha^{-1}) as influenced by mineral N fertilizer and N from previous crop(s) residues for the three sites.

Fertilizer-N rate kg N ha^{-1}	**Previous crop**					Mean
	Cotton	Cowpea	1:1 cotton/cowpea	2:1 cotton/cowpea	Control	
0	3.7	5.6	6.1	5.4	4.3	5.0
30	6.8	8.0	8.4	7.8	7.3	7.7
60	8.9	11.9	11.6	10.3	9.6	10.5
Mean	6.5	8.5	8.7	7.9	7.1	
$LSD_{0.05}$			0.4			

6.6.8 Soil fertility indicators and grain yield of a successive maize crop

There was a positive relationship between soil qualities (i.e. mineral N, Fig. 6.1 microbial biomass-N, Fig. 6.2 and available P, Fig.6.3) on the yield of a successive maize crop after cotton-cowpea intercrops. Microbial biomass N was closely related to the yield of the following crop (R^2=0.82).

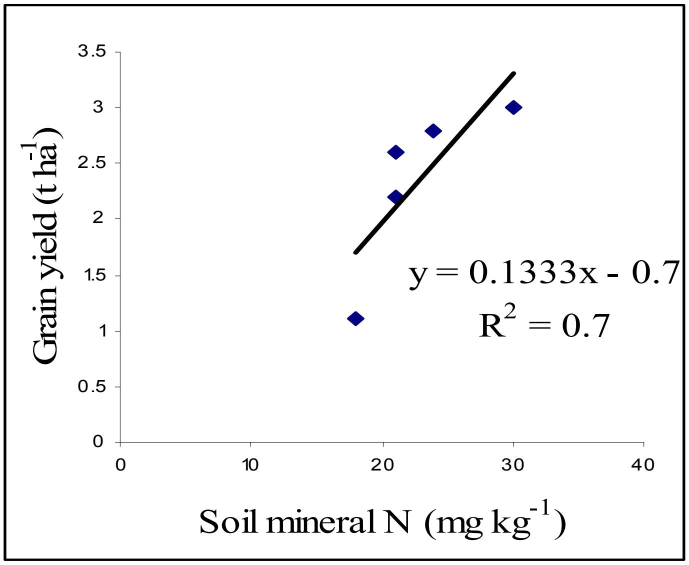


Fig. 6.1. The relationship between soil mineral N after cotton-cowpea cropping systems and grain yield of the following maize crop.

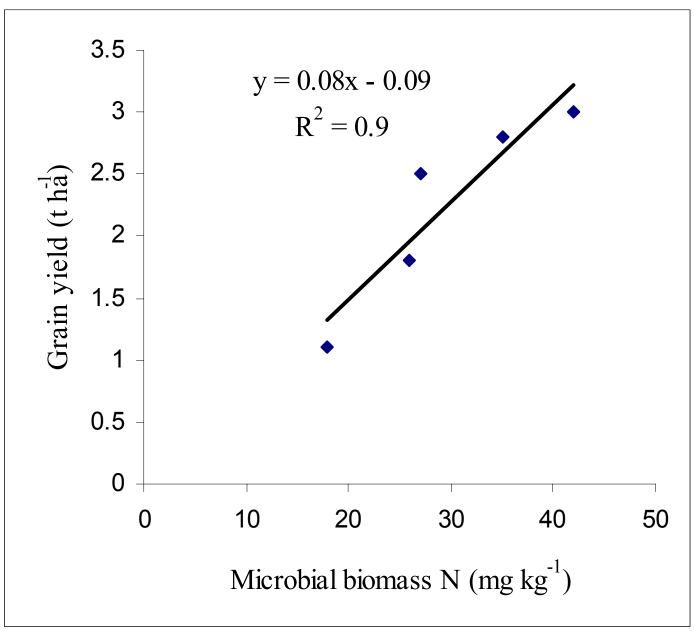


Fig. 6.2. The relationship between microbial biomass- N after cotton-cowpea cropping systems and grain yield of the following maize crop.

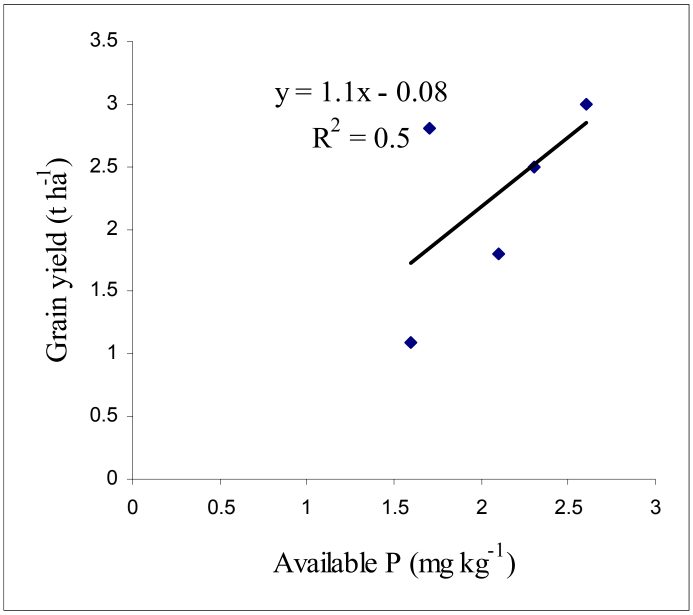


Fig. 6.3. The relationship between plant available P after cotton-cowpea cropping systems and grain yield of the following maize crop.

6.7 Discussion

6.7.2 Effect of cotton-cowpea intercrops on soil nutrient levels

Results showed an increase in soil mineral N and a decrease in plant available P after cotton and cowpea intercrops. The increase in mineral N for most treatments except for sole cotton was a result of the production of readily decomposable crop residues from cowpea. For instance, 78% of cowpea residues were found to decompose within 4 months, with most of the decomposition occurring within the first 4 weeks (Franzleubbers, *et al.,* 1994). The cowpea residues contributed to increase in mineral N levels in the soil especially in simultaneously planted treatments where litter started falling as early as end of January, the peak of the rain season. The lower percentages of lignin and other fibrous materials in annual legumes such as cowpea resulted in faster decomposition rates (Jensen, 1994). The increase in mineral N content of soils under intercropping meant that legume N was far less susceptible to loss from the system than N fertilizer and the ability of the soil to supply plant-available N was greatly improved in the intercrops (Sullivan, 1998). Grain legume crops can provide substantial savings in the amounts of fertilizer N required to optimize cotton lint yields, as well as improve soil quality.

The higher levels of available P found after cotton-cowpea intercrops and sole cowpea than after sole cotton could be explained by the ability of legumes to solubilize P from the soil and make it available to plants. Vanlauwe *et al*. (2000) reported that a greater proportion of legumes are able to improve the bioavailability of sparingly soluble soil P. These findings agree with Oberson *et al*. (2001) who observed that legume-based cropping systems maintained higher organic and available P levels than non- legumes in rotation. Greater turnover of roots and above-ground litter in legume-based cropping systems could provide for steadier organic inputs and therefore higher P cycling and availability. The decrease in the plant available P mainly after the 1:1 cotton-cowpea intercrops could be a result of higher uptake of P required for the higher N_2-fixation which was higher than in sole cowpea. Phosphorus is reported to stimulate root and plant growth, initiate nodule formation, as well as influence the efficiency of the rhizobium-legume symbiosis. It is also involved in energy transfer reactions as it is a constituent of ATP in nitrogenase activity (Israel, 1987).

Previous cropping system had a considerable effect on soil microbial C and N. Cropping system can cause changes in soil C and N cycling rates and accumulation of organic matter (Chen and Stark, 2000). The previous cropping system effects on microbial biomass C were probably related to the changes in soil C cycling rate, accumulation of soil organic matter and differences in the qualities of soil organic matter, factors which are crucial in microbial biomass C formation. The similarity in change between soil microbial biomass C and N due to differences in previous cropping system was mainly due to a relatively stable microbial C/N ratio (ranging from 10 to 15). This therefore meant that there existed a relatively stable C/N ratio in the body of microorganisms under different previous cropping systems. There was also a good relationship between microbial N and mineral N and it is evident that there existed a dynamic balance between microbial N and soil mineral N (Smith and Paul, 1990). It is therefore evident that microbial biomass N might be a potential biological indicator of soil N supplying level.

Particulate organic matter (POM), particularly the POM250 fraction, comprising macro-organic matter and soil litter was found to be highly related to soil biological properties such as microbial biomass and available N especially under sole cowpea or 1:1 intercrops suggesting a key role for this SOM fraction as a substrate and source of nutrients for soil microbial activity. It has been shown to be a sensitive indicator of management effects on soils. There is a decrease in POM-N but an increase in POM-C under sole cotton and 2:1 intercrops giving wider C/N ratios than under sole cowpea and the 1:1 intercrops. The wider C/N ratios for the larger particle size fractions confirms the fact that the POM250 is the main source of plant nutrients. These results concur with those found by Hullugalle and Entwistle, (1996) who found more POM-C in the soil after cotton than after cowpea or a bare fallow. These results concur with the general trend of little response of a decline in POM after legumes because POM changes as a result of changes in crop residue quantity, quality and or a combination of these factors. It has been demonstrated by Vanlauwe *et al.* (1998) that POM-N from legume residues contributed significantly to subsequent crop N uptake.

6.7.2 Yield of maize after cotton-cowpea intercrops

There is evidence of soil fertility improvement in cropping systems that includes legumes such as cowpea as shown by the yield of the succeeding maize crop. This is a good starting point when encouraging farmers to take up cotton-cowpea intercropping. The effect of previous crop was very significant in the yield of the succeeding maize crop. There were differences in yield between the research site (CRI) and farmers' fields (Ntini and Mukosi) which could be explained by losses of legume residues during the dry season and inadequate rainfall (Table 3.1) received for those sites. Livestock was allowed to graze in the farmers' fields during the dry season resulting in losses of the legume residues. The reduction in yield obtained in plots that had sole cotton could be explained by the poor quality cotton residues which caused immobilization of soil available N. Yield from CRI were high for both fertilizer and residual fertility. This could be explained by improved soil fertility at the research station than farmers' fields. Also at CRI, irrigation was used when long dry spells were experienced and this also contributed to higher yields. The increase in yield from plots previously under sole cowpea of more than double that from fallow indicate an obvious incentive for farmers to integrate legumes in their cropping systems.

Benefits of cowpea rotation unrelated to N supply are sometimes evident, such as when the yield of cereal with optimum fertilizer N is less than yield following cowpea (Vanluawe *et al*., 2002). The positive effect of the previous cowpea observed in these trials could have been partly due to the previous cowpea absorbing less soil N than the previous cotton which is referred to as sparing effect (Peoples *et al.,* 1995). Additionally, there was probably additional N fixed and left in the soil (Chapter 5) for the subsequent maize crop. This study however did not evaluate the contribution of below ground N from roots and hence the below-ground N contribution cannot be quantified.

6.7.3 Soil fertility indicators and grain yield of a successive maize crop.

The positive correlation between some of the major soil fertility indicators and yield made it possible to use these as simple indicators of soil productivity assessment. Farmers are always interested in measurements that can be related easily to yields and short term profitability. On the other hand crop response to soil quality might be difficult to separate from yield response to management and climate (Gregorich *et al.*, 1997). The stronger correlation shown between grain yield and microbial biomass N indicates that N is a major limiting factor to productivity for most crops and for most soils. The limit of P was less than that shown by N and hence the correlation coefficient was lower for P than for N.

6.8 Conclusion

Cotton-cowpea intercropping does improve soil fertility status and yield of the succeeding crop as shown by most of the soil quality indicators and yield of maize respectively. The soil fertility (especially N) contribution of cowpea to the soil coupled with the grain yield are enough incentives to encourage farmers to intercrop cotton and cowpea. Phosphorus fertilization is critical for the success of the following crop due to increased uptake of P by the previous legume intercrops. The system reduces the economic risk to the farmer by providing for both food security and income during the intercrop year and at the same time building soil fertility for the next crop.

CHAPTER 7

7.0 CARBON AND NITROGEN MINERALIZATION FROM MIXTURES OF COTTON AND COWPEA RESIDUES AND SOIL PREVIOUSLY UNDER COTTON-COWPEA INTERCROPS.

7.1 Introduction

Organic resources play a dominant role in soil fertility effects on nutrient supply and long-term contribution to SOM formation (Palm *et al.,* 2001). Nutrient release and efficiency of nutrient availability can be improved by controlling the quantity and quality of organic inputs that sometimes help retain added inorganic inputs (Vanlauwe *et al.,* 1995). The amounts of organic and inorganic N constituents in soil can alter rapidly and drastically as a consequence of complex biological and chemical transformation processes such as mineralization, immobilization, denitrification, adsorption and physical transport phenomena such as leaching and volatilization (Hussein, *et al.,* 1996). Nitrogen availability in the soil environment also plays a significant role in determining soil C status, as it is an essential nutrient for microbial metabolism. Nitrogen availability through influence on yield, will also affect quantity and quality of plant residue available as a source of soil C (Kirchmann and Bergquist, 1989).

When crops are grown as intercrops (especially legumes and non-legumes), residues of different crops become mixed so that those residues of different quality decompose simultaneously within the same volume. The mixture of these different crop residues may give products with very diverse chemical characteristics and may result in mineralization patterns which are not readily predicted from the N mineralization of separate components of the mixture (Handayanto et al., 1997). The magnitude of benefit to the next crop from N in previous crop residues will depend on the rate at which the residues decompose and the soil's N mineralization potential. Chemical composition or quality of these crop residues has a major influence on the rates of decomposition and ultimately on N release when added to the soil (Cadisch and Giller, 1997).

The aim of this study was therefore to measure the potential of C and N mineralization from soil previously under cotton-cowpea intercrops and cowpea residues, and also from cotton and cowpea residue mixtures using residue rates obtained from the intercrops. It was hypothesized that residue mixtures that occur under different cotton-cowpea intercrops will reduce the N immobilization capacity of cotton residues, and that the cowpea companion crop improves the soil N mineralization potential and increase mineral N contribution to the succeeding crop.

7.2 Materials and Methods

The study made use of the leaching tube method developed by Stanford and Smith (1972). The experiment was conducted in a constant temperature room at 25°C. Soil were pre-incubated for 5 days after which cowpea residues were added at rates equivalent to dry matter yields obtained under the different intercrops. Thirty grams of soil were used and mixed with an equal amount of acid-washed sand to facilitate drainage. A vial containing 0.1 M NaOH was inserted into the leaching tube above the soil to trap CO_2-C. One of the modifications was to the leaching solution contained 1 mM $CaCl_2$, 1 mM $MgSO_4$, 0.1 mM KH_2PO_4 and 0.9 mM KCl (Cassman and Munns, 1980) instead of KCL.

This leaching solution represented the main cations present in the soil. Tubes were leached stepwise with 150ml of leaching solution in 50 ml aliquots per every leaching day. Tubes were leached on days; 0, 7, 21, 28, 42 and 56, and leachate was collected in conical flasks and analyzed for NO_3^- and NH_4^+. After every leaching, tubes were brought back to 70% of water holding capacity. Tubes were opened every third day to allow for aeration (Stanford and Smith 1972).The rates of residue application were entirely based on the results of dry matter yield obtained from the different intercrop treatments and sole crops. The assumption was that cotton leaves contributed 25% of TDM and that leaves will not be burned but the stalk which contributed 75%. The study was split into two experiments, one for residue mixtures and the other for soil. The treatments are as follows:

Experiment 1

1. 2.25 t ha^{-1} Cotton (100% cotton)
2. 3.5 t ha^{-1} Cowpea (100% cowpea)
3. 1.25 t ha^{-1} Cotton : 2.5 t ha^{-1} Cowpea (30 Ct : 70 Cp)
4. 1.5 t ha^{-1} Cotton : 1.5 t ha^{-1} Cowpea (50 Ct : 50 Cp)
5. 3.0 t ha^{-1} Cotton: 1.5 t ha^{-1} Cowpea (70 Ct : 30 Cp)
6. Soil only (control)

Experiment 2

This experiment was for measuring the C and N mineralization potential of soil previously under different cotton/cowpea intercrops and sole crops.

1. Soil from sole cotton
2. Soil from sole cowpea
3. Soil from 1:1 simultaneous
4. Soil from 1:1 relay
5. Soil from 2:1 simultaneous
6. Soil from 2:1 relay

Thirty (30) grams of soil was used and each of these was replicated 3 times. Rates of residues application were based on the dry matter yield for both crops obtained from the different intercrop treatments. The differences in C and N mineralization attributed to treatment effect were analyzed using the analysis of variance (ANOVA) procedure of Genstat 8.0 statistical package. The least significance difference (95 %) was used to compare means of the different treatments.

7.2.1 Soil analysis

Soil used for incubation was analyzed for pH (Section 3.3), total C (Section 3.4), Total N (Section 3.5), total P (Section 3.7) and texture (Section 3.10).

7.2.2 Leachate analysis

The leachate collected from the leaching tubes was analyzed for ammonium and nitrate concentration (Section 3.6).

7.2.3 Carbon mineralization measurement

The amount of C mineralized was determined by the rate of CO_2 evolved. The methodology involved the trapping of carbon dioxide in a strong base and back titrating the strong base remaining with a strong acid. Periodic replacement of the absorbing base and subsequent determination of carbon dioxide permits the investigator to follow decomposition during a timed sequence.

$$CO_2 + H_2 \rightarrow H_2CO_3$$
$$H_2CO_3 + NaOH \rightarrow NaHCO_3 + H_2O$$
$$NaHCO_3 + NaOH \rightarrow Na_2CO_3 + H_2O$$
$$Na_2CO_3 + BaCl_2 \rightarrow BaCO_3 + 2NaCl$$
$$\text{Re}maining\ NaOH + HCl \rightarrow NaCl + H_2O$$

A test tube containing 10 ml of 0.5 M NaOH was placed into each container sealed and incubated. The vials were to be replaced with new vials of NaOH in a week cycle. Carbon dioxide absorbed was determined by the acid / base titration. Contents of capture tube (vials) were poured into an Erlenmeyer flask. The tube was rinsed with exactly 10 ml of water and added to flask to make a total volume of 20 ml. $BaCl_2$ (5 ml) was added to precipitate CO_3^{2-}. Phenolphthalein indicator (1-2 drops) are added which changes from red to clear. Titration was carried out using 0.5 M HCl.

7.3 Results

7.3.1 Soil and crop residue characterization

The soil used for the incubation had a near neutral pH of 6.5 and had high C and N contents of 3.2 % and 0.3 % respectively giving a C/N ratio of 11 (Table 7.3a). The low N content of cotton residues (1.3 %) resulted in wider C:N ratio of 34 in cotton residues compared to cowpea residues with a ratio of 17. The C content for cotton and cowpea were not significantly different so N content variation was the only factor determining C:N ratio (Table 7.3b)

Table 7.3a. Physical and chemical characteristics of the soil used for the leaching experiment.

pH	C%	N%	P%	C/N ratio	Clay %	Silt %	Sand %	Soil type
6.5	3.2	0.30	0.18	11	37	21	42	Clay loam

Table 7.3b. Initial characterization of cowpea and cotton crop residues and mixtures used for the leaching tube experiments.

Residue	C%	N%	P%	C/N ratio
Cowpea	43	2.5	0.75	17
Cotton	44	1.3	0.21	34
Mixture (30:70)	43	2.1	0.62	20
Mixture (50:50)	42	2.0	0.45	21
Mixture (70:30)	44	1.6	0.32	28

7.3.2 Nitrogen and C mineralization of cotton and cowpea residue mixtures

The amount of N released was directly proportional to the amount of cowpea residues in the mixture. Cowpea residues (0:100) yielded the highest amount of mineral N of 36 mg kg^{-1} soil while cotton residues (100:0) recorded the least amount of 19 mg kg^{-1} soil while the other mixtures were in between (Table 7.3a). The results show that cowpea residues reduced the decomposition rate during the early stages of the process as shown by the shapes of graphs (Fig. 7.3a) and C evolution. All the other treatments except sole cowpea residues (0:100) and the 30:70 mixture showed immobilization of soil N during the first two weeks of incubation (Figure 7.3b). The 50:50 treatment immobilized soil N on day 3 only and after that it was net mineralization. The amount of cotton residues in the mixture reduced the rate of release of N from the residues.

For C mineralization the trend was reversed and cotton residues (100:0) released the highest amount of 5 g C kg^{-1} soil while the cowpea residues (0:100) recorded the least of 3 g C kg^{-1} soil. The C mineralization rate was directly proportional to the proportion of cotton residues in the mixtures. Sole cotton residues (100:0) and 70:30 treatments' mineralization pattern was exponential and was well described by the equation, $C = C_E(1 - e^{-kt})$ where C_E is exponentially mineralizable C fraction, k is the rate constant and t is time in days (Table 7.3b). The other treatments i.e. sole cowpea residues (0:100), 30:70, and 50:50 mineralization patterns were sigmoidal and were well described by the equation, $C = \frac{C_S}{1 + e^{-\left(\frac{t - t_0}{k}\right)}}$ where C_S is sigmoidally mineralizable C fraction, t_0 is time in days required for complete mineralization of C_S while k is rate constant (Table 7.3b). The course of C evolution changed from exponential rise to sigmoidal with increase in the proportion of cowpea residues.

7.3.3 Carbon and N mineralization potential of soil previously under cotton/cowpea intercrops

The amount of N released from soil previously under cotton/cowpea intercrops and sole crops was approximately a third of the amount released when the residues were incorporated. The highest amount of N released (12 mg kg^{-1} soil) was from soil previously under sole cowpea while soil from the 1:1 cotton/cowpea intercrop released 10 mg kg^{-1} soil, and soil from sole cotton released 6 mg kg^{-1} soil (Table 7.3a). Cotton reduced the potential N mineralization capacity of soils.

The C mineralization pattern of the soil was not significantly different ($LSD_{0.05}$) from each other for all the treatments. The highest amount of C released was 1.2 g kg^{-1} soil for soil previously under sole cotton and the lowest was 1.1 g kg^{-1} soil for soil previously under sole cowpea, and 1:1 simultaneous cotton/cowpea (Table 7.3a).

Table 7.3c. Total net C and N released from crop residue mixtures and soil previously under cotton/cowpea intercrops after 10 weeks of incubation.

Treatment	Net N mineralized (mg kg^{-1} soil)	Net CO_2-C released (g kg^{-1} soil)
Cotton residues (100:0)	19.2	4.9
Cowpea residues (0:100)	36.4	3.0
50:50	27.1	3.5
70:30	21.6	4.3
30:70	33.4	3.3
Soil (cotton)	5.9	1.2
Soil (cowpea)	12.2	1.1
Soil (1:1 simultaneous)	9.9	1.1
Soil (1:1 relay)	8.4	1.2
Soil (2:1 simultaneous)	7.5	1.2
Soil (2:1 relay)	6.7	1.2
Mean	17.1	2.4
$LSD_{0.05}$	2.4	0.2

* The ratios given are for Cotton: Cowpea residues

Table 7.3d. Parameter values and coefficient of determination for cotton and cowpea residue mixtures after 10 weeks of incubation in soil.

Treatment	Course of C evolution	C_E (g kg^{-1})	C_S (g kg^{-1})	k (day^{-1})	T_0 (Days)	R^2
Cotton (100:0)	Exponential	5.1	-	0.1		0.99
Cowpea (0:100)	Sigmoidal	-	3.1	9.3	31.5	1.0
50:50	Sigmoidal	-	3.6	9.0	26.7	0.99
70:30	Exponential	4.4	-	0.1		0.99
30:70	Sigmoidal	-	3.4	8.5	26.5	0.99

- C_E is exponentially mineralizable C fraction, C_S sigmoidally mineralizable C fraction and T_0 is time required for complete mineralization of sigmoidally mineralizable C fraction.

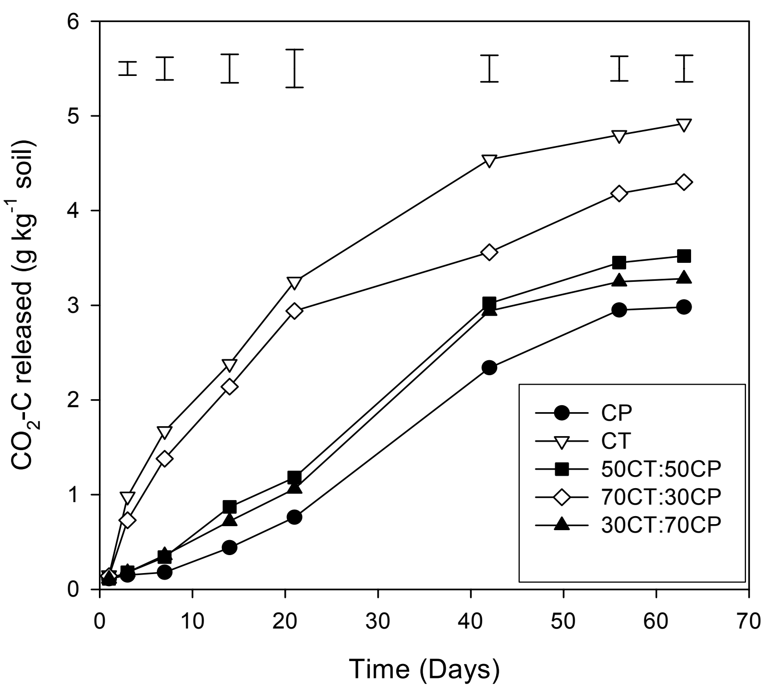


Figure 7.3a. Carbon mineralization as affected by the proportion of cotton and cowpea in the residues mixtures.

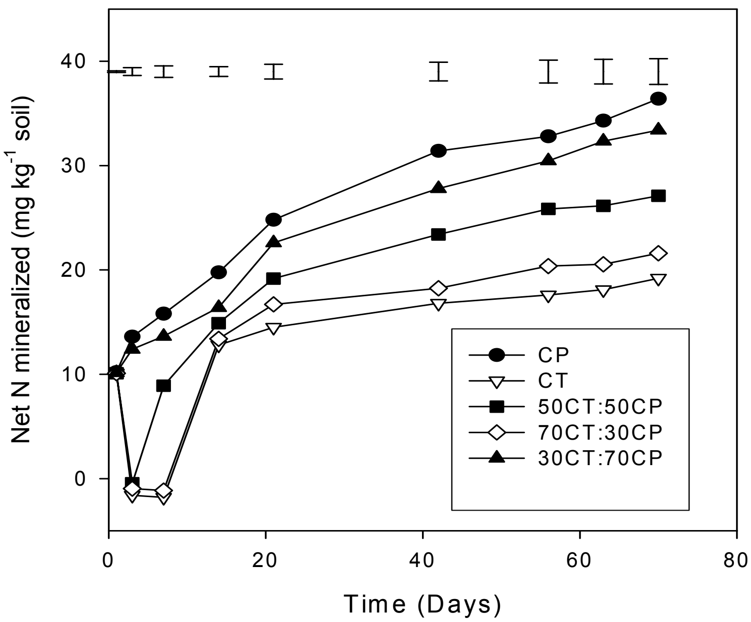


Figure 7.3b. Net cumulative N mineralized as affected by the proportion of cotton and cowpea in the residue mixtures.

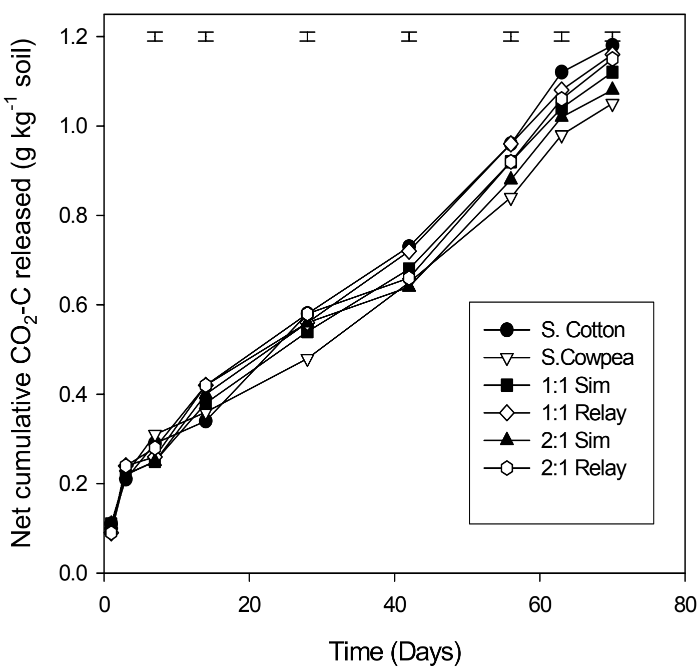
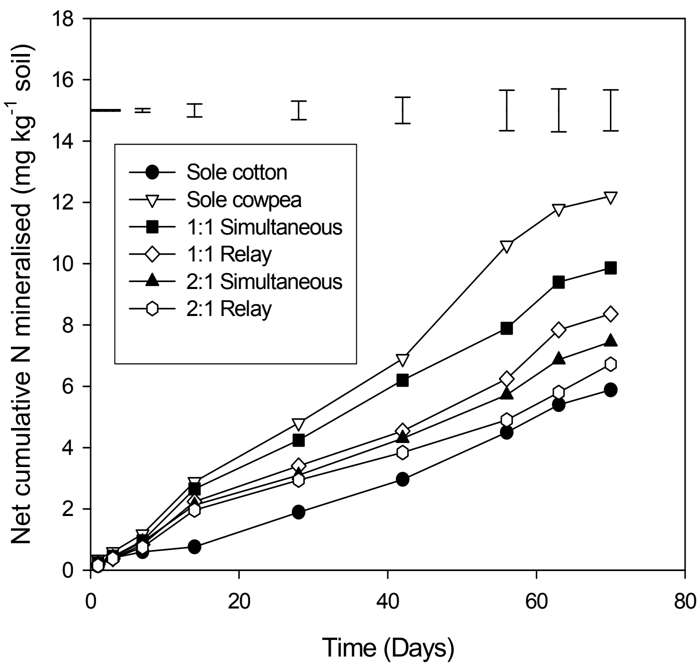


Figure 7.3c. The C mineralization potential of soil previously under cotton/ cowpea intercrops and sole crops.



1Fig. 7.3d. The N mineralization potential of soil previously under cotton/ cowpea intercrops and sole crops.

7.3.3 Effect of C: N ratio on total N mineralized

The amount of N mineralized after 10 weeks of incubation of the plant mixtures was linearly related to their C: N ratio (Fig. 7.3e). From this study, the critical C:N ratio at which neither net mineralization nor immobilization occurred after 10 weeks of incubation, determined from the derived linear equation was 52. However this is not to say that this should be the ultimate aim but rather to achieve ratios that are below this value.

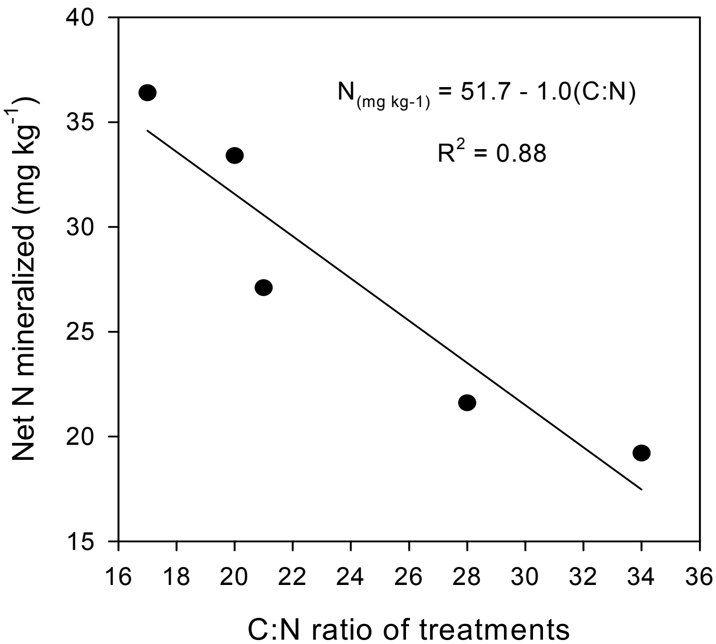


Fig. 7.3e. The relationship between total amount of N mineralized from mixtures of cowpea and cotton residues and their C:N ratio. Symbols are measured data points, lines represent linear regression equations.

7.4 Discussion

Large differences were found in the chemical composition and the decomposition pattern of cowpea, cotton and crop residue mixtures. The C:N ratio played a critical role in the N release in soil during decomposition of the added crop residues. Higher available C content in the added material was found to be leading the N immobilization in relation to unamended soil during the early phase of decomposition. The amount of N mineralized appeared to be dependent on the type of substrate (the proportion of cotton to cowpea residues in the mixtures), particularly it's C: N ratio. The decrease in the rate of N mineralization with increasing proportion of cotton residues in the mixtures indicated that N mineralization of residues could ontrolled by mixing different quality materials but again at the expense of reducing the total amount of N released especially in the short-term. Legumes have generally been characterized as high quality residues because of their high N, low lignin and or polyphenol contents (Frankenberger and Abdelmagid, 1985). Legumes are able to provide more mineral N in the short term than residues of other crops because chemical composition has a major influence on the rates of decomposition and N release (Cadisch and Giller, 1997).

The reduction in the C mineralization rate with increase in cowpea residues in the mixtures could be explained by reduction in competition among microorganisms for soil N because cowpea residues had a narrow C:N ratio as compared to cotton residues. Consequently, the wide C:N ratios of residues mixtures which had a larger proportion of cotton residues meant that the system had less available N leading to higher degradation of cotton residues by microbes. Zingore *et al*. (2003) reports that the reduction in release of C from mixtures could be a result of the interaction due to the influence of more reactive polyphenols from lower quality materials. Soluble polyphenols slow the mineralization of residue N by forming complexes with proteins, thus making them inaccessible to the microorganisms (Mafongoya *et al.,* 1998). The low N concentration in cotton residues may also limit microbial biomass build-up. Nitrogen availability may control the kinetics of decomposition of crop residues, particularly those with high C:N ratio such as cereals, when the N requirements of the soil decomposers are not fulfilled by the residue or soil contents (Recous *et al.,* 1995). Under these conditions the biochemical quality of the residue no longer control the dynamics of C and the associated

N dynamics, and residues containing various amounts of N will no longer be comparable, whatever the nature of their constituents.

The natural mixture of crop residues that happened when cotton and cowpea crops were grown together resulted in a reduction in the mineralization of N from cowpea residues and the cotton residues could contribute to the maintenance of soil organic matter and hence the increase in the residual benefits in subsequent cropping seasons. The mixture can help synchronize nutrient release and crop uptake and thus reduce N losses and increase N-use efficiency (McGill and Myers, 1987). The leaching procedure used in this study allowed the movement of soluble polyphenols from cotton residues so that they were able to bind proteins from the cowpea residues and thus influence N mineralization (Handayanto *et al*., 1997). Nitrogen mineralization rates of crop residues were linearly related to their N concentration and C:N ratio, with all treatments showing net N mineralization after 10 weeks incubation agreeing with the findings of Franzluebbers *et l.* (1994) who observed a similar trend for materials with a C:N ratio of less than 39. The N added by the residues constituted most of the N available for decomposition, so it is apparent that a significant relationship existed between decomposition rates and the C:N ratio of the residues (Trinsoutrot, *et al.,* 2000). This relationship or the obtained equation can allow for a quick estimate of the amount of N that will mineralize from incorporated crop residues of known C:N ratio.

The reaction kinetics for the mixtures confirmed that mixtures produced different trends which were mostly unpredictable as reported by Handayanto *et al.* (1997). The intention of the mixture was to increase the N release from cotton residues by mixing them with cowpea residues to improve on synchrony between N release and uptake by the crop. Cotton residues followed exponential decomposition pattern while cowpea followed sigmoidal pattern. This meant that the rate of C release was higher for cotton residues than for cowpea mainly because of differences in C:N ratios. It has been shown that the decomposition of crop residues can be affected by the availability of N since C:N ratio of decomposers is far much lower than the C:N ratio of many crop residues (Recous *et al.,* 1995). In the short term, soil inorganic N availability controls the kinetics of C decomposition (Corbeels *et al.,* 2000).

The C mineralization patterns of soil previously under cotton-cowpea intercrops and sole crops were similar and the net C released was not significantly different from each other. This could be a result of the short time frame for the build-up of organic C to be significantly different for the different cropping treatments since the experiment had been run for 2 years or seasons.

The N minerization potential of the soil was significantly affected by the previous cropping system. The N mineralization potential increased with increase in amount and or proportion of cowpea residues in the previous cropping system mainly because of the N content in cowpea residues compared to cotton. Haynes (1986) reported that in most cases net N release occurs if the N content of the residue is greater than 2% and values below that usually cause immobilization especially in the short term. Janzen (1987) using long-term rotations reported that the highest potential to mineralize N was from cropping systems that had the highest plant inputs. The extent to which cropping history influences soil mineralizable N is a function of both soil mineralizable N and the size and activity of the soil biomass. From this study, the residues had an effect on the final C:N ratio with cowpea narrowing whereas cotton residues widened the ratio. It could also be a result of the positive N balance of the cotton-cowpea intercrop treatments (Chapter 5) that lead to higher N mineralization potential from plots that had cowpea.

7.5 Conclusion

This study demonstrated that in intercrops, plant residues of different quality mix naturally and this has an effect on the rate of N release and N uptake by the succeeding crops. Adding cowpea residues to cotton residues improved the total N released but reduced the amount of C released. The patterns of decomposition were also diverse and highly unpredictable. The decomposition and the effects of cotton and cowpea residue mixtures have on soil fertility is a function of the different properties of the residues. In the intercrop system cotton residues can be used to control the N release from cowpea residues and hence control N losses that might occur. The poor quality of cotton residues means that during the early stages of the season, mineral N should be added in higher amounts to cover for periods of immobilization. A mixture or diversity of residues in the cropping system is most desirable and will possibly lead to a slow steady increase in OM levels.

CHAPTER 8

8.0 GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

8.1 Intercrops productivity and efficiency

Water conservation measured as soil moisture at harvest was higher in the simultaneous intercrops, and in the cowpea sole crop than in the relay intercrops and in the cotton pure stands. These results indicated that delaying the time of planting cowpea in the intercrop caused greater loss of water through evaporation from the soil surface due to the wider space between cotton rows and this is mainly due to slow growth of cotton especially during the first 8 weeks after planting. These conditions resulted in lower ground cover which in turn resulted in lower radiation interception and higher soil evaporation (Soetedjo *et al.,* 1997). Soil moisture conservation by intercrops is beneficial to cotton; a long season crop that continues to grow after cowpea had reached senescence. This is particularly important in the semi-arid regions were cotton is grown. Cowpea is highly competitive as shown by grain yield in sole crop compared to intercrop particularly for the 1:1 simultaneous treatment, the plant population was reduced by half in the intercrop but the yield only recorded a 20-30% decline. From the economic point of view, the 2:1 relay intercrop is recommended because cotton lint yield is slightly reduced and there is also a better grain yield from cowpea.

This study has shown that intercropping has biological advantages over the growing of pure cultures or monocropping. However, in real life, usually it is not biological but economic advantage which decides what farming and cropping systems are actually adopted. Since mixed cropping often involves staggered plantings (relay intercropping) and selective harvesting it tends to be labour intensive and labour needs can be spread over a long period of time. Where there is rural unemployment, where capital is in short supply and where production must be sustainable without expensive inputs and pollution control, intercropping is a possible solution.

On the average, intercropping increased the LER by 20% over sole crops using the economic yield although considerable variation occurred across the treatments. These LERs were however lower than those reported by Reddy *et al. (*1994) under similar conditions. The relay planted intercrop especially the 1:1 intercrop was more productive in terms of both grain and lint yield than the simultaneous intercrop and sole crops indicating the significant yield advantage of this intercrop treatment over the other treatments. When planting of cowpea was delayed, there was increased seed cotton yield but there was no significant effect on cowpea yield. Yield advantages of this magnitude occur when component crops complement each other in utilizing the growth resources such as light, water and nutrients as reported by Fukai and Trenbath (1993). The implications are that in areas of land shortages, small pieces of land can be made more productive and sustain livelihoods.

As has been shown by results in this study, for intercropping to be biologically advantageous, the mixture components need to be chosen with great care. Unfortunately, the interactions among the crops are so subtle and specific to particular locations that present knowledge only provides a rough guide as to what new combinations of crops and or varieties should be tried. If then the possible advantages of mixed cropping are to be exploited, further on-farm experimentation will be needed, using a range of possible components and a series of seasons instead of one or two.

8.2 Biological nitrogen fixation in intercrops

Results show that cowpea reliance on BNF increases in intercrop as compared to sole crop mainly as a result of competition with the companion cotton for uptake of soil N. Though there is increased BNF in intercrop, the amount fixed per unit area is much lower due to low cowpea plant population. In areas of intensive agriculture, the role of N_2 fixation appear increasingly limited but opportunities to reduce fertilizer N inputs substantially without loss of production do exist as reported by Peterson and Russelle (1991). The BNF estimates mentioned in this study are solely based on above-ground shoot material. These have been shown to underestimate BNF by 18-25% when including fixed N in stubble and roots (Hogh-Jensen and Kristensen, 1995). The % of BNF does increase in intercrops compared to sole cowpea and the ^{15}N dilution method for measuring BNF proved to be a reliable and efficient method because it gave values in ranges reported by previous studies.

Interspecific competition in intercrops between legumes and non-legumes helps increase the N_2 fixation capacity of legumes and crop mixtures are recommended in this regard to improve the efficiency of BNF. It is often generally assumed that the ability to fix atmospheric N will reduce the legume's competitive strength towards the non-fixing component in the intercropping system (Vandermeer, 1989). This assumption however is only one-sided because it focuses on N only without paying attention to other critical nutrients required for BNF such as P and K as well as water. The study of P and K dynamics in intercropping systems that involves legumes and non-legumes is therefore important in order to fully understand nutrient dynamics and competition in intercrops.

It must be noted that N transfer in intercrops does occur but it is limited especially when the rows are wide apart but this also helps to reduce competition. To increase N transfer in intercrops, the component crops have to be closer to each other to improve interaction but this reduces the final economic yield due to increased interspecific competition. Nitrogen transfer is of little significance to the nutrition of the companion cotton crop and as such N management of intercrops should not consider N transfer for substantial contribution. In cropping systems like the one reported here where cotton had a longer growing season and cowpea had a shorter season, transfer may be maximized by incorporating cowpea residues after senescence to speed up decomposition and N release.

8.3 Residual fertility and yield of rotational crops

All intercrops and sole crops had lower Ca, Mg, K and higher CEC levels in comparison to the uncropped fallow. The available P level was lower after sole cotton but higher after sole cowpea and intercrop treatments, perhaps the result of solubilization of P in the rhizosphere of cowpea plants (Gardner *et al.,* 1981). In areas where soil fertility decline is a major threat to sustainable crop production, the incorporation of legumes such as cowpea will help raise soil nutrient levels. Cowpea residues of the crop grown in intercrop have the capacity to substantially raise the yield of successive crops on the same piece of land that cotton had been grown. The intercrops were more advantageous than sole crops because the strategy improved the intensity of production in a sustainable way.

The results presented for 2005 were used to show the rotational effect of cotton-cowpea intercropping to subsequent maize grain yield and soil fertility parameters. The increase in maize grain yields following cotton-cowpea intercrops than cotton was a result of plant-available N from decomposing plant residues with improved quality. Literature reports that N is a key factor in the response of cereals following legumes compared with cereals following non-legumes. The decomposition of legume residues during the season preceding the sowing of cereal may explain differences in the relative contribution of fixed-N to the N economies of intercropped and rotational systems (Peoples and Herridge, 1990). This could also be a result of N-sparing effects of the legumes planted in the previous season, thus cereals cropped in sequence with legumes derive N benefits compared with cereal monoculture. On the other hand the decline in yield following cotton and a bare fallow could be a result of soil fertility depletion and deterioration of soil physical properties.

Although yields of a subsequent maize crop were higher following cowpea and cotton intercrops, a result which was attributed mainly to N effects, mineral fertilizer inputs (Ca, Mg, P and K) are still required to prevent nutrient mining of soils. Residual benefits even for N are seldom sufficient under intensive sustainable crop production hence inorganic or organic fertilizer amendments are still important.

8.4 Conclusion

The study showed the importance of including cowpea in cotton cropping system in maintaining or improving soil fertility. All the cotton-cowpea intercrop treatments were more productivity and efficient as compared to the sole crops. Delaying planting of cowpea led to increased cotton yield but with no effect on cowpea grain yield in the intercrops. The cowpea component in cotton-cowpea intercropping had a great potential of supplying inorganic soil N as evidenced by increased grain yields and short-term soil fertility indicators after intercrops as compared to sole cotton. Given the foregoing, I would recommend the 2:1 relay intercrop as it does not disturb much the important cash crop, cotton. Maize grain yields following sole cowpea and intercrops were substantially higher than following sole cotton and uncropped fallow Mixing cowpea residues and senesced cotton leaves on the basis of the amounts (dry matter) produced in intercrops did reduce the N immobilization tendency of cotton residues. Intercrop treatment effects on soil nutrient status were positive as shown by the increase in mineral N, microbial biomass N and C, POM-N and C, CEC and plant-available P. The decomposition patterns of crop residue mixtures naturally obtaining in a cotton-cowpea intercrop system all points to the increased sustainability of the system. The % of BNF does increase in intercrops compared to sole cowpea and the ^{15}N dilution method for measuring BNF proved to be a reliable and efficient method because it gave values in ranges reported by previous studies.

8.5 Future Research Needs

Cotton-cowpea intercropping is not a common practice in sub Saharan Africa and as such smallholder farmers who are supposed to benefit are not aware of the benefits associated. It is necessary therefore to devise ways of involving more farmers (participatory) in validating this strategy. A number of question still remain unanswered though assumptions have been put forward about cotton-cowpea intercrops. One of these has been the issue of cotton pesticides effects on humans and animals especially after consumption of grain and leaves. Although most cotton pesticides are synthetic pyrethroids which are relatively safe to humans an exhaustive study to find out the true effects is still desirable (Myaka and Kabissa, 1996). Cowpea residues have been shown to improve the N release from cotton residues, it is also very important to find out how these residues interact with added mineral fertilizer.

The study was carried out within a relatively short time-frame, therefore future research should focus on lengthening the period and including more crops that can be intercropped with cotton. Improved adoption of this system will mean increased cowpea grain output and given that the cowpea market is underdeveloped there is need to carry out a market research and development to see how farmers respond to the dictates of the market.

9.0 REFERENCES

Adu-Gyamfi, J.J., Katayama, K., Devi, G., Rao, T.P. and Ito, O. (1996). Improvement of soil and fertilizer N use efficiency in sorghum/pigeon pea intercropping.493-506. In Dynamics of roots and nitrogen in cropping systems of the semi-arid tropics. Ito, O., Johansen, C., Adu-Gyamfi, J.J., Katayama, K., Kumar Rao, J.V.D.K., and Rego, T.J. (Eds). Ibarki 305, Japan: Japan International Research Centre for Agricultural Sciences (JIRCAS).

Alteri, M.A. (1993). Crop protection strategies for subsistence farmers. Westview studies in insect biology. Boulder, Westview Press. 197 pp.

Anderson, J. M and Ingram, J. S. I. (Eds.) (1993). Tropical soil biology and fertility: A hand book of methods. CAB International.

Ashagrie , Y., Zech, W and Guggengerger, G. (2004). Soil aggregation, and total and particulate organic matter as affected by continuous cultivation in Ethiopia.

Asquith, T. N and Butler L. G. (1986). Interactions of Condensed Tannins with Selected Proteins, Phytochemistry 25*:*1591-1593.

Azam, F and Farooq, S. (2003). An Appraisal of Methods for Measuring Symbiotic Nitrogen Fixation in Legumes. Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad, Pakistan

Azam, F. (2002). Added nitrogen interaction-its occurrence, mechanism and implications to fate of N in the soil-plant system. Pak. J. Agron 1:54-59.

Azam, F. (2001). Legume-bacterium (*Rhizobium*) association-symbiosis, a marriage of convenience, necessary evil OR bacterium taken hostage by the legume. Pak. J. Biol. Sci.4:757-761.

Babu, R., Rao, M.V.H and Muralikrishna. (1995). Cotton based multiple cropping systems for sustained yield. Indian Journal of Agricultural Sciences 66:10:577-80.

Ball, S. T. (1998). Cotton crop monitoring. NMSU and USDA, USA.

Bationo, A., Ntare B.R., Tarawali, S.A and Tabo, R. (2002). Soil fertility management and cowpea production in the semiarid tropics. In C.A. Fatokun, S.A. Tarawali, B.B. Singh, P.M. Kormawa, and M. Tamò (Eds.) Challenges and Opportunities for Enhancing Sustainable Cowpea Production. International Institute of Tropical Agriculture, Ibadan, Nigeria

Bezerra Neto, F and Robichaux R. H. (1997). Spatial arrangement and density effects on annual cotton/cowpea/maize intercrop. Pesq. Agropec. 32: 10:1029-1037.

Bergersen, F.J. (1988). Measurements of biological dinitrogen fixation. In Biotechnology of Nitrogen Fixation in the Tropics, edited by Z.H. Shamsuddin, W. M. W. Othman, M. Marziah, and J. Sundram. University of Pertanian Malaysia.

Biederbeck, V.O and Bouman, O.T. (1994). Water use by annual green manure legumes in dryland cropping systems. Agronomy Journal 86:3: 543-549.

Black, C.A. (1965). Methods of Soil Analysis: Part I Physical and mineralogical properties. American Society of Agronomy, Madison, Wisconsin, USA.

Blair, J.M., Parmelee, R.W and Beare, M.H. (1990) Decay rates, nitrogen fluxes and decomposer communities in single and mixed-species foliar litter. Ecology 71: 1976-1985.

Boddey, R.M., Alves, B.J and Urquiaga, S. (1997). The contribution of biological nitrogen fixation for sustainable agriculture systems in the tropics. Soil Biology and Biochemistry 29:787-799.

Boquet, D.J., Breitenbeck, G.A., Coco, A.B. and Aguillard, W. (1991). Fertilizer nitrogen rates to optimize cotton yield and fiber quality. Louisiana Agric. 35:10-11.

Brady, N. C. (1990). The Nature and Property of Soils, 10th Ed. MacMillan Publishing Company New York.

Bremner, J. M and Mulvaney, C. S. (1982). Nitrogen-total. In: A. L. Page, et al. (Ed.) Methods of soil analysis: Part 2. Chemical and microbiological properties. ASA Monograph Number 9: 595-624 .Madison, Winconsin

Bremner, J.M. (1965) Nitrogen availability indexes In: Black, C.A. (ed.), Methods of Soil Analysis Part 2. Chemical and Microbiological Properties. ASA Monograph 10:1324-1345. Madison, Winconsin.

Brophy, L. S., Heichel, G.H and Russelle, M. P. (1987). Nitrogen transfer from forage legumes to grass in a systematic planting design. Crop Sci. 27: 753-758.

Broadbent, F.E., Nakashima, T and Chang, G.Y. (1982). Estimation of nitrogen fixation by isotope dilution in field and greenhouse experiments. Agron. J. 74: 625-628.

Cadisch, G and Giller, K.E. (Eds.) (1997). Driven by Nature: Plant Residue Quality and Decomposition. CAB International, Wallingford, UK, 409pp.

Carsky, R.J. (2000). Potential of herbaceous legume cover crop fallow systems in the savanna zone. In C. Floret and R. Pontanier (Eds.) La Jachère en Afrique tropicale. Proceedings of the International Seminar, April, Dakar, John Libbey Eurotext, Paris. 594–602.

Cassman, K.G and Munns, D.N. (1980). Nitrogen mineralization as affected by soil moisture, temperature, and depth. Soil Sci. Soc. America Journal 44:233-1237.

Central Statistics Office. (2004). Agricultural production on small scale farms. CSO, Harare, Zimbabwe. 125pp.

Chalk, P.M and Ladha, J.K. (1999). Estimation of legume symbiotic dependence: an evaluation of techniques based on ^{15}N dilution. Soil Biology and Biochemistry 31:1901–1917

Chalk, P.M. (1998). Dynamics of biologically fixed N in legume-cereal rotations: a review. Aust. J. Agric. Res 49:303-316

Chen, J and Stark, J. M. (2000). Plant species effects and carbon and nitrogen cycling in a sagebrush-crested wheatgrass soil. Soil Biology and Biochemistry 32:47–57.

Chen, D.L., Freney, J.R., Mosier, A.R and Chalk, P.M. (1994). Reducing denitrification loss with nitrification inhibitors following presowing applications of urea to cotton field. Aust. J. Exp Agric 34:75-83.

Christensen, B. T. (1992). Physical fractionation of soil and organic matter in primary particle size and density separates. Advances in Soil Science 20: 1-90

Corbeels, M., G. Hofman and Van Cleemput, O. (2000). Nitrogen cycling associated with the decomposition of sunflower stalks and wheat straw in a vertisol. Plant and Soil Journal 218:71–82.

Cornforth, I.S and Davis, J.B. (1968). Nitrogen Transformations in Tropical Soils; I. The Mineralization of Nitrogen - Rich Organic Materials added to Soil. Trop. Agriculture Journal 45:3: 211-221.

Cotton Research Institute Annual Report 1993/4. (1996). Department of Research and Specialist Services, Harare Zimbabwe.

Cotton Training Center. (2000). Zimbabwe Cotton Handbook. Kadoma, Zimbabwe.

Dalal, R.C. (1974). Effects of intercropping maize with pigeon peas on grain yield and nutrient uptake. Environmental Agriculture 10:219-224.

Dakora, F.D and Keya, S.O. (1997). Contribution of legume nitrogen fixation to. sustainable agriculture in Sub-Saharan Africa. Soil Biol. Biochem. 29:809-817

Dakora, F.D., Atkins, C.A and Pate, J.S. (1992). Effect of NO on N fixation and nitrogenous solutes of xylem in two nodulated West African geocarpic legumes, Kersting's bean (*Macrotyloma geocarpum* L.) and Bambara groundnut (*Vigna subterranea* L.). Plant and Soil Journal 140:255-262.

Danso, S.K.A., Hardarson, G and Zapata F. (1993). Misconceptions and practical problems in the use of N soil enrichment techniques for estimating N fixation. Plant and Soil 152: 25-52.

De Beltrao, N.E.M., Da Nobrega, L. B., Azecedo, D.M.P., De Veiera, D.J and Crisostomo, J.R. (1986). Intercropping of upland cotton with cowpea cultivars. Respuisa Agropec. Bras..21:3:271-284.

Doughton, J. A., Saffigna, P.G., Vallis, I and Mayer, R. J. (1995). Nitrogen fixation in chickpea II. Comparison of 15N enrichment and 15N natural abundance methods for estimating nitrogen fixation. Australian Journal of Agricultural Research, 46:225-236

Endondo, C and Samatana, M. (1999). Influence of cowpea sowing date on cotton yield in cotton/ cowpea intercropping sequence. Cahiers Agricultures 8: 215-7.

Frankenberger, W.T and Abdelmagid, H.M. (1985). Kinetic parameters of nitrogen mineralization rates of leguminous crop incorporated into soil. Plant and Soil Journal 87:257-271

Franzluebbers, K., Weaver, R.W and Juo, A.S.R. (1994). Mineralization of labeled N from cowpea (*Vigna unguiculata* [L.] Walp.) plant parts at two growth stages in sandy soil. Plant and Soil Journal 160: 259–266.

Freebairn, D.M., Hulugalle, N.R., Tullberg, J and Connolly, R.D. (1998). Greenhouse gas emission from cropping - the role of alternative tillage systems on clay soils. paper presented at symposium on "Conservation Tillage: Can it Assist in Mitigating the Greenhouse Gas Problem?", 30 April 1998, University of Queensland, St. Lucia, Qld.

Fukai, S and Trenbath, B. R. (1993). Processes determining intercrop productivity and yields of component crops. Field Crops Research 34: 247-271.

Gardner, M.K., Parbery, D.G and Barker, D.A. (1981). Proteoid root morphology and function in legumes alnus. Plant and Soil Journal 60:143-147.

Gee, G.W and Bauder, J.M. (1986). Particle-size analysis. In Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods. ASA Monogroph 9: 383-411 (2nd Ed.), American Society of Agronomy, Madison, WI

Genstat 2005 Genstat 8th Edition, Release 8.1, VSN International Ltd, Oxford, UK.

Giller, K. E. (Ed). (2001). Nitrogen Fixation in Tropical Cropping Systems. 2nd Ed. CAB International, Wallingford, UK, 423 pp.

Giller, K. E., Amijee, F., Brodrick, S. J and Edje, O. T. (1998) Environmental constraints to nodulation and nitrogen fixation of *Phaseolus vulgaris* L. in Tanzania. II. Response to N and P fertilizers and inoculation. African Journal of Crop Science 6:171-178.

Giller, K.E and Cadisch, G. (1995). Future benefits from biological nitrogen fixation: An ecological approach to agriculture. Plant and Soil Journal 174:225-227.

Giller, K.E., McDonagh, J.F and Cadisch, G. (1994) Can biological nitrogen fixation sustain agriculture in the tropics? In: J.K, Syers and D.L. Rimmer. (Eds). Soil Science and Sustainable Land Management in the Tropics:173-191. CAB International, Wallingford.

Giller, K.E and J.F. Witty. (1987). Immobilized ^{15}N-fertilizer sources improve the accuracy of field estimates of N_2-fixation by isotope dilution. Soil Biol. Biochem.19:459-463.

Graham, P.H and Vance, C.P. (2003). Legumes: Importance and Constraints to Greater Use. Plant Physiology 131:872-877.

Grain Marketing Board. (2004). Commodity Price Bulletin. Dura House, Harare, Zimbabwe, 44pp.

Greenland, D.J and Szabolcs, I. (Eds) (1994). Soil Resilience and Sustainable Land Use. CAB International, Wallingford, RU.

Gregorich, E.G., Carter, M.R., Doran, J.W., Pankhurst, C.E and Dwyer, L.M. (1997). Biological attributes of soil quality. In Gregorich, E.G and Carter, M.R. (Eds). Soil quality for crop production and ecosystem health: 81-114. Elsevier Science, Amsterdam.

Gregorich, E.G., Carter, M.R., Angers, D.A., Monreal, C.M and Ellert, B.H. (1994). Towards a minimum data set to assess soil organic matter quality in agricultural soils. Can. J. Soil Sci. 74:367-385.

Groot, J.J.R., Koné, D., Traoré, M and Kamissoko, N. (1995). Description du système racinaire de l'*Andropogon gayanus*, du *Vigna unguiculata* et du *Stylosanthes hamata* en zone soudanosahélienne. Rapports Production Soudano-Sahélienne 8. AB-DLO, Wageningen, The Netherlands.

Gupta, V.V.S.R and Germida, J.J. (1988). Distribution of microbial biomass and its activity in different soil aggregate classes as affected by cultivation. Soil Biol. Biochem. 20:777-786.

Handayanto, E., Giller, K.E and Cadisch, G. (1997). Nitrogen mineralization from mixtures of legume tree prunings of different quality and recovery of nitrogen by maize. Soil Biology and Biochemistry 29**:**1417-1426.

Hansen, A.P. (1994). Symbiotic N_2 fixation of crop legumes. Margraf Verlag, weikersheim, 248 pp.

Hansen, A., Rerkasem, B., Lordkaew, S and Martin, P. (1993). Xylem-solute technique to measure N_2 fixation by *Phaseolus vulgaris* L.: calibration and sources of error. Plant and Soil Jpournal 150:223-231.

Hardarson, G and Danso, S.K.A. (1993). Methods for measuring biological N_2-fixation in grain legumes. Plant and Soil Journal 152:1:19-24.

Hargrove, W. L. (1986). Winter legume as a nitrogen source for no-till grain sorghum. Agronomy Journal 78:70-74.

Hassink, J and Whitmore, P. A. (1997). A model of the physical protection of organic matter in soils. Soil Sci. Soc. Am. J. 61:131–139

Hauggaard-Nielsen, H and Jensen, E. S. (2001). Evaluating pea and barley cultivars for complementarity in intercropping at different levels of soil N availability. Field Crop. Res 72:185–196.

Haynes, R.J. (2000). Labile organic matter as an indicator of organic matter quality in arable and pastoral soils in New Zealand. Soil Biol. Biochem. 32: 211–219

Hearn, A.B. (1986). Effect of preceding crop on the nitrogen requirements of irrigated cotton (*Gossypium hirsutum* L.) on a vertisol. Field Crops Research 13:159-175.

Høgh-Jensen, H. (1996). Symbiotic N_2 fixation in Clover-Grass mixtures and Nitrogen Transfer from Clovers to the accompanying Grass. In J. Raupp. (Ed.). Symbiotic nitrogen fixation in crop rotations with manure fertilization. Proc. on Fertilization Systems in Organic Farming :7-31.. Institute for Biodynamic Research, Darmstadt.

Hogh-Jensen, H and Kristensen, E.S. (1995). Estimation of BNF in clover-grass system by ^{15}N dilution method and the total-N difference method. Biological Agriculture and horticulture 11:203-219.

Hoshikawa, K. (1990). Significance of legume crops in improving the productivity and stability of cropping systems. International Symposium on the Use of Stable Isotopes in Plant Nutrition, Soil Fertility and Environmental Studies, Vienna, Austria

Hulugalle, N.R and Entwistle, P. (1996). Effects of sowing cowpea on properties of irrigated Vertisol and growth and yield of succeeding cotton, Aust. J. Soil Res. 34:529-544.

Hungria, M and Vargas, M. A. T. (2000). Environmental factors affecting N fixation in grain legumes in the tropics, with an emphasis on Brazil. Field Crops Research, 65: 2/3:151-164.

Hussain, M.A and Basahy, A.Y. (1998). Nutrient composition and amino acid pattern of cowpea (Vigna unguiculata (L.) Walp, Fabaceae) grown in the Gizan area of Saudi Arabia. Int. Journal of Food Science and Nutrition 49:2:117-24.

Hussein, M.Z., Tarmizi, R.S.H., Zainal, Z.; Ibrahim R and Badri, R.M. (1996) Preparation and characterization of active carbons from oil palm shells. Carbon 34:11:1447-1453.

Ikeorgu, J.E.G., Unamma, R.P.A and Ezumah, H.C. (1989). Effects of fertilizer and time introduction of cassava or maize on the productivity of yam and cassava-based intercrops in a humid ultisol. Cassava-based cropping systems research II. Contributions from the second annual meeting of the collaborative group in cassava-based cropping systems research held at IITA, Ibadan, Nigeria.

Insam, H., Mitchell, C.C and Dormaar, J.F. (1991). Relationship of soil microbial biomass and activity with fertilization and crop yields of three Ultisols. Soil Biol. Biochem. 23:459-464.

Isaac, L, Wood, C.W and Shannon, D.A. (2000). Decomposition and Nitrogen Release of Prunings from Hedgerow Species Assessed for Alley Cropping in Haiti. Agronomy Journal 92:501-511.

Israel, D.N. (1987). Investigation of the role of phosphorus in symbiotic nitrogen fixation. Plant Physiology 84:835–840.

Janzen, H. H and Gilbertson, C. (1994) Exchange of ^{15}N among plants in controlled environment studies. Can. J. Plant Sci.74:109-110.

Janzen, R.R. (1987). Effect of fertilizer on soil productivity in long-term wheat rotations. Can. J. Soil Sci., 67:165-174.

Jensen, L. S., Mueller, T, Magid, J and Nielsen, N. E. (1997). Temporal variation of C and N mineralization, microbial biomass and extractable organic pools in soil after oilseed rape straw incorporation in the field. Soil Biol. Biochem. 29:1043-1055.

Jensen, E.S. (1994) Mineralization-immobilization of nitrogen in soil amended with low C:N ratio plant residues with different particle sizes. Soil Biology and Biochemistry 26:519-521.

Jensen, E. S., Høgh-Jensen, H., Jørgensen, F. V., Schjørring, J. K and Vinther, F. P. (1997). Management of biological nitrogen fixation in grass/clover leys. In N.H. Kristensen and H. Høgh-Jensen. (Eds.) New Research in Organic Agriculture:89-96. IFOAM, Tholey-Theley.

Jensen, L. S., McQueen D. J and Shepherd, T. G. (1996). Effects of soil compaction on N mineralization and microbial-C and -N. Soil and Tillage Res. 38 : 3-4:175-188.

Jeranyama, P., Hesterman, O.B., Waddington, S.R and Harwood, R.R. (2000) Relay-Intercropping of Sunnhemp and Cowpea into a Smallholder Maize System in Zimbabwe. Integrated Agricultural Systems. Agronomy Journal 92:239-244

Jeranyama, P., Hesterman, O.B and Waddington, S.R. (1998). The impact of legumes relay intercropped into maize at Domboshava, Zimbabwe. In Soil fertility research for maize-based farming systems in Malawi and Zimbabwe. (Eds.) S.R. Waddington, H.K Murwira, J.D.T Kumwenda, D. Hikwa, and F, Tagwira. Proceedings of the Soil

Fert Net results and planning workshop, 7-11 July 1997, Mutare, Zimbabwe. Soil Fert Net and CIMMYT-Zimbabwe:31-34. Harare, Zimbabwe.

John, P.S., Pandey, R.K., Buresh, R.J and Prasad, R. (1992). Nitrogen contribution of cowpea green manure and residue to upland rice. Plant and Soil Journal 142: 53–61.

Johnson, D.T. (1970). The cowpea in the African areas of Rhodesia. Rhodesia Agricultural Journal 67:61-64

Kanyama-Phiri, G.Y., Snapp, S.S and Minae, S. (1997). Developing improved organic matter technologies in partnership with smallholder farmers in southern Malawi. African Crop Science Conference Proceedings 3:375-384.

Kareiva, P. (1983). Influence of vegetation texture on herbivore populations: resource concentrations and herbivore mopvement. In: R..F. Denmo and M.S. McClure (Eds). Variable plants and herbivores in natural and managed systems: 59-289. New York, Academic Press.

Kasasa, P. (2000). Quatification of nitrogen fixation by promiscuous soyabean in Zimbabwean soils. MPhil. Thesis. University of Zimbabwe, Harare, Zimbabwe.

Kasasa, P., Mpepereki, S., Musiyiwa, K., Makonese, F and Giller, K. E. (1999). Residual nitrogen benefits of promiscuous soybeans to maize under field conditions. African Crop Science Journal:375-382.

Keating, B.A and Carberry, P.S. (1993). Resource capture and use in intercropping : solar radiation. Field Crops Research 34:273-301.

Kennedy, I.R and Cocking, E.C. (1997). Biological Nitrogen Fixation: The Global Challenge and Future Needs. Position Paper of the Meeting at the Rockefeller Foundation Bellagio Conference Center.

Kirchmann, H and Bergquist, R. (1989). Carbon and nitrogen mineralization of White Clover plants (Trifolium repens) of different age during aerobic incubation with soil. Pflonzenernohr. Bodenkd 152:283-288

Koptur, S. (1992). Extrafloral nectary-mediated interactions between insects and plants. In E. Bernays. (Ed). Insect-Plant Interactions:81-130. CRC Press, Boca Raton, FL.

Kumwenda, J.D.T., Waddington, S.R., Snapp, S.S., Jones, R.B. and M.J. Blackie. (1997). Soil fertility management in Southern Africa. In D. Byerlee and C.K. Eicher (Eds.). Africa’s emerging maize revolution :153-172., Boulder, Colorado: Lynne Publishers.

Kumwenda, J.D.T., Waddington, S.R., Snapp S.S., Jones, R.B and Blackie, M.J. (1996). Soil fertility management research for maize cropping systems of smallholders in southern Africa: A review. NRG Paper 96-02. CIMMYT, Mexico, DF.

Kurdali, F., Domenach, A.M. and Bardin, R. (1990). Alder-poplar associations: Determination of nitrogen sources by isotope techniques. Biol. Fertil. Soils :321-329.

Ladd, J. N., Oades, J. M and Amato, M. (1981). Distribution and recovery of nitrogen from legume residues decomposing in soil sown to wheat in the field. Soil Biol. Biochem. 13:251-256.

Laidlaw, A. S., Cristie, P and Lee, H. W. (1996). Effect of white clover cultivar on apparent transfer of nitrogen from clover to grass and estimation of relative turnover rates of nitrogen in roots. Plant and Soil Journal 179:243-253.

Lal, R. (1997). Degradation and resilience of soils. Philosophical Transactions of the Royal Society of London Series B - Biological Sciences 352:997-1008.

Lanyon, L.E and Beegle, D.B. (1989). The role of on-farm nutrient balance assessments in an intergrated approach to nutrient management. J. Soil Water Conservation, 44:164-168.

Ledgard S. F., Penno, J. W and Sprosen M. S. (1999). Nitrogen inputs and losses from clover/grass pastures grazed by dairy cows, as affected by nitrogen fertilizer application. Cambridge University Press, Journal of Agricultural Science 132:215-225.

Ledgard, S.J. and Giller, K.E (1995). Atmospheric nitrogen fixation as an alternative nitrogen resource. In: Bacon, P (Ed.), Nitrogen fertilization and the environment. Marcel Dekker, New York.

Ledgard, S. F and Steele, K. W. (1992). Biological nitrogen fixation in mixed legume/grass pasture. Plant and Soil Journal, 141:137-153.

Ledgard, S. F., Simpson, J.R., Freney, J. R and Bergersen F. J (1985). Field evaluation of ^{15}N techniques for estimating nitrogen fixation in legumes-grass associations. Aust. J. Agric. Res. 36: 247-258.

Le Roi, A. (1997). Evaluation of the situation of pigeonpea production in the semi-arid areas of Kenya. MSc Thesis, University of Gembloux, Belgium.

MacColl, D. (1989). Studies on maize (Zea maysL.) at Bunda, Malawi. II. Yield in short rotation with legumes. Exp. Agric..25:367-374.

Mafongoya, P.L., Nair, P.K.R and Dzowela, B.H. (1998). Mineralization of nitrogen from decomposing leaves of multipurpose trees as affected by their chemical composition. Biol. Fertil. Soils, 27:143–148.

Mafongoya, P.L and Nair, P.K.R. (1997). Multipurpose tree prunings as sources of nitrogen to maize under semi-arid conditions in Zimbabwe: interactions of pruning quality and time and method of application on nitrogen recovery by maize in two soil types. Agroforestry Systems 37:1-4.

Mapfumo, P and Giller, K.E. (2001) Soil fertility management strategies and practices by smallholder farmers in semi-arid areas of Zimbabwe. ICRISAT and FAO, Bulawayo, Zimbabwe. 60 pp.

Marschner, H. (1995). Mineral nutrition of higher plants. Academic Press. Muenchen, 2nd Edition.

McDonagh, J.F. (1998). A review of soil fertility in Northern Namibia: an aid for assessing research needs. DFID PSP Project: Increasing pearl millet production through improved use of grain legumes. Project working paper. 40pp. (unpublished).

McGill, W.B and Myers, R.J.K. (1987) Controls on dynamics of soil and fertilizer nitrogen. Soil fertility and organic matter as critical components of production systems. Soil Science Society of America Special Publication 19: 73-99.

McNeill, A.M., Zhu, C and Fillery, I. (1997). Use of in situ ^{15}N-labelling to estimate the total below-ground nitrogen of pasture legumes in intact plant-soil systems. Aust. J. Agric. Res. 48:295-304.

McNeill, A.M., Pilbeam, C.J., Harris, H.C and Swift, R.S. (1996). Seasonal variation in the suitability of different methods for estimating biological nitrogen fixation by grain legumes under rainfed conditions. Aust. J. Agric. Res. 47:10661-1073.

McNeill, A.M and Wood, M. (1990). ^{15}N estimates of nitrogen fixation by white clover (*Trifolium repens.* L.) growing in mixture with rye grass (Lolium perenne L.), Plant and Soil 128:265-273.

Morris, R.A and Garrity, D.P. (1993a). Resource capture and utilization in intercropping: water. Field Crops Research 34:303-307.

Morris, R.A and Garrity, D.P. (1993b). Resource capture and utilization in intercropping: non-nitrogen nutrients. Field Crops Research 34:319-334.

Morris, D.R., Weaver, R.W., Smith, G.R and Rouquette, F.M. (1990). Nitrogen transfer from arrowleaf clover to ryegrass in field plantings. Plant and Soil Journal 128:293-297.

Mpepereki, S and Pompi, I. (2003). Promoting New BNF Technologies among smallholder farmers: A success strory from Zimbabwe. In: R. Waddington (Ed) Grain legumes and green manures for soil fertility in Southern Africa: Taking Stock of Progress. CIMMYT, Zimbabwe, 246 pp.

Mpepereki, S and Makonese, F. (1995). Prevalence of cowpea and soyabean rhizobia in field soils of Zimbabwe. Zimbabwe Journal of Agricultural Research 33:1-15.

Mugwira, L.M and Nyamangara, J. (1998). Organic carbon and plant nutrients in soil under maize in Chinamhora communal area, Zimbabwe. In: Bergstrom and Kirchmann (Eds) Carbon and nutrient dynamics in natural and agricultural tropical systems: 15-21. CAB International.

Musiyiwa, K. (2001). MPhil. Thesis. University of Zimbabwe, Harare, Zimbabwe.

Myaka, F.A and Kabissa, J.C. (1996). Fitting short duration cowpea into a cotton-based cropping system in Tanzania: Effect of planting pattern, time of planting cowpea, and insecticide application to the cotton. Experimental Agriculture 32:225-230.

Natarajan, M and Naik, D.M. (1992). Competitive effect of short duration, bush type cowpea when intercropped with cotton in Zimbabwe. Experimental Agriculture 28:409-416.

Nelson, D. W and Sommers, L. E. (1982). Total carbon, organic carbon and organic matter. In*:* A. L. Page et al. (Eds.) Methods of soil analysis: Part 2. Chemical and microbiological properties. ASA Monograph Number 9: 539-579

Nnadi, L.A and Balasubramanian, V. (1978). Root nitrogen content and transformation in selected grain legumes. Tropical Agriculture (Trinidad) 55: 23–32.

Nyamapfene, K. W. (1991). Soils of Zimbabwe: 75-79. Nehanda Publishers (Pvt) Ltd, Harare, Zimbabwe.

Oberson, A., Friesen, D.K., Rao, I.M., Bühler, S and Frossard, E. (2001). Phosphorus transformations in an oxisol under contrasting land-use systems: the role of the soil microbial biomass. Plant and Soil Journal 237:197–210.

Ocio, J.A., Martinez, J and Brokes, P.C. (1991). Contribution of straw derived N to total microbial biomass N following incorporation of cereal straw to soil. Soil Biol. Biochem. 23:655-659.

Palm, C. A., Giller, K. E., Mafongoya, P.L and Swift. M.J. (2001). Management of organic matter in the tropics: translating theory into practice, Nutrient Cycling in Agroecosystems 61:1 – 2: 63 – 75

Peterson, T.A and Russelle, M.P. (1991). Alfalfa and nitrogen cycle in the corn belt. J. Soil Water Conservation 46:229-233.

Peoples, M.B., Lilley, D.M., Brnett, V.F., Ridley, A.M and Garden, D.L. (1995). Effects of surface applications of lime and superphosphate to acid soils on the growth and N2 fixation by subterranean clover in mixed pasture swards. Soil Biol. Biochem. 27: 663-671.

Peoples, M.B and Herridge, D.F. (1990). Nitrogen fixation by legumes in tropical and subtropical agriculture. Adv. Agron. 44:155-223

Rao, M.R and Mathuva, M.N. (2000). Legumes for improving maize yields and income in semi-arid Kenya. Agriculture, Ecosystems and Environment 78:123-137.

Rao, M.R., Rego, T.J and Willey, R.W. (1987). Response of cereals to nitrogen in sole cropping and intercropping with different legumes. Plant and Soil Journal 101:167-177.

Rattray, A.G.H and Ellis, B.S. (1952). Maize and green manuring in Southern Rhodesia. The Rhodesia Agricultural Journal 49:188-197.

Recous, S., Robin, D., Darwis, D and Mary, B (1995). Soil inorganic N availability: effect on maize residue decomposition. Soil Biol. Biochem. 27:1529–1538.

Reddy, K.C., Visser, P.L., Klaij, M.C. and Renard, C. (1994). The effects of sole and traditional intercropping of millet and cowpea on soil and crop productivity. Experimental Agriculture 30:83-88.

Reddy, K.C., P. Visser, and P. Buekner. (1992). Pearl millet and cowpea yields in sole and intercrop system, and their after-effects on soil and crop productivity. Field Crops Research 28: 315–326.

Reid, M.G. (1977). The early agriculture of Matebeleland and Mashonaland. Rhodesia Agricultural Journal 74:97-102

Rice, C.W., Moorman, T.B and Beare, M. (1996). Role of microbial biomass carbon and nitrogen in soil quality. In J.W. Doran and A. Jones, (Eds.) Methods of assessing soil quality, SSSA Spec. Publ. 49:203-215. SSSA, Madison, WI.

Rochester, I.J., Peoples, M.B., Hulugalle, N.R., Gault, R.R and Constable, G.A. (2001). Using legumes to enhance nitrogen fertility and soil condition in cotton cropping systems. Field Crops Research 70:27-41.

Rochester, I.J., Peoples, M.B., Constable, G.A and Gault, R.R. (1998). Faba beans and legumes and nitrogen to irrigated cotton systems. Ausralian Journal Experimental Agriculture 38:253-260.

Rupela, O.P and Saxena, M.C. (1987). Nodulation and nitrogen fixation in chickpea. In M.C. Saxena and K.B. Singh. The Chickpea, Farnham Royal UK, Commonwealth Agricultural Bureaux International and International Center for Agricultural Research in the Dry Areas:191-206.

Rusell, C.A and Fillery, I.R.P. (1996). In situ ladelling of lupin below-ground biomass N. Aust. J. Agric. Res. 47:1035-1046.

Rusinamhodzi, L, Nyagumbo, I and Murwira, H. K. (2004) Farmer participatory evaluation of cotton-cowpea intercropping treatments. TSBF-CIAT, Harare (Unpublished).

Sanchez, P.A. (2002). Soil fertility and hunger in Africa. Science 295:2019-2020.

Schmidt, O and Scrimgeour, C. M. (2001). A simple urea leaf-feeding method for the production of 13C and 15N labeled plant material. Plant and Soil Journal 29: 2:197-202.

Schulz, M and Janssens, M. (2001). The Potential of pigeonpea-cotton intercropping in Uganda. In S. N. Silim., G. Mergeni and P.M. Kimani (Eds). Status and potential of pigeonpea in Eastern and Southern Africa: Proceedings of a regional workshop, 12-15 September, Nairobi, Kenya. ICRISAT and Gembloux Agricultural University. 232pp.

Schwendiman, J.L and Kaiser, V.G. (1960). Alfalfa to replace sweetclover for dryland green manure crop rotations in Pacific Northwest. J. Soil Water Conserv. 15:257-263.

Shearer, G., and Kohl, D.H. (1986). N_2 fixation in field settings:estimates based on natural 15N abundance. Aust. J. Plant Physiol. 13:699-756.

Siame, J., Willey, R. W and Morse, S. (1998). The response of maize *Phaseolus* intercropping to applied nitrogen on Oxisol in northern Zambia. Field Crops Research 55:73-81.

Silim, S.N., Singh, L and Omanga, P.A. (1995). Development of agronomy of short-duration pigeonpea. Pp. 38-43 In Silim, S.N.,King, S.B. and Tuwafe, S., (Eds) Improvement of Pigeonpea in Eastern and Southern Africa: Annual Research Planning Meeting, Nairobi, Kenya.

Simpson, G. D. (1976). New Developments in Agricultural Sampling. American Journal of Agricultural Economics 58: 3: 30-41.

Smaling, E.M.A., Nandwa, S.M and Jansen, B.H. (1997). Soil Fertility in Africa is at stake. In R.J. Buresh et al. (Eds.) Replenishing soil fertility in Africa. SSSA Special Publication Number 51: 47-61.

Smith, J.L and Paul, E. A. (1990). The significance of soil microbial biomass estimations. In: Bollang J, Stosky, G (Eds) Soil Biochemistry:357-393, Dekker, New York.

Smith, M.S., Frye, W.W and Varco, J.J. (1987). Legume winter cover crops. Adv. Soil Science 7:95-139.

Snapp, S.S., Mafongoya, P.L and Waddington, S. (1998). Organic matter technologies for integrated nutrient management in smallholder cropping systems of Southern Africa. Agric. Ecosyst. Environ. 71:185-200

Snoeck, D., Zapata, F and Domech, A.M. (2000). Isotopic evidence of the transfer of nitrogen fixed by legumes to coffee trees. Biotechnol. Agron. Soc. Environ. 4 :2: 95-100.

Soetedjo P., Martin L.D and Tennant, D. (1997). Productivity and water use of intercrops of field pea and canola, Adv.Agron. 58**:**293-338

Sparling, G.P. (1991). Organic matter and soil microbial biomass C as indicators of sustainable land use. In G.R. Elliot, M. Latham, and J. Dumanski (Eds). Evaluation for sustainable land management in developing world Technical Papers 2:12. IBSRAM. Bangkok, Thailand

Stanford, G and Smith, S.J. (1972). Nitrogen mineralization potentials of soils. Soil Science Society of America Journal, 36:465-472.

Steiner, K.G. (1984). Intercropping in tropical smallholder agriculture with special reference to. West Africa. Stein, West Germany.

Sullivan, P. (1998). Intercropping Principles and Production Practices. Appropriate Technology Transfer for Rural Areas (ATTRA), Fayetteville, AR.

Swift, M.J and Woomer, P. (1993). Organic matter and the sustainability of agricultural systems: Definitions and measurements. In K. Mulungoy and R. Mercks (Eds). Soil organic matter dynamics and sustainability of tropical agriculture: 3-37. John Wiley and Sons, Chichester, UK.

Thompson, J. G and Purves, W.D. (1978). A guide to the soils of Rhodesia. Technical Handbook No.3. Rhodesia Agricultural Journal. 64 pp.

Tian, G., Kang, B.T and Brussaard, L. (1992). Biological effects of plant residues with contrasting chemical compositions under humid tropical conditions-decomposition and nutrient release. Soil Biology and Biochemistry 24:1051-1060.

Tirawali, S.A., Singh, B.B., Gupta, S.C., Tabo, R., Harris, F., Nokoe, S., Fernández-Rivera, S., Bationo, A., Manyong, V.M., Makinde, K and Odion, E.C. (2002) Cowpea as a key factor for a new approach to integrated crop–livestock systems research in the dry savannas of West Africa. In C.A. Fatokun, S.A. Tarawali, B.B. Singh, P.M. Kormawa and M. Tamò (Eds) Challenges and opportunities for enhancing sustainable cowpea production. Proceedings of the World Cowpea Conference III International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria: 233-250

Trinsoutrot, I., Recous, S., Bentz, B., Lineres, M., Cheneby, D and Nicolardo, T. (2000). Biochemical quality of crop residues and C and N mineralization kinetics under non-limiting Nitrogen conditions. Soil Sci. Soc. Am. J. 64:918-926.

Turner, N.C. (1997). Further progress in Crop Water Relations. Advances in Agronomy, 58:293-338.

Turner, G.L and Bergersen, F.J. (1983). Natural abundance of ^{15}N in root nodules of soyabean, lupin, subterranean clover and Lucerne. Soil Biol. Biochem. 15:525-530.

Turner, G.L and Gibson, A. H. (1980). Measurement of nitrogen fixation by indirect means. In: Methods for evaluating biological nitrogen fixation. Ed. Bergerson, F.J. J. Wiley and Sons, Chichester, pp 111-138.

Unkovich, M.J and Pate, J.S. (2000). An appraisal of recent field measurements of symbiotic N_2 fixation by annual legumes. Field Crops Res. *65*: 211-228.

Vallis, I., Haydock, K. P., Ross, P. J and Henzell, E. F. (1967). Isotope studies on the uptake of nitrogen by pasture plants. III. The uptake of small additions of N- labeled of fertilizer by Rhodesgrass and Townsville lucerne. Australian J. Agric. Res. 18:865-877.

Vance, C.P and Graham, P. H. (1995). Nitrogen fixation in Agriculture: application and perspectives. In I. A. Tikhonovich, N. A Provorov, V.L Romanov and W. E Newton (Eds). Nitrogen Fixation: Fundamentals and applications. Kluwer Academic Publishers. Dordrecht.

Van der meer, J. (1989). The ecology of intercropping. Cambridge University Press, New York.

Van der Pol, F. (1992). Soil mining. An unseen contributor to farm income in southern Mali. Royal Tropical Institute Bulletin 325. Royal Tropical Institute, Amsterdam.

Vanlauwe, B., Aihou, K., Iwuafor, E. N. O., Houngnandan, P., Diels, J., Manyong, V. M and Sanginga, N. (2002). Recent developments in soil fertility management of maize-based systems: The role of legumes in N and P nutrition of maize in the moist savanna zone of West Africa.

Vanlauwe, B., Diels, J., Sanginga, N., Carsky, R.J, Deckers, J and R. Merckx. (2000). Utilization of rock phosphate by crops on a representative toposequence in the northern Guinea savanna zone of Nigeria: response by maize to previous herbaceous legume cropping and rock phosphate treatments. Soil Biology and Biochemistry 32: 2079–2090.

Vanlauwe, B., Sanginga, N and Merckx, R. (1998). Soil organic matter dynamics after addition of nitrogen-15 labeled Leucaena and Dactyladenia residues, Soil Sci. Soc. Am. J. 62: 461-466.

Vanlauwe, B., Vanlangenhove, G and Merckx, R. (1995). Impact of rainfall regime on the decomposition of leaf litter with contrasting quality under subhumid tropical conditions . Biology and Fertility of Soils 20: 8-16.

Van Kessel, C and Hartley, H. (2000). Agricultural management of grain legumes: has it led to an increase in nitrogen fixation? Field Crops Res. 65:165-181.

Walker, J and Reuter, D.J. (Eds.) (1996). Indicators of Catchment Health: A Technical Perspective. CSIRO, East Melbourne.

Wander, M.M and Bollero, G.A. (1999). Soil quality assessment of tillage impacts in Illinois. Soil Sci Soc Am J. 63:961–971

Wani, S.P., Rupela, O.P and Lee, K.K. (1995). Sustainable agriculture in the semiarid tropics through biological nitrogen fixation in grain legumes. Plant and Soil Journal 174: 29–49.

Watanabe, F.S and Olsen, S.R. (1965). Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. Soil Science Society of America Proceedings 29:677-678.

Webster, J. R and Meyer, J. L. (1998). Organic matter budgets for streams: a synthesis. Journal of the North American Benthological Society 16:3-161.

Webster, C and Wilson, P (1998). Agriculture in the Tropics. Blackwell Science, Oxford

Wood, M and McNeill, A. M. (1993). $^{15}N_2$ studies on nitrogen fixation by legumes and actinorhizals: theory and practice. Plant and Soil Journal 155/156:329-332

Wych, R.D. and Rains, D.W. (1978) Simultaneous measurements of nitrogen fixation estimated by acetylene reduction assay and nitrate absorption of soybeans. Plant Physiol. 443-448.

Zimbabwe Crop Chemicals Handbook. (2002). Insecticides, fungicides, growth regulants, fumigants, and public health products: 1, ACIA and DR&SS.

Zingore, S., Mafongoya, P., Nyamugafata, P and Giller, K.E. (2003). Nitrogen mineralization and maize yields following application of tree prunings to a sandy soil in Zimbabwe. Agroforestry Systems 57: 199-211.

APPENDICES

Appendix 3.2. The soil physical and chemical characteristics of the three research sites, CRI, Ntini and Mukosi within the plough layer (top 20cm).

Site	**CRI**	**Ntini**	**Mukosi**
Sand (%) (20-2000 µm)	41.6	40.8	51.6
Silt (%) (2-20 µm)	21.0	20.3	45.2
Clay (%) (< 2 µm)	37.4	38.9	33.2
Soil texture	Clay loam	Clay loam	Sandy clay loam
pH ($CaCl_2$)	6.5	5.9	5.7
OC%	1.45	1.48	1.15
N (mg kg^{-1})	28.4	27.7	13.4
P (%)	0.26	0.28	0.28
Zn (mg kg^{-1})	66	76	56
Mo (mg kg^{-1})	502	92	98
S (WT%)	0.06	0.07	0.07
Ca (cmol+ kg^{-1})	8.38	7.99	7.47
Mg (cmol+ kg^{-1})	7.67	6.5	6.49
K (cmol+ kg^{-1})	0.28	0.07	0.12
Na (cmol+ kg^{-1})	3.67	2.89	2.24

Appendix 3.2. Soil profile description of red clay soil at Kadoma Cotton Research Institute.

0-30 cm. Dark reddish brown (2.5 YR 3/4) dry clay; dark reddish brown (2.5 YR 2/4) moist: moderate fine granular structure; granular, sticky, low permeability, plastic; abundant roots and animal burrows; clear smooth boundary.

30-70 cm. Dark reddish-brown (2.5 YR ¾) moist, maintains most of the physical characteristics as above except for the decrease in number of roots and much less permeable than above.

70 cm +. Reddish brown (2.5 YR 4/4) dry clay, dark reddish-brown (2.5 YR ¾) moist, sticky, plastic; few thin cracks, very few roots, low permeability.

Table 3.1. Total rainfall received for the three experimental sites.

Season	Total rainfall received (mm)		
	CRI	Ntini	Mukosi
2003/2004	798.3	707.6	761.4
2004/2005	523.5	420.5	486.3
Long-term average		740.7	

Appendix 3.3. Rainfall patterns for 2003/2004 for the three experimental sites.