THE EFFECT OF CROPS/CROP COMBINATIONS ON SOME INDICES OF YIELD AND SOME SOIL NUTRIENT DYNAMICS

A Thesis

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by

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DEDICATION

Dedicated to my wife Gina and my children, Steve, Stephanie, Ivan.

DECLARATION

I hereby declare that this thesis has been written by me and that it is the record of my own research work. It has neither in whole nor in part been presented for another degree elsewhere. Works of other researchers have been duly cited by references to the authors and all assistance received also acknowledged.

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ABSTRACT

Crop production in peasant cropping systems in the semi-arid areas of West Africa is generally constrained by low and uncertain rainfall, poor soil fertility and lack of credit facilities to purchase inputs such as fertilizers and improved varieties. In this study, two field experiments (September to November 1996 and March to June 1997) were conducted on an Ultisol (Bekwai series) at Kwadaso, Kumasi in the semi-deciduous forest zone of Ghana. An assessment was made of production potential and nutrient depletion or conservation of sole crops cowpea (*Vigna unguiculata L. Walp*) (C), maize (*Zea mays L. var. obatanpa*) (M), sweet potato (*Ipomea batatas*) (P) as well as their intercrops, maize-cowpea (MC), cowpea-potato (CP) and maize-potato (MP). The cultivation of the sole crops particularly cowpeas and maize least depleted soil nutrients than the intercrops with the MP combination resulting in the greatest fall in soil nutrients. At the end of the first cropping season, cowpea total dry matter yield reduced to about 50 % in the intercropped maize and intercropped sweet potato possibly due to shading by the companion crop. Rainfall amount and distribution in the study site (minor cropping season) is insufficient for full expression of maize yield potential especially if planted in late September. Evidently, low November rainfall appears to be most critical in influencing maize yield if planting is done in September.

Land equivalent ratio (LER) and the area-time equivalent ratio (ATER) demonstrated the superiority of MC intercrop to sole crops in terms of grain yield when moisture was adequate for crop growth in the 1997 cropping season. The results provide useful information for fine tuning choice of appropriate crops and cropping systems that will respond to prevailing rainfall conditions and soil nutrients; results of the present study can be used as a guide.

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CHAPTER ONE

INTRODUCTION

Traditional cropping systems based on short cropping cycles and long fallow periods maintained soil fertility at low but adequate levels for the non-intensive agriculture in the past. In recent years however, the trend in shifting tropical agriculture is towards shorter fallow periods and ultimately to attempt at continuous cultivation. This trend, driven largely by an increasing landless rural population, usually leads to land degradation, reduced productivity, and clearing of more forest land (Allen and Barnes, 1985; Sanchez *et al.*, 1990). With the progressive intensification of cropping and the consequent reduction in the fallow period, soils in developing countries are faced with the problem of supplying adequate nutrients in soil to maintain the yields of crops. In a highly productive agricultural system, nutrient losses are comparatively rapid. For example, the harvesting of 10 t maize grain ha^{-1} removes about 150 kg ha^{-1} of N and 30 kg ha^{-1} each of P and K respectively, from the field (Ahenkorah, 1997). Losses of nutrients from the soil-plant system other than those resulting from those removed in harvested crops are often large also (Tiessen *et al.*, 1992).

Major efforts to improve agricultural production in developing countries have relied on much the same formula of production "package" as in developed countries, which consists mainly of improved varieties, inorganic fertilizers and accompanying modifications in crop management (IITA, 1992). Removal of heavy subsidy on fertilizer has increased the cost of this input, making it difficult for farmers to offset reduced soil fertility with higher fertilizer doses. The current emphasis on the sustainability of tropical agriculture and the development of strategies aimed at maintaining improved yields, without depleting natural resources or destabilizing the environment, therefore appear appropriate (Lal, 1993). The strategies involve adapting old farming systems and research findings such that there is a more long-term impact on soil fertility as well as evolving new methods to ensure that yield increases are maintained. Systems, which incorporate biological nitrogen fixation offer great potential in this regard. Examples of such systems include alley cropping, the use of nitrogen-fixing trees in agroforestry systems, the use of legumes in multiple cropping systems and the exploitation of the azolla/anabaena symbiosis. Biological N_2 fixation (BNF), which enables legumes to use atmospheric N_2, is important in legume-based cropping systems when fertilizer N is limited. A complex series of transformations takes place to convert the atmospheric nitrogen fixed by rhizobia into a form that can be taken up and transported within the legume and assimilated. Biological nitrogen fixation contributes N for the legume growth and grain production under different environmental and soil conditions. In addition, the soil may be replenished with N through decomposition of legume residues when BNF contributes more than the crop requires. Evidence also suggests that associated cereals may benefit through N transfer from legumes (Fujita *et al.*, 1990a). The many processes involved in nitrogen fixation (into the legume, the subsequent transfer to the non-legume component), transformation, transport within the plant, and its subsequent release have been studied (Hauck and Tanji, 1982). Nitrogen fixed in plants may be lost from the system, made available to companion crops, or incorporated into the organic matter of the soil (Ofori and Stern 1987). Release of this nitrogen from the soil organic matter will lead to further transformations; some may become available to companion crops, some may be available to succeeding crops; some may be leached out of the root zone and some may be lost to the atmosphere. As these processes become better understood, there are prospects for developing greater efficiencies in agronomic practice, so enhancing the beneficial effects of legumes in farming systems. In improved farming systems involving legumes, soils should be compensated for the nutrients removed by crops.

Management of the fallow period under improved farming systems, can lead to an increased land use intensity without decreasing crop yields. Significant but variable amounts of plant nutrients are present in crop residues which could be returned to the soil instead of disposing of them in various ways. If this is done, at least part of the nutrients removed from the soil will be returned and the rate of decline of soil fertility can be slowed down. Lal *et al.*(1979) established that continuous application of organic matter in the form of litter and mulch improves soil structure and reduces the risk of erosion. Badanur *et al.* (1990), also indicated that inputs of organic material can enhance the nutrients balance besides serving as a nutrient reservoir in the soil. Organic matter also enhances the nutrient status of the soil by raising its cation exchange capacity (CEC) particularly on kaolinitic and siliceous soils (Juo and Lal, 1977).

Rational use of cropping systems and supplementary fertilization based on an understanding of the nutrient transformations of traditional cropping systems could provide better alternatives to those that have resulted in the current trend of fertility decline in the tropics. More information is needed on the many processes that are responsible for fertility decline during cropping cycles and those that enhance the recovery of soil fertility during bush fallow in semi-arid regions. In this study the objectives were:

(i) to evaluate the agronomic effectiveness of cropping systems with or without legumes

(ii) to evaluate the biological efficiency of the different cropping systems.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction to literature review

A generally declining resource base for food production has led to a precarious food production in parts of West Africa. Increased and diversified food production as well as improved soil management systems are essential for coping with increasing human population in the sub-region. The potential of biological management systems for famine mitigation and poverty alleviation has been demonstrated through various collaborative projects in Africa. In this chapter, relevant scientific literature to soil productivity is discussed.

2.1 Characteristics of traditional agriculture

Rotational or forest fallow methods have characterized many agricultural systems in the tropics. Plant nutrients are released following land clearing and burning and the nutrients are exploited by crops during one to two-year cultivation cycle. The few years of continuous cultivation without fertilization is followed by a relatively longer fallow period of 10 or more years during which both organic matter and nutrients are restored (Aweto, 1988). Soil regeneration has been attributed to the addition of organic matter and nutrients contained in litter, and to root activity (Sabharsri, 1978). Soil organic carbon increases with an increasing length of the fallow period. In Brazil, for example, 3 years of fallow after 5 years of cultivation returned soil organic carbon to 80 % of that in a well drained soil under natural forest (Martins *et al*., 1991). A long, 30 to 50 year fallow in Puerto Rico restored 90-100 % of the soil organic carbon of a mature forest (Lugo and Sanchez, 1986). Restoration of fertility after about 10 years in the humid tropics of northern Thailand has been reported (Zinke *et al*., 1978). Soil regeneration due to continuous inputs from litterfall and root turnover after about 10 years fallow has been observed in semi-arid regions (Tiessen *et al.*, 1992). The fallow period reverses the trends measured during a cropping period. The return of organic matter to the soil is the key to the functioning of these systems (Schroeder, 1995). Effects of increasing levels of organic matter on soil physical properties during the fallow, along with the protective action of the fallow vegetation, may be as important as the chemical nutrient increases (Ahn, 1979). Increased organic matter improves soil structure which leads to lower bulk density and to better aeration, permeability, and rainfall infiltration as well as improvement in available water and water holding capacity (Nye and Greenland, 1960; Ahn, 1979). It is therefore necessary to replace traditional shifting cultivation with some forms of continuous cropping as has been suggested in numerous studies (Ridder and Keulen, 1990; Bationo and Mokwunye, 1991). Cropping systems which have the potential to maintain nutrient levels, restore soil structure and soil water relationships will have to be developed. A system of continuous supply of organic matter to the soil surface is essential to meet this requirement and, therefore, may be a viable alternative in areas where long fallow periods are no longer feasible (Lal, 1986; Tiessen *et al.*, 1992).

2.2 Organic matter depletion

The addition of organic materials either in the form of manures or crop residue has been shown to have beneficial effects on the soil's chemical and physical properties (Kinchesh *et al.*, 1995). The return of the crop residue is therefore essential for reversing high rate of organic matter decline associated with cultivation under the high temperatures in the tropics (Bationo and Mokwunye, 1991). Forest clearing has an adverse effect on organic matter and C dynamics (Schroeder, 1995) and is discussed below.

2.3 Effects of clearing on soil organic matter and carbon.

The effects of forest clearing and cultivation of tropical soils have received much research attention (Cunningham, 1963; Nye and Greenland, 1964; Okigbo, 1978; Juo and Lal, 1979). Cultivated tropical soils in general contain lower levels of carbon than forest soils (Ayanaba *et al.*, 1976; Allen, 1985). The extent of organic matter loss caused by cultivation depends on the length and intensity of cultivation (Nye and Greenland, 1960), but depletion can be rapid. Sanchez *et al.* (1983) observed a 25 % loss of soil organic carbon during the first year of cultivation, followed by a 20 % loss after one year of cultivation. Martins *et al.* (1991) showed a 22 % loss of soil organic matter after 5 years of cultivation. Forest soils converted to pasture also undergo rapid initial loss of soil carbon. Eden *et al.* (1991) reported a 23 % drop in soil carbon during the first year of pasture establishment, while, Cerri *et al.* (1991) showed a 25 % decrease in soil organic matter over 2 years. Beyond their implications for soil fertility, these carbon losses represent a flux of CO_2 to the atmosphere that is in addition to emissions directly caused by clearing and burning of forest biomass.

Several studies have shown that burning is usually not responsible for site degradation or soil carbon depletion, and that coarse woody debris, charcoal, and soil carbon, may actually briefly increase as a result of incomplete combustion (Nye and Greenland, 1960; Ewel *et al.*, 1981; Cerri *et al.*, 1991). Under cultivation, however, organic carbon declines in part because the amount of plant organic materials returned to the soil decreases dramatically (Ramakrishnan and Toky, 1981; Dalal and Mayer, 1986). At the same time decomposition rates increase sharply due to removal of canopy shading which causes increased soil temperature (Cunningham, 1963; Martins *et al.*, 1991). The combination of decreased organic inputs and accelerated decomposition leads to the observed sharp soil carbon declines (Ahn, 1979). The commonly observed crop yield decline under continuous cultivation without fertilizer application has been attributed to plant nutrient depletion, deterioration of soil physical properties, and pests (Lal, 1986). The first two of these factors are directly linked to loss of organic matter. Maintaining adequate levels of organic matter, therefore, would address some of the major factors that lead to the need to clear additional land. Understanding traditional forms of long fallow shifting agriculture, agroforestry systems as well as cropping systems that successfully replenish stocks of organic matter should provide some clues to achieving sustainability.

2.4 Organic matter as an indicator of soil quality

Any consideration of soil quality, must be in the context of the use that is envisaged for the soil. Even within a given land use it is unlikely that a single soil property, or index combining several properties, will capture all of the factors that contribute to soil quality because of the complex interactions involved (Powlson and Dexter, 1992). Organic matter content however, comes close to being an indicator of overall soil quality (Powlson and Dexter, 1992), because it influences so many properties. This section outlines the beneficial effect of soil organic matter on soil fertility.

2.4.1 Effect of organic matter content on soil physical properties.

Organic matter enhances virtually all desirable physical properties of the soil. These include friability (or ease of crumbling), which is necessary if a soil is to be easily cultivated, and a stable aggregate structure in order to resist mechanical damage by machinery. The degree of aggregation affects pore volume and pore size distribution and hence infiltration capacity and soil moisture retention characteristics (Ridder and Keulen, 1990; Powlson and Dexter, 1992). Tisdall and Oades (1980) have discussed the process of water-stable soil aggregation by organic material. Persistent binding agents consist of degraded, aromatic materials associated with amorphous iron, aluminium and aluminosilicates, which together form the large organo-mineral fraction of soils (Jo, 1990). Braunack and Dexter (1989) have summarized various references which quote optimum aggregate size ranges to promote earlier seed emergence, a higher rate of emergence and the highest yield for given crops. An aggregate size range of 1-4 mm is reported to be favourable for the growth of almost all crops (Jo, 1990). Soil bulk density changes according to organic matter content. Adams (1973) showed that the amount of organic matter (% X) had a significant effect on the soil bulk density (ρ) according to the following equation:

$$\rho = \frac{100}{\left(\frac{X}{\rho_o}\right) + \left(\frac{100 - X}{\rho_m}\right)} \qquad \text{..(2.1)}$$

where ρ_o = average bulk density of the organic matter (0.224 g cm^{-3}), and ρ_m = bulk density of the mineral matter (g cm^{-3}). Soane (1975) found that the bulk density (ρ) was reduced by increasing the amount of organic matter (%) (M), as in the following relationship:

$$\rho = 1.86 - 0.055\,M \qquad \text{....................................(2.2)}$$

Jung *et al*. (1976) reported that soil erodibility values were inversely correlated with organic matter in the range of 3-13 %, but there was no relationship with the organic matter level when this was below 3 %. This suggests that soil erodibility is affected more by texture than by organic matter content when little organic matter is present in the soil, but that high rate of organic matter application may control soil erodibility (Jo, 1990). Organic matter also tends to enhance the continuity and stability of soil pores. This increases water storage, provides suitable habitats for aerobic microorganisms and facilitates root growth.

2.4.2 Effect of organic matter content on soil chemical properties.

For many soils of the tropics, inputs of organic residues are essential to sustain soil fertility; they supply nutrients through mineralization, and help to maintain an optimal soil organic matter content that counteracts adverse phenomena like a decreasing cation exchange capacity, soil structure degradation and erosion (Vanlauwe *et al*., 1995). Juo and Lal (1977) reported that organic inputs are vital for crop growth particularly in West Africa's kaolinitic and siliceous soils in which low CEC is a major chemical constraint to improved yields. The importance of crop residues for long-term soil fertility maintenance has been highlighted by Juo and Kang (1989). They reported that on an Alfisol following forest clearing and continuous cropping under no tillage system, retention of crop residue resulted in slower decline and higher soil organic matter, cation exchange capacity, pH, exchangeable magnesium status and crop yield compared to treatments from which crop residues had been removed. Organic matter is also a major source of plant nutrients. By maximizing the use of this source, and ensuring that nutrients derived from the mineralization of organic matter are used efficiently, reliance on inorganic fertilizers can be decreased (Koenig and Cochran, 1994). In contrast to earlier findings, results from some long-term experiments now show that maximum crop yields can only be achieved in a soil maintained at a high organic matter content (Poulain, 1977). Maintaining soil at a high organic matter content however, is not without problems. The release of nutrients through mineralization of organic matter by the soil microbial population should be well synchronized with crop growth (IITA,1992). In the case of nitrogen, reckless use of organic sources increases the risk of nitrate loss from soil with the consequent impact on water quality (Powlson, 1993).

2.5 Soil fertility improvement alternatives to the traditional farming system.

Improved and new farming technologies designed as alternatives to shifting cultivation and bush fallow systems include mechanisms that can replenish soil organic matter. This section reviews some major alternatives to these traditional farming practices.

2.5.1 Soil organic matter management.

Soil organic matter (SOM) is a material resource, a reservoir and a source of key nutrients and a modifier of soil textural properties (Sanchez *et al.*, 1989). A change in the soil environment may result in decline of the organic carbon because it is a labile resource. However, SOM is replenished by synthesis from organic matter inputs because it is a renewable resource. The maintenance of this resource in a non-declining and stable trend from crop cycle to crop cycle in a cropping system is the goal for sustainable soil management (Ahenkorah, 1997). The response of crops to the addition or retention of organic residues is reported in the literature (Oschwald, 1978; Kang *et al.*, 1990). Also, the recognition of the diversity of organic matter fractions associated with soil fertility is essential to sustainable organic matter management (Chan *et al.*, 1992).

Management of soil organic matter within an ecosystem can be achieved by manipulating the organic matter fractions and/or regulating the factors which govern their transformation. The benefits of OM management may result from (1) an immediate effect within the current cropping season (2) a residual effect expressed in sequential seasons and (3) a long-term effect having a continuous influence over periods of a decade or more of management (Jenkinson and Ayanaba, 1977). There is the possibility of using model predictions of SOM equilibria under different cropping systems as an index of sustainability (e.g. the CENTURY model of Parton *et al.*, 1987).

It is important to demonstrate the link between productivity, sustainability and SOM dynamics under different cropping systems.

2.5.2 Alley cropping

Alley cropping is an agricultural practice with much potential in which food crops are grown in alleys usually 4 to 6 m wide formed by fast growing shrubs and trees planted in an orderly arrangement (Wilson and Kang, 1981). Leguminous shrubs and trees such as *Gliricidia sepium*, *Leucaena leucocephala*, pigeon peas (*Cajanus* species), and *Tephrosia candida* are commonly employed. These under proper management are capable of supplying nitrogen to the soil via their root systems while their green leaves, often amounting to 12-16 kg per year per tree, and twigs serve as mulch and a further source of plant nutrients (FAO, 1987). The larger branches are used for poles, stakes for climbing plants, or as a source of firewood. After six years of alley cropping with *Leucaena leucocephala*, on an Entisol with a pH of 6, plots receiving prunings had a higher nutrient status and twice the organic matter content than of plots not receiving prunings (Kang *et al.*, 1984).

In some types of agroforestry systems, litterfall can be an important component of organic matter dynamics. No examples of litter production by alley cropping systems have been reported in the literature (Schroeder, 1995). Although alley cropping works well in moderately fertile soils, current experience suggests that it will be necessary to use lime, and possibly P, to allow successful establishment of alley-cropping species and subsequent recycling of nutrients on acid infertile Ultisols and Oxisols (Tropsoils, 1986).

Some tree and shrub species can selectively accumulate certain nutrients even in soils containing very low amounts of these nutrients (Sanchez, 1987). For example, it has been reported that palms and palm litter are rich in potassium (Folster *et al.*, 1976), tree ferns accumulate nitrogen (Muller-Dombois *et al*., 1984), and *Cecropia* spp. appeared to accumulate Ca (Sanchez *et al*., 1985).

The incorporation of such nutrient-conserving species into agroforestry technologies should consider the location and site/soil characteristic as they influence plant-nutrient responses (Golley, 1986). Implementation of agroforestry systems as an alternative to continuous cropping however, should also reduce the loss of soil organic C and extend the cropping period (Schroeder, 1995).

2.5.3 Agroforestry

The many diverse contributions of tree components are the key to the ecological benefits of agroforestry systems (Kang & Wilson, 1987; Young, 1989; Ingram, 1990). Agroforestry systems are believed to increase, or at least maintain, the organic matter levels of the soil (Young, 1986 a,b; Young *et al*., 1986). One of the advantages commonly attributed to agroforestry technologies is the potential for soil fertility improvement via more efficient cycling of nutrients (Nair, 1984) and it is often recommended to include nitrogen-fixing trees and shrubs in such technologies (Lundgren and Nair, 1985; Young *et al*., 1986; Young, 1987). The nutrient-cycling potential of agroforestry systems on Alfisols and Andepts of moderate to high fertility have been reported. A good example is *Erythrina poeppigrana* shade trees over *Coffea arabica* in Costa Rica (Glover and Beer, 1986; Russo and Budowski, 1986). Similarly, Roskoski (1981) reported that *Inga jinicuil*, a leguminous shade tree in coffee plantations fixed around 40 kg N ha^{-1} yr^{-1}.

Juo and Lal (1977) comparing the effects of a leucaena fallow versus a bush fallow on selected chemical properties on an Alfisol in Western Nigeria, reported that after 5 years, during which leucaena was cut annually and left as mulch, the leucaena fallow resulted in significantly higher effective cation exchange capacity and levels of exchangeable Ca and K, compared to the bush fallow. Similarly, an agroforestry system involving oil palm with leguminous cover crops (*Centrosema pubescens* and *Pueraria phaseoloides*) appeared more efficient at nutrient cycling than an oil-palm plantation with no cover crop (Glover and Beer, 1986). In addition to fixing about 150 kg N ha^{-1} yr^{-1} the loss of nitrate nitrogen via leaching was significantly lower in the agroforestry system than in the sole crop of oil palm (Agamuthu and Broughton, 1985).

Agroforestry systems can also have some disadvantages that must be considered. Trees occupy space that would otherwise be available for crop plants, and they compete for water, light and nutrients (Schroeder, 1995). The altered microclimate of agroforestry systems tends to be more humid than monocrop situations and, therefore, be more conducive to fungal diseases (Schroeder, 1995). Operationally, agroforestry systems may require more manual labour than other systems (MacDicken and Vergara, 1990). Optimizing these advantages and disadvantages can be a complex task which is in itself a disadvantage where there is scarcity of trained personnel and extension workers to provide information and advice to farmers.

2.5.4 Biological nitrogen fixation (BNF)

Nitrogen-fixing plants offer an economically attractive and ecologically sound means of reducing external inputs and improving the quality and quantity of internal resources. Biological nitrogen fixation can be a major source of N in agriculture. When symbiotic N_2-fixing systems are used, the amount of N input is reported to be as high as 360 kg N ha^{-1} (Bohlool *et al*., 1992). Nitrogen contributions from non-symbiotic micro-organisms (associative and free-living) are relatively minor to be of practical significance in soils (Stevenson, 1986). Among symbiotic N_2-fixing systems, nodulated legumes have had a long and comprehensive involvement in cropping systems. According to La Rue and Patterson (1981), the role of legumes as sources of N is certain to increase in importance. They can serve a multitude of purposes in sustainable agriculture. Their importance includes serving as primary sources of food, fuel, fiber and fertilizer. They also enrich the soil, preserve moisture and prevent soil erosion. They can also be used as wind-break, ground cover, trellis, hedgerow and shade or as sources of resins, gums, dyes and oils (NAS, 1979). Azolla, a freshwater fern, is used extensively in parts of South East Asia as a green manure crop and as a substitute or supplement for N fertilizers in rice paddy culture (Stewart, 1973). This plant forms a symbiotic relationship with the blue-green alga *Anabaena azollae*, fixing up to 2-4 kg N $ha^{-1}day^{-1}$ under optimal conditions (Lumpkin and Plucknett, 1982). Watanabe and Liu (1992) recognized other benefits of Azolla to include weed suppression, a K scavenger from flooded water, animal feed, fish feed, P scavenger in sewage treatment plants and a suppressor of ammonia volatilization. Notwithstanding the potential of BNF as a sustainable alternative to the traditional slash-and-burn, there are constraints to its utilization. A thorough understanding of the ecology of the various nitrogen fixing systems is crucial to the acceptance and successful application of BNF technologies for sustainable crop productivity. Several environmental factors that affect the performance of the legume/rhizobial symbiosis (Alexander, 1985; Atkins, 1986) and actinorrhizal (Frankia) symbioses (Torrey, 1978; Tjepkema *et al.*, 1986) have been studied. Gibson (1977), Munns and Francop (1982), Friere (1984) and Ladha *et al.*(1990) have reviewed the soil constraints to symbiotic performance. Major considerations affecting either the microbe, the host, or their symbiotic interaction include soil acidity (Munns, 1977), other acid-related factors including aluminium and manganese toxicity, and calcium deficiency (Beck and Munns, 1984, 1985; Singer and Munns, 1987), phosphorus (Cassman *et al.* 1981; Almendras and Bottomley 1988), salinity (Singleton and Bohlool, 1983) and flooding (Ladha *et al.*, 1992).

The symbiotic activity within a plant community is also conditioned by the amount of N mineralized from organic sources (George *et al.*, 1988). The performance of azolla is also influenced by P deficiency, sensitivity to drought and high temperature (Watanabe and Liu, 1992). In the presence of native rhizobia, an introduced Rhizobium strain usually faces strong competition for nodule formation which may eventually affect its successful establishment and effective performance (Bohlool *et al.*, 1992). The competition is, however, complex as environmental factors such as soil temperature, or additions of P and K can alter competition patterns (Weber and Miller, 1972; Dowling and Broughton, 1986; Almendras and Bottomley, 1988). In symbiotic associations, both partners are subjected to biological constraints such as disease and predation which can directly or indirectly affect the amount of N fixed, as well as the quantity made available to other components of the cropping system. In general, and especially, so far as legumes are concerned, the amount of nitrogen fixed is directly related to the growth potential of the host in a particular system (Bohlool *et al.*, 1992). When growth is limited, for example by disease, the amount of nitrogen fixed will be reduced accordingly. In developing countries, the scale of production, the availability of suitable carrier material, preservation of germplasm and shelf-life are serious constraints to the use of microbial inoculants. The lack of reliable techniques for measuring nitrogen fixation in the field especially for perennial pasture, legumes and trees (Danso *et al.*, 1992) is also a setback. BNF technology is difficult to deliver by normal extension mechanisms. Thus a lack of illustrative and explanatory materials seriously affects its adoption.

2.5.5 Chemical fertilizer application

Chemical fertilizers have had a substantial impact on food production in the recent past, and are today an indispensable part of modern agricultural practices. Russel *et al.*(1989)

estimated that in 1985, the use of 38.8 million Mt of N fertilizer on cereals globally resulted in increased world cereal production of 938 million Mt; more than half of the total cereal production in that year. They defined a relationship between world N fertilizer use on cereals (x) and mean world cereal yield (Y), between 1956 and 1985, by the equation:

$$\mathbf{Y = 1202 + 13.3x}, \qquad R^2 = 0.983 \qquad \text{.......................................(2.3)}$$

emphasizing N fertilizers as a major driving force in food production. There are, on the other hand, vast areas of the developing world where N fertilizers are neither available nor affordable. Furthermore, in most of these countries, removal of N fertilizer subsidies, due to balance of payment problems, has resulted in higher prices and lower supplies. Even in wealthier nations, economic and environmental considerations dictate that biological alternatives which can augment, and in some cases replace N fertilizers must be sought. Modern agriculture is based on maximum output in the short term, with inadequate concern for input efficiency or stock maintenance (Odum, 1989). Nitrogen fertilizers rank first among the external inputs to maximize output in agriculture. Input efficiency of N fertilizer is one of the lowest among the plant nutrients, and, in turn, contributes substantially to environmental pollution. The continued and unabated use of N fertilizers would further accelerate depletion of stocks of non-renewable energy resources used in fertilizer production. The removal of large quantities of crop produce from land additionally depletes soil of its native N reserves. In the developed countries, Plucknett and Smith (1986) and in developing countries, Barker and Chapman (1988) and Byrlee (1987) have reported of declines in crop yields even with continuous use of N fertilizers. Odum (1989) indicated that a 4-fold increase in crop yield during the 1970s and 80s occurred at an 11-fold increase in fertilizer N use in Georgia, U.S.A. An analysis of several years data on rice yields from experimental stations in Philippines, Indonesia and Thailand by Pingali *et al.* (1990) shows trends of stagnation or decline. Pieri (1986), who summarized experimental results by the International Research Institute for Tropical Agriculture (IRAT) in Saria (Burkina Faso), over a period of 29 years, concluded that fertilizer application is an effective means to increase yields in arable farming systems without fallow. However, in the long term problems may arise, especially, in drier areas as reported by Pichot *et al.* (1981), that application of NP and NPK fertilizers result in increased yields for some years, but in the long run they lead to decreased base saturation and acidification of the soil.

In addition to the above, the external costs of environmental degradation and human health resulting from the continuous use of chemical fertilizers is alarming. Nitrate in ground water is a major health concern. Nitrogen in runoff and surface waters has led to extensive pollution and eutrophication of rivers and lakes. The gaseous oxides of nitrogen, derived from N fertilizers are highly reactive and pose a threat to the stability of the ozone layer (Keeney, 1982). These are the circumstances that justify the search for alternative sources of soil fertility improvement that are sustainable and environmentally friendly.

2.6 Cropping systems

A cropping system is a crop production technique involving a space and time arrangement of one or more crops known to usually maximize productivity per unit area of land (Agboola, 1980). The choice of a cropping system depends on the physical environment, socio-economic factors and specific objectives of the farmer. There are thus a large number of cropping systems, a few of which are discussed below.

2.6.1 Intercropping

In this cropping system, several types of crops are grown simultaneously in one field (Ruthenberg, 1971). The main benefit seems to be an insurance against failure of any one crop. Several workers have reported improved production levels of intercropped cereals and legumes over sole cropping (Okigbo and Greenland, 1975; Andrews and Kassam, 1976; Agboola and Fayemi, 1972, Ofori and Stern, 1987). Willey (1979), and Francis (1989), have provided insight into the biological interactions of mixed cropping systems in general, while Ofori and Stern (1987) dealt with cereal-legume intercropping systems in particular.

Among the reasons for the yield advantages obtained from intercropping are the following:

(i) different branching and leaf patterns of the various crops may intercept more light compared to sole crops;

(ii) roots of different crops could use nutrients and water from different zones of the soil, hence more nutrients and moisture are utilized;

(iii) different crops may grow at different rates and thus a slow growing crop will not compete in the early stages with a quick one. The quick growing types, may use moisture which could be lost if only a single slow growing crop was in the field;

(iv) legume crops in an intercrop may produce nitrogen for use by other crops, or in the least, would spare much of the soil N for use by the non-N_2-fixing crop;

(v) pests, diseases and weed problems are usually reduced.

For maximum efficiency however, it is important to use determined optimum plant populations and spacing. Crops which interact well together should be sown and the choice of a variety is especially important.

2.6.2 Sole cropping

Sole cropping is the growing of a crop variety or species in pure stand. This is the system least practised by the local farmers in developing countries. It is, however, a common practice on government farms, research stations and University farms (FAO, 1980). According to Federer (1993), the main advantage of sole cropping is that it is easily mechanized in contrast to its numerous disadvantages which include:

(i) high risk of crop failure

(ii) yield decline with continuous cultivation as a result of pest build up.

(iii) labour distribution and saleable produce is limited to certain parts of the year.

(iv) increasing need for commercial fertilizers.

2.6.3 Crop rotation

Crop rotation may be defined as alternating two or more different crop species over time on the same land, following a regulated sequence with the objective of improving soil productivity (FAO, 1980). Whichever pattern of cropping is employed it is useful to change the crop from season to season to reduce the decline in soil fertility. Different crops usually have different nutrient needs and different rooting patterns. Legumes have the advantage that they may return to the soil nitrogen to supplement the soil N available to cereals and root crops. The differences in growth and cultivation patterns with different crops help to prevent build-up of weeds, pests and diseases which tend to occur with repeated monocropping. Apart from beneficial effects on soil fertility and the reduced pest problems, rotations also tend to even out labour peaks and economic risks (FAO, 1987). The nature of the rotation is essential and the more the proportion of crops with plentiful residues included in the rotation, the more will the recycling of these residues be enhanced. Where residues are abundant it will no doubt be possible, if recycling is very effective, to solve the organic matter problem.

2.7 Legumes in multiple cropping

Legumes have long been recognized as important components of crop rotations and intercrops. Apart from the direct benefits of N_2-fixation in the grain or fodder produced, any N contributed to the soil can be used by subsequent or companion crops. Legumes that can contribute N to subsequent crops in rotations or from legumes to companion crops in intercrops include grain legume crops, legume green manures, legume cover crops, tree crops or legume/grass leys. The benefit from N_2-fixation is seen when the N budgets of systems with or without the legume component are compared (Searle *et al.*, 1981). This approach, however, does not bring out the net contribution of N from N_2-fixation. The legume may in fact be removing more N from the soil than it is contributing but since it may still be removing less overall than the non-legume crop with which it is being compared, a net benefit of including the legume will be seen (Nambiar *et al.*, 1982).

Similarly, if a legume is grown in a mixture with a cereal, it can improve the N economy of the cereal both by contributing N to the soil for uptake by the cereal (often called nitrogen transfer), or simply by the legume removing less N than if the cereal was grown in the pure stand. This is sometimes referred to as the N sparing effect (Vallis *et al.*, 1967), which means that if the legume removes only a small amount of soil N, more is then available for use by the companion crop (Danso and Papastylianou, 1992). To optimize the contribution of N_2-fixation, a better understanding of the legume within various cropping systems is needed (Petch and Smith 1985).

2.7.1 Legumes in crop rotations

There is comparatively little quantitative information on the amount of N available to crops succeeding legumes in a rotation. Most of the above-ground parts of grain legumes are removed at harvest so that a substantial portion of the residual effects must come from the below-ground parts and any leaves which fall to the soil during growth of the crop. In northern Nigeria, maize grain yields were found to be greater following a groundnut crop than after crops of cowpea, cotton or sorghum. The yield increase was related to an availability of mineral N in the soil after groundnut (Jones, 1974). The fact that no such beneficial effect was found after growth of cowpea in the same experiment indicates that residual effects do not always occur even with legume crops. In Zimbabwe, the yield of maize was greater after bambara groundnut than after groundnut (Mukurumbira,1985). In India, pigeon pea was found to give a residual benefit to a subsequent maize crop of 38-49 kg N ha^{-1} (Kumar Rao *et al.*, 1983) which was partially attributed to a contribution of N from pigeon pea leaf fall of 30-40 kg N ha^{-1} The residual benefit does not necessarily demonstrate a contribution of N from the legume N_2-fixation but could simply be due to sparing effects of soil N (Eaglesham *et al.*,1982). In Thailand, Suwanarit *et al.* (1986), using ^{15}N-fertilizers, showed that maize grown after legumes (mungbean, groundnut and soyabean), took up 17-23 kg N ha^{-1} more N than maize grown after a crop of maize. However, only in the case of soyabean was some of this N shown to have come directly from N_2-fixation. For grain legumes to play a more important role in the maintenance of soil fertility for other crops in the rotation, they must obviously leave more N from N_2-fixation than the amount of soil N that is removed in the crop. The role of grain legumes in contributing N to cropping systems is bound therefore to be compromised by the N removed in the grain (Henzell and Vallis, 1977). Lablab (*Lablab purpureus*), a relatively 'unimproved' legume with vigorous vegetative growth and poor grain yield left more residual N than groundnut, soyabean or pigeon pea (MacColl, 1989). A smaller grain yield of the legume might be a price that must be paid if the amount of legume N contributed through residual effects is to be increased.

2.7.2 Effects of intercropping on N_2-fixation

The overall benefit of growing two crops in a mixture will be a net benefit in which the yield contributed by the additional crop exceeds a small competitive reduction in the growth of the other and this is often seen where a short legume is intercropped with a tall cereal. For example, nodulation and total N fixed in groundnut were greatly reduced where it was intercropped with maize, sorghum or millet (Nambiar *et al.*, 1982). Similarly, growth and total N-fixed in soyabean wee reduced by a tall sorghum intercrop, whereas N_2-fixation of soyabean was not reduced by a dwarf sorghum (Wahua and Miller, 1978), indicating that the reduction in yield and N_2-fixation was partly caused by shading.

2.8 Nitrogen in an intercrop system

2.8.1 Components of the system

For the purpose of this review, a simple descriptive diagram is presented in Fig.2 to indicate the main nitrogen pathways in an intercrop system. The main inputs are atmospheric nitrogen and nitrogen fertilizers and outputs come from harvested and decaying material, denitrification, leaching and volatilization. Most of the outputs represent losses from the system. Residues and decaying material contribute to a "pool" of soil organic matter (SOM) and microbes assist in the mobilization as well as release of nitrogen from this pool. Most of the nitrogen contained in the SOM is generally stable. Only a small proportion, of the order 1-3 % becomes available annually to plants through mineralization to inorganic forms and this has the

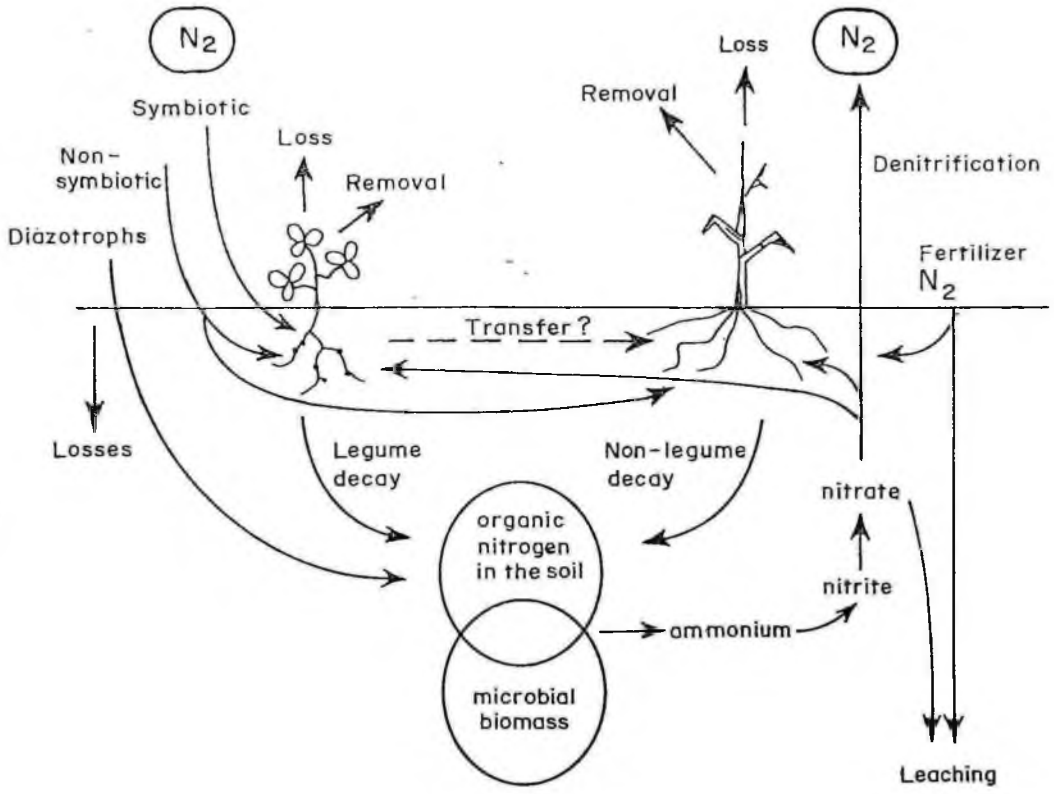


Fig. 2 Main nitrogen pathways in a legume/non-legume intercrop system. (The length or size of arrow is not an indication of its relative importance.)

SOURCE: Stern, W. R. (1993)

potential to re-enter the nitrogen cycle (Ladd,1990). The soil organic matter pool is in a continual state of synthesis and decomposition and acts as a sink and also a source of carbon and nitrogen. While microbial biomass is important in sustainability, little is known about its seasonal variation or how it changes with rotations or agronomic practices such as intercropping (Hauck and Tanji, 1982).

2.8.2 Nitrogen balance and some interactions

In intercrop systems containing a legume as a major component, the main sources of nitrogen to plants are the atmospheric nitrogen fixed in the legume, the nitrogen available from the soil either in organic or inorganic form and the nitrogen contained in applied fertilizers. Losses of nitrogen occur through harvested material, principally seed, and through denitrification, leaching and volatilization. While in some circumstances, intercropping with a legume may not contribute significantly to the total nitrogen economy, the loss of nitrogen from a comparable non-legume stand is often much greater. Ofori and Stern (1987), reported that by and large, intercropping with a legume will maintain the system in a positive nitrogen balance and if there has been good growth of the legume, the nitrogen contribution can be significant. The nitrogen economy of intercrop systems, was discussed in some detail in the review by Ofori and Stern (1987) and they made a number of salient points which were:

(i) provided the soil is not devoid of nitrogen, then at the end of the growing season, approximately half of the nitrogen contained in the legume crop will have been derived from atmospheric nitrogen.

(ii) shading of the legume by the non-legume component will reduce the growth of the legume and so reduce the amount of nitrogen fixed; however, this is not invariably so and some legume crops even though shaded, can continue to fix nitrogen and contribute significantly to the nitrogen economy of the intercrop system.

(iii) legumes with indeterminate growth habit fix nitrogen more efficiently than the determinate ones.

(iv) seed harvested from the component crops is likely to be largest source of nitrogen loss from the intercropping system and can range from 50 to 150 kg N ha^{-1}.

(v) the net nitrogen contributed by the legume to the soil will depend on how much has been stored in the seed.

(vi) provided the level of available soil nitrogen is not high, the legume can use soil nitrogen without impairing its nitrogen-fixing ability.

(vii) small amounts of applied nitrogen fertilizer may stimulate not only the growth of a companion crop but the legume as well, enhancing atmospheric nitrogen fixation.

(viii) where the total nitrogen needs of an intercrop system are not met, either because of insufficient available soil nitrogen or because of inadequate nitrogen fixation by the legume, competition for nitrogen will occur between the component crops; in these circumstances, any nitrogen fixed by the legume is likely to accumulate in the legume seed.

2.8.3 Nitrogen transfer

Nitrogen transfer is the movement of nitrogen from a nitrogen-fixing legume to another crop, either during growth of an intercrop association with a legume component, or as residual nitrogen for the benefit of a succeeding crop (Stern, 1993). Brophy *et al.* (1987) found that spatial arrangement can modify transfer; van Kessel and Roskoski (1988) on the other hand found no effect of row spacing. In discussing the nitrogen transfer from legumes to grass in forage legume/grass communities, Heichel and Henjum (1991) observed that transfer was greater in older than in seeding year stands, and concluded that "the major route of legume/grass nitrogen transfer is probably indirect, through death of members in the sward - rather than from direct transfer". Peoples and Herridge (1990) commented "that direct transfer of N from legume to non-legume may not be a rapid or common phenomenon". The ^{15}N method of measuring nitrogen fixation and transfer has been refined in recent times (Peoples and Herridge,1990; Giller and Wilson, 1991) and appears to be reliable. In a carefully conducted study with maize and cowpea in which two methodologies were compared in the field and the study duplicated in a glasshouse, Ofori *et al.*(1987) observed no direct nitrogen transfer from legume to grass. Rerkasem and Rerkasem (1988), working in Thailand with maize and ricebean (*Vigna umbella*), arrived at a similar conclusion. Generally, there appears to be a remarkable similarity in the basic results reported as far as nitrogen transfer in legume/non-legume intercropping system is concerned.

2.8.4 Importance of nitrogen fixation and transfer

Besides nitrogen available in the soil or applied in fertilizer, the most important source of nitrogen in a non-legume /legume intercrop system, is the nitrogen fixed by the legume. Many variables influence the nitrogen economy of an intercrop system containing a legume as a major component. The efficiency with which the legume fixes atmospheric nitrogen is essential in maintaining the nitrogen economy. This, however, depends on the health of the legume. The transfer of the nitrogen fixed, either directly to a companion crop in the current growing season (direct transfer) or to the soil, and its subsequent availability to either the companion non-legume in the current season (indirect transfer), or to crops grown subsequently (residual transfer), also influences the nitrogen economy of an intercrop system. Generally, transfer during the current season is small, and most transfer occurs at the end of the legume crop cycle. To promote transfer of nitrogen to the non-legume in an intercrop system, it is imperative to strive for as high a biomass of legume with as high a concentration of nitrogen as possible and then to devise appropriate management of legume residues to permit the build up of soil organic matter and encourage uptake by the non-legume. The quality of the residue will also be important in raising the nitrogen level in the system.

Beck and Roughley (1987) have discussed some ecological factors that limit the effectiveness of the rhizobium/legume symbiosis and recently, Robson and Bottomley (1991) reviewed the limitations to legume production in agricultural systems. They cited such factors as the presence of appropriate rhizobial strains, competition among rhizobia and effectiveness of nodulation. Soil phosphorus status and the internal phosphorus requirement of the legume species or cultivar, suboptimal soil temperatures and inadequate soil moisture availability were all factors influencing the success of the rhizobium/legume symbiosis.

2.9 Assessment of intercrop productivity

Many criteria are involved in making comparisons among intercropping systems and in comparing them with sole cropping. Some of these are associated with economic and social judgement. In this review, the focus is on yield.

2.9.1 Land Equivalent Ratio (LER)

Land equivalent ratio (*LER*) is a measure of the efficiency of an intercrop in terms of land area required under sole cropping to give the yields obtained from the individual crops (Willey and Osiru, 1972). It is estimated as:

$$LER = \sum_{i}^{n} \frac{y_i}{y_s} \qquad \text{.......................................(2.4)}$$

where y_i is the yield of component crop i in intercropping, and y_s is the yield of the crop in sole cropping. This is an index to compare productivity of the two cropping systems within a particular season when products of component crops are essential to farmers. A higher *LER* indicates a more productive practice. Many papers have reported a significant advantage of intercropping over sole cropping in terms of dry matter production and grain yield, as calculated on the basis of the land equivalent ratio (Patel *et al.*, 1993;Tobita *et al.*, 1994; Ofosu-Budu *et al.*, 1995).

Limitations to the use of *LER* should be realized, particularly when it is used to compare the productivity of an intercrop and sole crops. When yields of sole crops at the recommended densities are compared with those of intercrops in which density may be altered as an experimental variable to determine optimum density, it is likely that the advantage of intercropping is over estimated (Ifenkwe *et al.*, 1989). This over-estimation is likely to occur in an "additive" experiment where intercropping of two components together has twice the plant density of individual sole crops (Ofori and Stern, 1986). Another difficulty of comparing yields in sole cropping and intercropping is that the two cropping systems may require different inputs, and comparison of the two systems at a particular condition of input for calculation of LER may favour one over the other. For example the use of chemicals to control pests and diseases in trials may underestimate the advantage of intercropping, if intercropping reduces pest and disease incidence in farmer's fields. Again the concept of *LER* does not include the time factor as it is simply a summation of yields in intercropping to that in sole cropping, of all component crops. This tends to overestimate advantage of intercropping particularly when component crops differ greatly in maturity time, as the estimation of *LER* assumes that the land which early-maturing crop has occupied will not be used after its harvest until the harvest of the late-maturing crop. This may be common in intercropping where the canopy of late-maturing crop would spread to occupy the whole area, but in the case of sole cropping another crop may be planted immediately after the harvest of the early-maturing crop.

2.9.2 Area Time Equivalency Ratio (ATER)

One way to overcome the limitation of *LER* is to use yield production per day as proposed by Hiebsch and McCollum (1987). This concept has produced another ratio (*ATER*) which is computed as follows:

$$ATER = \sum_{i}^{n}\left(\frac{\left(y_i / t_i \right)}{\left(y_s / t_s \right)} \right) = \frac{1}{t_i}\sum_{i}^{n}\left(t_s . y_i / y_s \right) \quad \text{.......................................(2.5)}$$

where t_i is the total duration (days) of an intercrop, t_s is the duration (days) of crop in sole cropping, and y_i and y_s are as defined earlier. When there are only two components, maize (m) and cowpea (c), in an intercrop, and period of early-maturing crop (c) is a part of long-duration crop (m), then ATER is expressed in the following:

$$ATER = \{ (Y_{mc}/Y_{mm})t_m + (Y_{cm}/Y_{cc})t_c \} / T \quad \text{.......................................(2.6)}$$

where Y_{mm}, Y_{cc} are the sole crop yields of maize and cowpea respectively, Y_{mc} and Y_{cm} are the respective yields from the intercrop, Y_{mc}/Y_{mm} and Y_{cm}/Y_{cc} are the relative yield of intercropped maize and cowpea to sole crop (partial *LER*) and t_m, t_c, and T are the durations of maize, cowpea, and whole cropping system.

In *ATER*, relative yield of a short-duration crop is adjusted according to the duration of that crop relative to the late-maturing crop. Results showing the superiority of intercropping over sole cropping in terms of *ATER* have been reported (Patel *et al.*,1993; Tobita *et al.*,1994). When Hiebsch and McCollum (1987) calculated *ATER* for numerous crops available in the literature, they found that a large number of studies where *LER* was greater than 1 showed *ATER* of around 1 indicating that in these cases, there were no advantages of intercropping in biological efficiency (production per day). It is, however, likely that *ATER* underestimates the advantages of intercropping when component crops differ in growth duration (Fukai, 1993). One reason for this is that it is not common to be able to plant a crop immediately after the harvest of a preceding crop. Therefore there is 'lost' time in terms of biological productivity in sole cropping. It is also possible that a growing season is not long enough to have a double crop in sole cropping, but it may be possible to have a long duration crop intercropped with a short-duration crop. Fukai (1993), suggested that in semi-arid areas where double cropping is not possible, *LER* may be used for comparison whereas in humid tropics with continuous growing season *ATER* may be more appropriate.

2.9.3 Area Harvests Equivalency Ratio (AHER)

In areas where a long growing season is interrupted by a short dry period, AHER may be appropriate (Balasubramanian and Sekayange, 1990). During the growth of a late maturing crop, a short-duration crop (j) may be grown m_j times. The total yield of that crop in sole cropping is the product of sole-crop yield ($y_{j,s}$) and m_j, and this is used as a basis of assessment.

$$AHER = \sum_{i}^{n} \left(\frac{y_i}{y_s m} \right) \qquad \text{......................................(2.7)}$$

2.10 Summary of literature review

Crop production in peasant cropping systems in the semiarid areas of West Africa is generally constrained by low and uncertain rainfall, poor soil fertility and lack of credit facilities to purchase inputs such as fertilizers and improved varieties (Bationo et al., 1999). Knowledge of land use management for the tropics is important to address perpetual low crop productivity and to alleviate poverty.

Biological management systems are particularly appropriate to address the constraints in peasant cropping systems in the semi-arid areas of West Africa. Management systems developed to address these constraints include:

- The use of organic and N and P mineral fertilizers (Bationo and Mokwunye, 1991)
- Intercropping of cereals and legumes (Agboola and Fayemi, 1971)
- Legume-based cropping systems e.g. herbaceous green manuring, legume cover crops, agroforestry, improved fallow (kang et al., 1990; Yamoah et al.,1996)
- Crop residue mulch management (Madiangne et al., 1999) and
- Integrated soil husbandry comprising a combination of the above (Drechsel et al., 1996; Palm et al., 1997)

Crop yields will continue to decline in so far as appropriate remedial measures are not put in place to restore fertility.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

In this chapter the basic analytical techniques, the experimental design, data collection and the statistical approach used throughout the study will be described.

3.2 Experimental site

The experiment was conducted at the Soil Research Institute, Kwadaso, Kumasi (6°40' N, 1° 4'W; 255 m above sea level) (Soil Survey Staff, 1990) in the Ashanti Region of Ghana. The mean annual rainfall at the experiment site is 1473 mm per annum; the rainfall pattern is bimodal, the rainy season starting in March and ending in October, with a short dry spell in August.

The soil is classified as Bekwai series which falls under Forest Ochrosols (Charter, 1956) or Rhodudult (Soil Survey Staff, 1990) or Ferric Acrisol (FAO-UNESCO, 1990). The site is on the upper slope position of the landscape (about 2.5 %), it is well drained and is derived from phyllite. The topsoil generally has a dusky red colour and a texture of clay loam. The mean chemical properties of the surface soil and the subsoil (15-30 cm) at the beginning of the experiment is shown in Table 4.1. The field had been cropped to cowpea in August 1994 (minor season), and to maize in April 1995 (major season) and left fallow after the 1995 major season cropping. There was no evidence of *Rhizobium* inoculation having been practised on the cowpea in recent times. The vegetation around the experimental site consisted mostly of the weeds, *Chromolaena odorata* and *Panicum maximum*. Soil was sampled at depths of 0 to 15 cm and 15 to 30 cm. The samples were transported to the laboratory at the Soil Research Institute, Kumasi and air-dried. Undecomposed plant materials were sorted out and the samples crushed to pass through a 2-mm sieve. The sieved soil was thoroughly mixed and stored in thick polythene bags for laboratory analysis. Fresh soil samples were also stored in a refrigerator for mineral nitrogen estimations. Except where otherwise stated, all laboratory analyses reported in the following sections were carried out in duplicate.

3.3.0 Soil physical determinations

3.3.1 Determination of bulk density

About 1-2 cm depth of surface soil was removed from the sampling spot and the spot levelled. A 5cm diameter thin-sheet metal tube of known weight (W_1) and volume V was driven 5 cm into the soil surface. The soil around the tube was excavated and excess soil trimmed from the tube ends. The soil was put in an oven at 105 °C for 2 days and its weight (W_2) recorded. The bulk density (ρ_b) of the soil was calculated from the relation:

$$\rho_b = \frac{W_2 - W_1}{V} \qquad \text{.....................................(3.1)}$$

3.3.2 Gravimetric water content (θg) determination

A known weight (M_t) of freshly sampled soil was put in an oven at 105 °C for 2 days. The samples were removed and placed in a dessicator to cool. The new weight M_s was determined. The gravimetric water content was calculated as follows:

$$\theta_g = \frac{M_t - M_s}{M_s} \qquad \text{.....................................(3.2)}$$

3.3.3 Volumetric water content (θ_v) determination

The volumetric water content was obtained by the relation :

$$\theta_v = \rho_b . \theta_g \qquad \text{.......................................(3.3)}$$

3.3.4 Particle size analysis

Particle size distribution was determined by the modified Bouyoucos hydrometer method as described by Day (1965). A 40 g-soil sample was weighed into a dispersion cup and 100 ml of Calgon (sodium hexametaphosphate) solution prepared by dissolving 50 g of calgon in a litre of water was added. The suspension was allowed to stand for about 10 min followed by mixing for 5 min with a Vortex mixer after which the suspension was transferred into a sedimentation cylinder with the help of distilled water from a wash-bottle and the level of water brought to the 1 litre mark.

The suspension was allowed to equilibrate and the initial temperature taken. A plunger was inserted close to the bottom of the cylinder and the suspension stirred vigorously by moving it up and down several times (about 10 times). Timing was started immediately with a stopwatch and the hydrometer reading was taken at 5 min and at 5 h from the time of mixing of the suspension. The sand fraction was recovered by decantation and the dried weight recorded after it had been oven-dried for 2 days and cooled in a dessicator. The procedure was repeated for a blank which contained no soil and the textural class determined using the USDA textural triangle.

3.4 Chemical analysis

3.4.1 Soil pH

Soil pH was determined in both distilled water and 0.01 M $CaCl_2$ using a Glass electrode-Calomel electrode (McLean, 1982) MV 88 Pracitronic pH meter. In both water and 0.01 M $CaCl_2$, soil pH was measured at a soil:solution ratio of 1:1.

3.4.2 Organic carbon.

Organic carbon was determined using the wet combustion method of Walkley and Black (1934). Ten ml of 1N potassium dichromate ($K_2Cr_20_7$) solution and 20 ml concentrated sulphuric acid (H_2SO_4) were added to 0.5 g soil which had been passed through a 0.5 mm sieve. The flask was swirled to ensure full contact of the soil with the solution after which it was allowed to stand for 30 min. The unreduced $K_2Cr_2O_7$ remaining in solution after the oxidation of the oxidizable organic material in the soil sample was titrated with 0.2 N ammonium ferrous sulphate solution after adding 10 ml of orthophosphoric acid and barium diphenylamine sulphate indicator.

3.4.3 Total nitrogen

Half of a gram (0.5 g) of soil was weighed into a 250 ml Kjeldahl flask and a tablet of the digestion accelerator, selenium catalyst, added, followed by 5 ml conc. H_2SO_4. The mixture was digested until the digest became clear. The flask was then cooled and its contents transferred into a 100 ml volumetric flask with distilled water and made to volume. A 5 ml aliquot of the digest was taken into a Markham distillation apparatus and 5 ml of 40 % NaOH was added to the aliquot and the mixture distilled. The distillate was collected in 5 ml of 2 % boric acid to which a few drops of a mixed indicator containing methyl red and methylene blue were added and then titrated against 0.01 N hydrochloric acid (HCl) (Bremner, 1965).

3.4.4 Available phosphorus

Available phosphorus was determined using the method of Bray and Kurtz (1945). Thirty grams (30 g) of soil was weighed into a 100 ml centrifuge bottle and 60 ml of Bray 1 solution (0.03 M NH_4F in 0.025 M HCl) was added. The suspension was shaken for 1 min on a reciprocating shaker and filtered through a No.42 Whatman filter paper into a 100ml volumetric flask. Available phosphorus in the filtrate was determined colorimetrically with the molybdate-ascorbic acid method of Watanabe and Olsen (1965) as follows:

Twenty ml aliquots of the filtrate were taken (in duplicate) into 50 ml volumetric flasks. The pH was adjusted using p-nitrophenol indicator and neutralised with few drops of 4 N ammonium hydroxide (NH_4OH) until the solution turned yellow. The solution was diluted to about 40 ml with distilled water after which 8 ml of reagent B (a mixture of ascorbic acid and ammonium-molybdate solution) was added and made to 50 ml volume with more distilled water. The solution was mixed thoroughly by shaking and allowed to stand for 15 min for the colour to stabilize. A blank was prepared with distilled water and 8 ml of reagent B. The method was calibrated using a 5 (μg^{-1}) standard P solution in the same manner as above. The intensity of the blue colour was measured using the Philips PU 8620 spectrophotometer at a wavelength of 712 nm.

3.4.5 Ammonium-N and Nitrate-N determinations

Five grammes of fresh soil samples was weighed into an Erlenmeyer flask and 50 ml of 2 M KCl solution added. The contents were shaken for 30 min. Twenty ml of the filtrate was taken into a 100 ml micro Kjeldahl steam distillation apparatus and 200 mg of MgO previously dried at

300 °C for 1 hr was added. The flask was connected to the distillation apparatus and about 40 ml distillate was collected in 15 ml of 0.005 M HCl solution for ammonium-N determination.

To determine nitrate-N, a fresh receiver containing 15 ml of 0.005 M HCl was used to receive the distillate to which has been added 200 mg of Devarda's alloy. In each case the distillate was titrated with 0.005 M NaOH solution. The NH_4^+-N and the NO_3^--N were calculated as:

$$Y_N = \frac{70.A_1}{2} \; ppm \qquad \text{......................................(3.4)}$$

where A_1 is the difference between the millilitres of HCl used to reduce NH_4Cl and the millilitres of NaOH to neutralize the HCl.

3.5 Field experiment

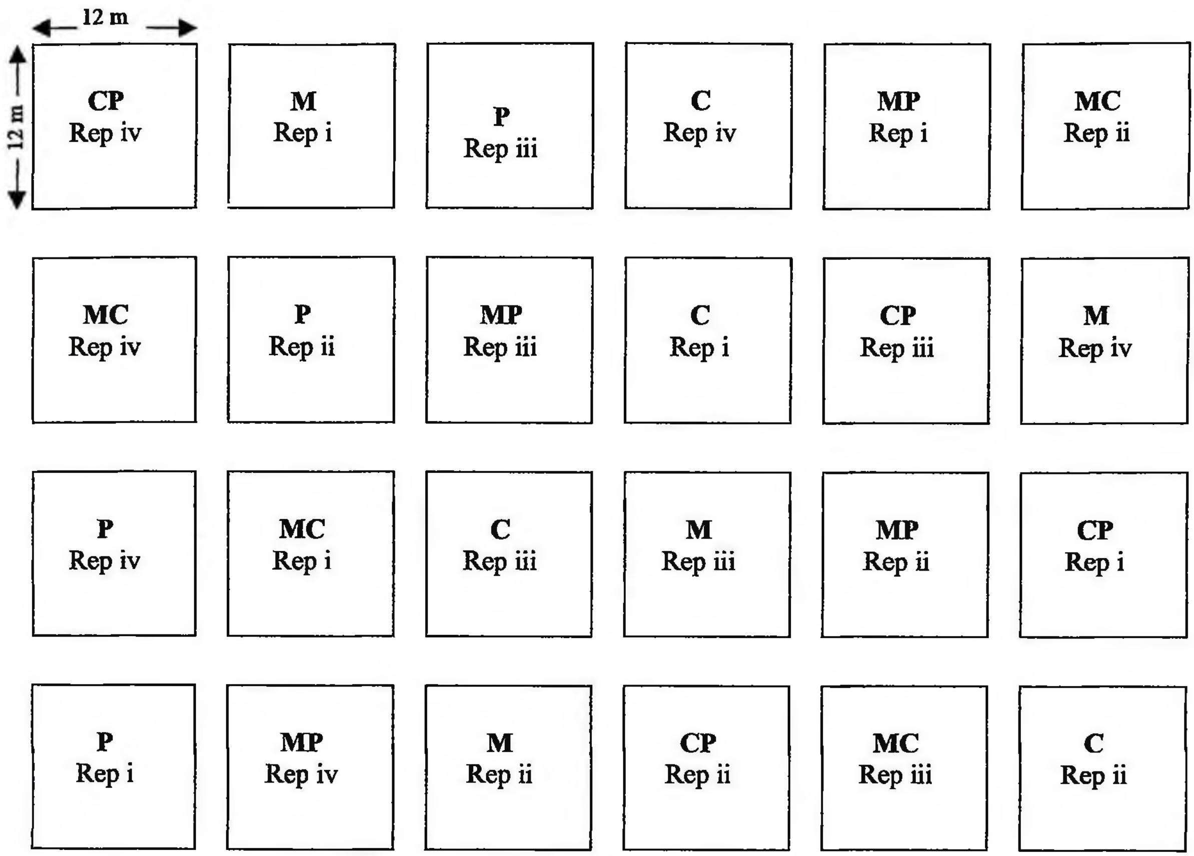
3.5.1 Experimental design for the first field experiment

The field was hand cleared of secondary thicket in August 1996 and the plant biomass was removed from the plots. The experiment was conducted as a randomized complete block design. Treatments were replicated 4 times. Six crops/crop combinations were used namely: sole maize (*Zea mays L var. obatanpa*) (M), sole cowpea (*Vigna unguiculata L.Walp*) (C), sole sweet potato (*Ipomea batatas*) (P), maize-cowpea intercrop (MC), maize-sweet potato intercrop (MP), and sweet potato-cowpea intercrop (CP). Individual treatment plots were 12 x 12 m. The crops were planted on 23 September 1996. Sole maize was planted at 90 x 40 cm. The planting distance for sole cowpea was 60 x 20 cm while that of sole sweet potato was 60 x 30 cm. The maize population was maintained in the MC intercrop system and the cowpea planted in between maize rows resulting in 1:1 (maize:cowpea) row proportion. Similarly the maize population was maintained in the MP intercrop system with 1:1 (maize:potato) row proportion. In the CP intercrop system the sweet potato was superimposed on the cowpea crop density resulting in a 1:1 (cowpea:potato) row proportion. For both cowpea and maize, three seeds were planted per hole. The seedlings were thinned down to two per hole 7 days after germination. Two (2) potato vines (about 15 cm) were planted per hill on the flat. Table 3.1 shows the plants per ha of the various cropping systems. Weeding by hand was done as often as necessary and the weeds removed from the plots. Spraying of Karate insecticide (36 ml^{-1} 15 L water) was done at weekly intervals on all treatments for 6 weeks. The field layout for the 1996 cropping season is shown in Fig.3.1. The experiment was carried out under rainfed condition.

3.5.2 Experimental design for the second field experiment

The second field experiment began in March, 1997. The dominantly grown weed *C.odorata* during the intervening fallow period was hand cleared and the trash removed from the plots. Each 12 x 12 m plot size of the first field experiment was divided into three (3) for the appropriate cropping system. Each plot size thus measured 4 x 12 m. The crop combinations (treatments) were as follows:

- C/CP = Cowpea following cowpea–potato intercrop
- C/P = Cowpea following sweet potato
- C/MC = Cowpea monocrop following maize-cowpea intercrop
- C/C = Cowpea monocrop following cowpea monocrop
- C/M = Cowpea monocrop following maize monocrop
- M/P = Maize monocrop following potato monocrop
- M/C = Maize monocrop following cowpea monocrop
- M/M = Maize monocrop following maize monocrop
- M/MP = Maize monocrop following maize-potato intercrop



CP Rep iv	**M** Rep i	**P** Rep iii	**C** Rep iv	**MP** Rep i	**MC** Rep ii
MC Rep iv	**P** Rep ii	**MP** Rep iii	**C** Rep i	**CP** Rep iii	**M** Rep iv
P Rep iv	**MC** Rep i	**C** Rep iii	**M** Rep iii	**MP** Rep ii	**CP** Rep i
P Rep i	**MP** Rep iv	**M** Rep ii	**CP** Rep ii	**MC** Rep iii	**C** Rep ii

M - Maize monocrop
C Cowpea monocrop
P - Potato monocrop
MC - Maize-cowpea intercrop
MP Maize-potato intercrop
CP - Cowpea-potato intercrop

Fig. 3.1. Field layout of treatments during the first cropping season.

- M/MC = Maize monocrop following maize-cowpea intercrop and
- MC/MC = Maize-cowpea intercrop following maize-cowpea intercrop.

Treatments were replicated 4 times. Planting of cowpea and maize as well as weeding and spraying were carried out as in the first cropping season. Planting of potato and its associated crop combinations however, was not possible because the potato vines (planting material) were severely affected by the long dry season encountered during the first field experiment. The field layout during the 1997 major cropping season is shown in Fig.3.2. The crop arrangement in the intercropping systems is shown in Fig. 3.3.

3.5.3 Planting density

The plant population ha-^{1} of the component crops in the sole cropping and the associated intercrops is shown in Table 3.1.

3.5.4 Data collection

At maturity, an area of 7.2 m^{2} was harvested from each plot to estimate total dry matter and grain/tuber yields. The dry weight of each treatment was determined after oven drying at 60 °C for 48 h. The land equivalent ratio (LER) and the area time equivalent ratio (ATER) for grain and total dry matter yield were used to evaluate the biological efficiency of the intercropping systems relative to sole cropping. They were calculated according to the method of (Hiebsch and McCollum, 1987). At the same time, soil samples were taken from the surface soil and the subsoil for chemical analyses. Cowpea was harvested 60 days after planting while maize was harvested 90 days after planting with potato (first field experiment) being harvested at 150 days after planting. Crop residues were removed from the plots after the first season harvest.

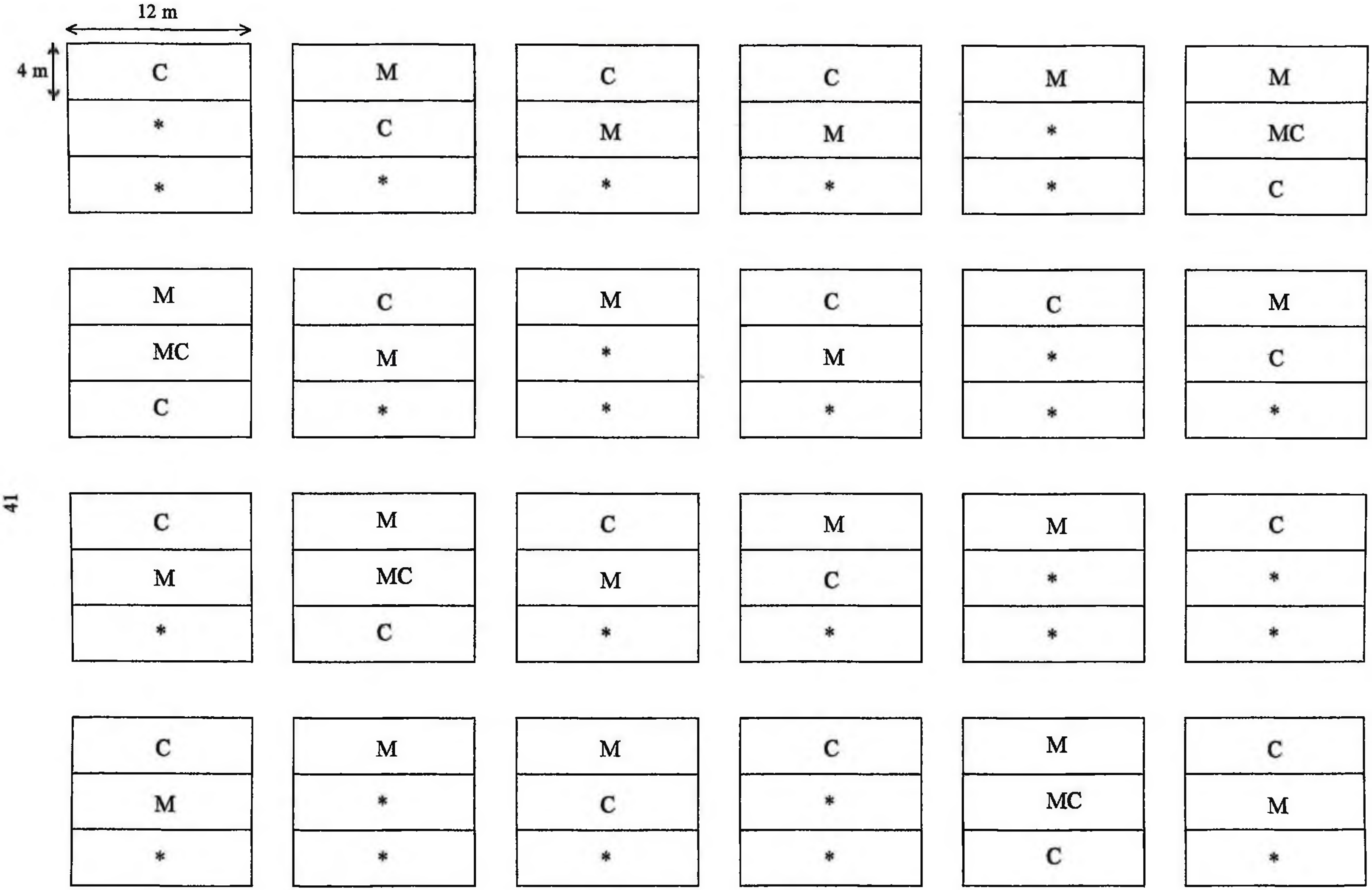


Fig. 3.2 Schematic layout of treatments during the 1997 major cropping season.
M = Maize monocrop, C = Cowpea monocrop, MC = Maize Cowpea intercrop, * = fallow

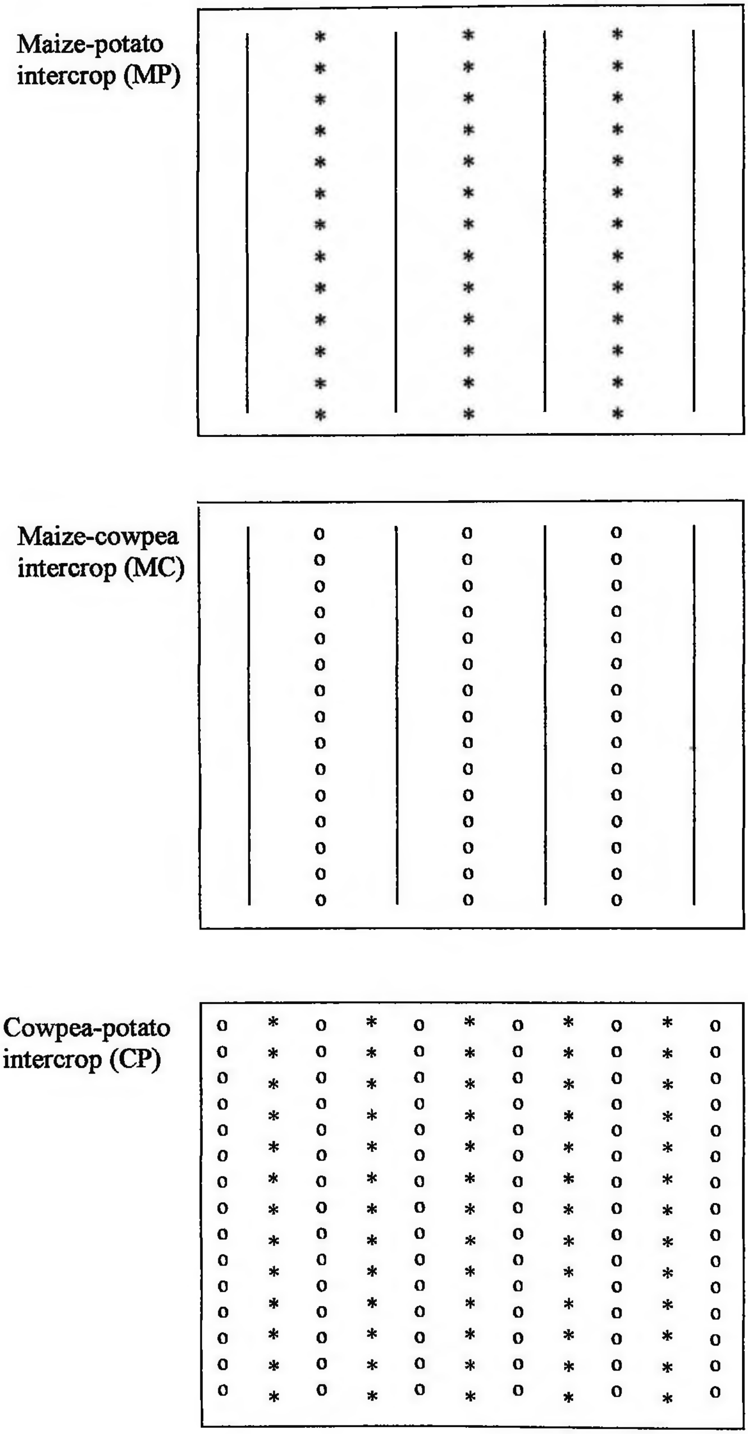


Fig. 3.3 Schematic presentation of the intercrop systems. (o = cowpea, I = maize and * = potato).

3.5.5 Statistical approach

The data collected was analysed using MSTAT-C (MSU, 1988). The testable hypothesis was:

- ☐ there is differential performance of cropping systems with respect to biomass yields, nutrient contribution/depletion and their impact on crop yield.

Analysis of variance was used to determine the effects of the cropping system on crop/s performance. Least significant difference (LSD) was used to separate significant means.

Table 3.1 Plant population per ha of the components crops of the intercrops

Cropping systems	Maize	Cowpea	Potato	Total
Maize-cowpea (MC)	55,556	111,111		166,667
Maize-potato (MP)	55,556		111,111	166,667
Cowpea-potato (CP)		166,667	74,074	240,741

CHAPTER FOUR

RESULTS

4.0 Rainfall distribution at the study site during the first and second cropping season

The average rainfall of 1473 mm per annum and the bimodal rainfall pattern is typical of the humid environments of West Africa. Rainfall amount at the start of the experiment rose from almost 60 mm in the month of September to a peak value of nearly 105 mm in October before declining drastically to less than 5 mm in the month of November (Fig. 4.1). It is evident from Fig. 4.1 that during the minor cropping season at the experimental site drought begins in November and continues through December to the following year.

The major cropping season (March- June) rainfall distribution is shown in Fig. 4.2. The drought period which begun in November 1996 extended to January and February, 1997. There was a high rainfall in the month on March (beginning of the rainy season) but declined to an almost a constant value of 100 mm in the months of April and May before rising to almost 250 mm in the month of June.

4.1 Initial soil characteristics

The soil bulk density of 1.2 g cm^{-3} calculated is low compared to 1.4 g cm^{-3} reported by Opara-Nadi (1993) who worked on a similar soil in South-eastern Nigeria. The gravimetric water content as well as the volumetric water content were, 0.35 g g^{-1} and 0.42 cm^3 cm^{-3} respectively; indicating sufficiently higher moisture storage at the start of the field experiment. The particle size analysis showed that the texture of the soil is sandy clay loam and it is typical of soils of phyllite parent material developed under semi-deciduous forest vegetation as suggested by Brammer (1962). The baseline soil chemical properties are shown in Table 4.1. The soil is acidic

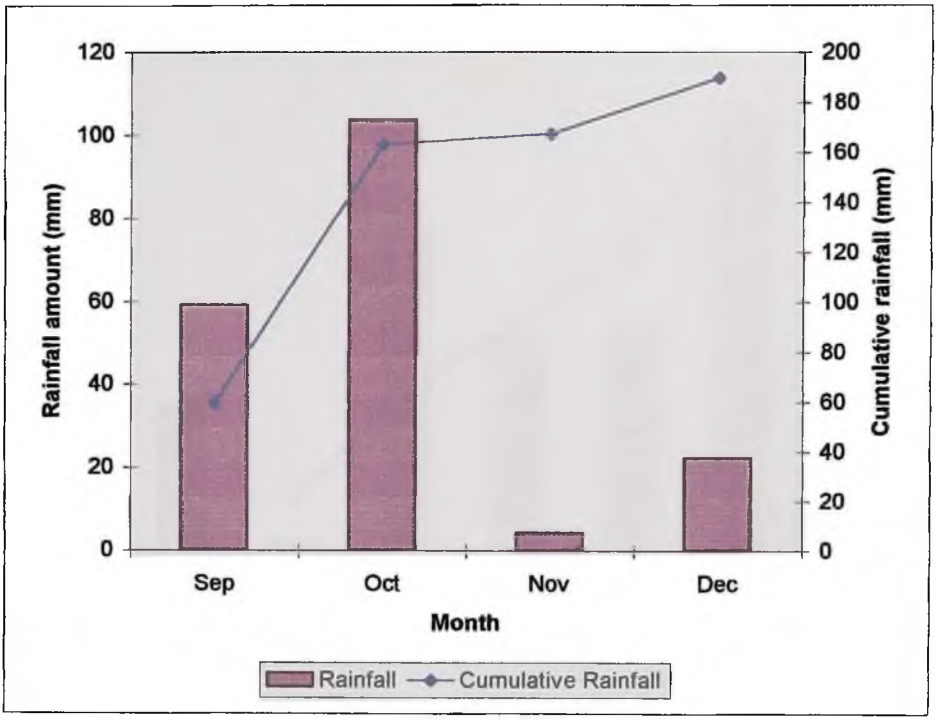


Fig. 4.1 Rainfall distribution and cumulative rainfall at the experimental site during the first season of the experiment (Sep. - Dec. 1996)

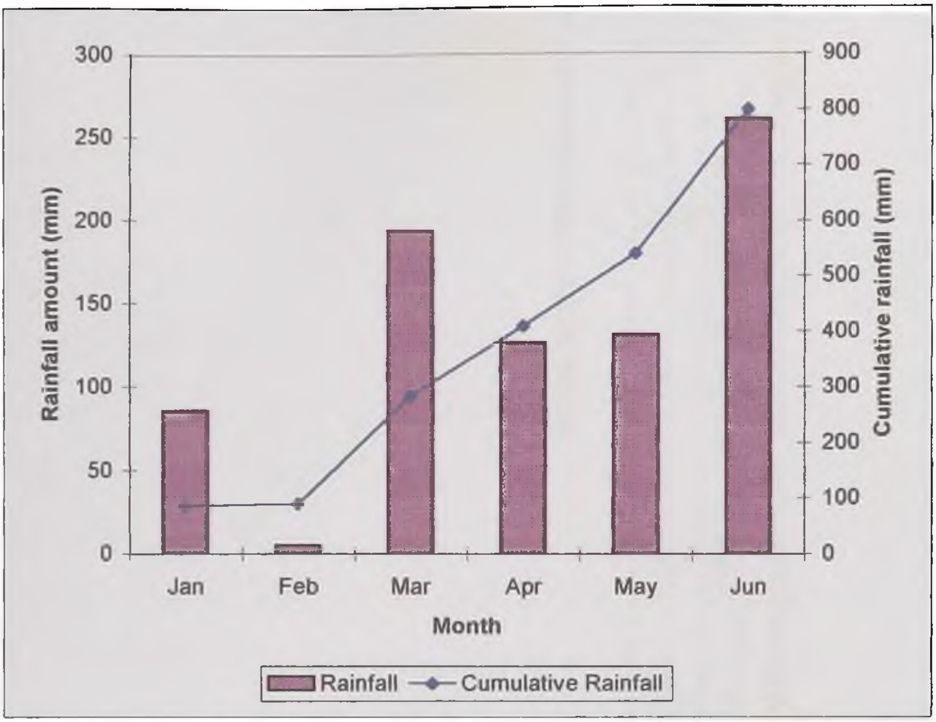


Fig. 4.2 Rainfall distribution and cumulative rainfall at the experimental site during the second cropping season of the experiment (Jan. - June 1997)

Table 4.1 Selected soil chemical properties of the field site prior to land clearing

Depth	*pH(1:1)H_20*	*pH (1:1)$CaCl_2$*	*% Org.C*	*% N*	*C/N*	*Avail.P (ppm)*	*NH_4-N (ppm)*	*NO_3-N (ppm)*	*T.N (pp*
(0-15 cm)	*6.0*	*5.6*	*1.54*	*0.15*	*10.3*	*2.8*	*65.33*	*25.2*	*90.53*
(15-30 cm)	*5.6*	*5.3*	*1.25*	*0.13*	*9.6*	*1.9*	*60.68*	*21.7*	*82.38*

T.N = Total available nitrogen (NH_4-N +NO_3-N) with pH declining with depth possibly due to increasing exchangeable Al at the lower depth (Chan et.al.,1992). The soil nutrients are typical of Ultisols suffering from acid infertility, especially aluminium (Al) toxicity, and the often-related problems of phosphorus deficiency and high P fixation as a result of continuous low-input cropping (Smithson and Giller, 1999).

4.2 Effect of cropping systems on some soil chemical properties

Intercropping resulted in much lower soil organic matter content in the topsoil than the corresponding monocrop. However, at the 15-30 cm soil depth, the average soil organic matter content of the monocrops was similar to that of the intercrops (Fig.4.3). Cultivation of crops resulted in decline of soil organic matter at both depths with grater decline occurring in the topsoil. Intercropping involving legumes least depleted the soil total nitrogen compared to the corresponding monocrops (Fig.4.4). The topsoil (0-15 cm) contained more soil total nitrogen than in the corresponding subsoil (15-30 cm). At the subsoil however, there was little variation between the intercrops and the monocrops. At the end of the study period, intercropping resulted in almost 14 % decline in soil available phosphorus at the 0-15 cm soil depth while monocropping showed a drop of 11 % at similar depth (Fig. 4.2). The cropping systems resulted in a decline of soil total available nitrogen (Fig.4.6). However, intercropping involving legumes showed a slightly higher levels at the 0-15 cm soil depth compared to the monocropping at the same depth. While intercropping resulted in almost 27 % decline, monocropping showed almost 30 % decline with respect to the initial soil total available nitrogen at the 0-15 cm soil depth. At the 15-30 cm soil depth, the decline in total available soil in the intercropping system was similar to that of the monocrops

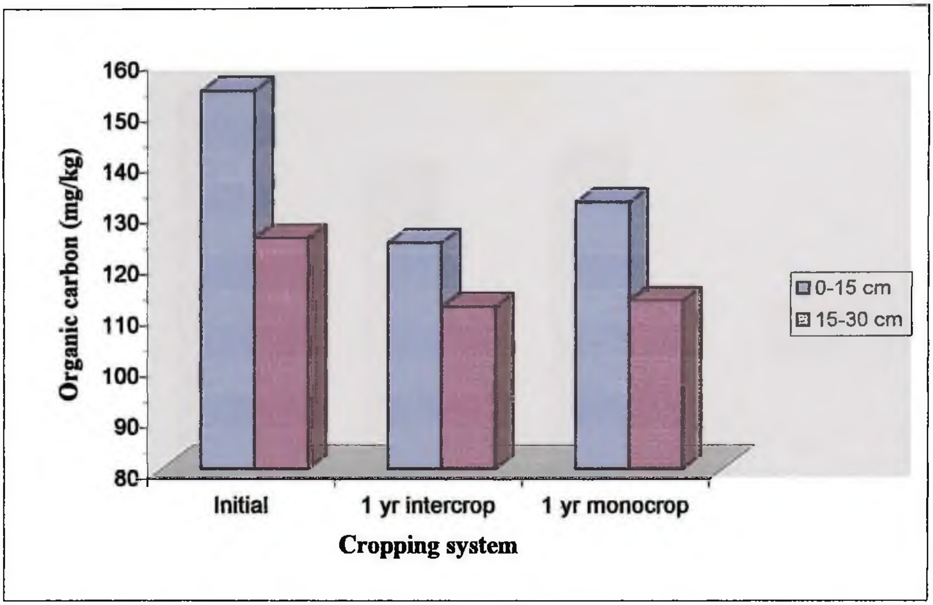


Fig.4.3 Effect of cropping systems on soil organic carbon

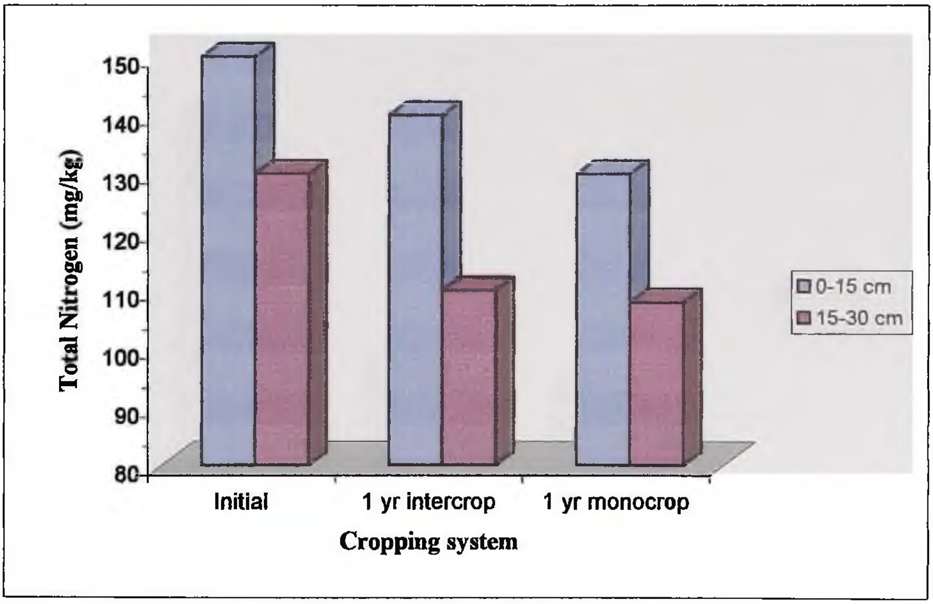


Fig.4.4 Effect of cropping systems on soil total nitrogen

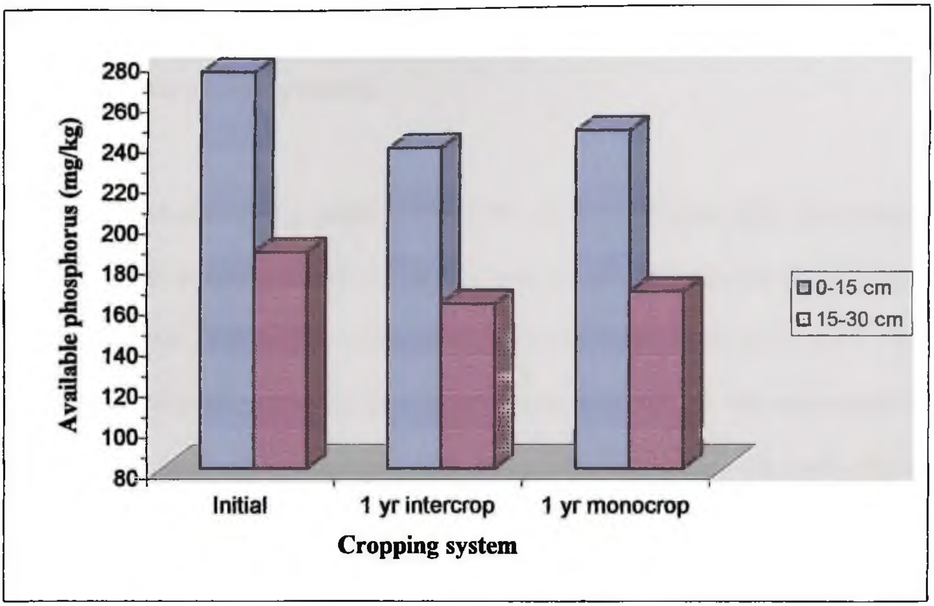


Fig.4.5 Effect of cropping systems on soil available phosphorus.

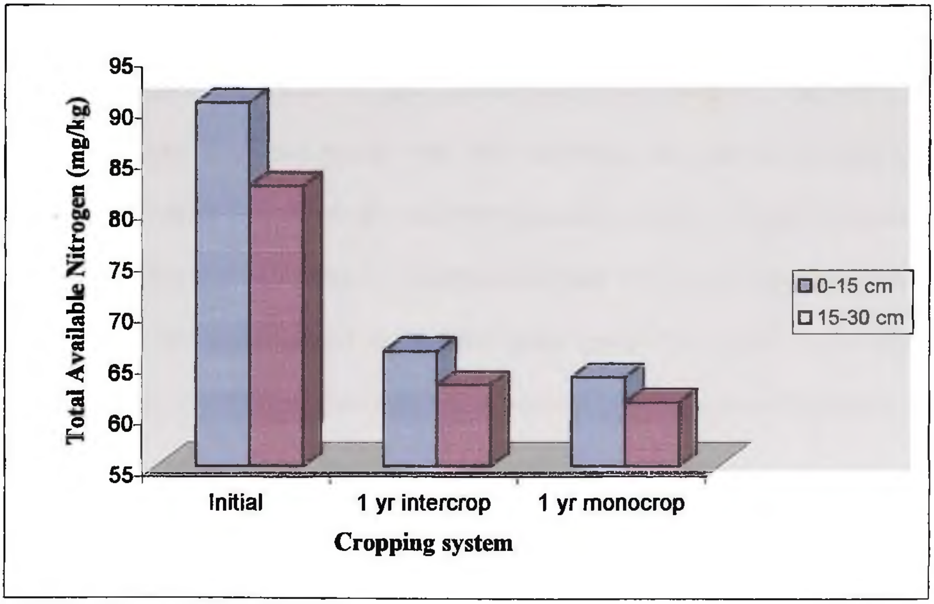


Fig.4.6 Effect of cropping systems on soil total available nitrogen.

4.3 Effect of cropping system on dry matter yield, grain yield and tuber yield at the end of the first cropping season.

4.3.1 Cowpea

The effect of cropping systems on total dry matter and grain yield of cowpea at the end of the first cropping season is shown in Fig.4.7. Sole cowpea (C) had the highest total dry matter yield of 0.65 t ha^{-1} followed by cowpea intercropped with potato (CP), 0.37 t ha^{-1}, with the cowpea of the maize -cowpea intercrop (MC) registering the lowest dry matter yield of 0.33 t ha^{-1} Thus in terms of dry matter yield cowpea intercropping with potato was better than intercropping with maize. This is however, not unexpected given the almost 50 % more cowpea plant population in the CP relative to MC (Table 3.1). The grain yield followed a similar trend to that reported for total dry matter. The order for the cowpea grain yield from the highest to lowest was C > MC = CP. The data indicated that intercropping resulted in about 50 % reduction in cowpea grain yield compared to sole cowpea crop. In terms of land equivalent ratio (*LER*), total dry matter yield gave a value of 1.21 and 1.34 for grain yield (Table 4.2). However, although CP showed superiority of intercropping over sole cropping, this was in contrast to area time equivalent ratio (*ATER*) for which the corresponding values were, 0.83 and 0.88, respectively. It is evident from Fig. 4.7 and Table 3.1 that the additional 50 % more cowpea population in the CP than in the MC intercrop did not parallel grain yield. This result is consistent with the findings of Dalal, (1974) who reported yield decline of both cowpea and maize in an intercrop system.

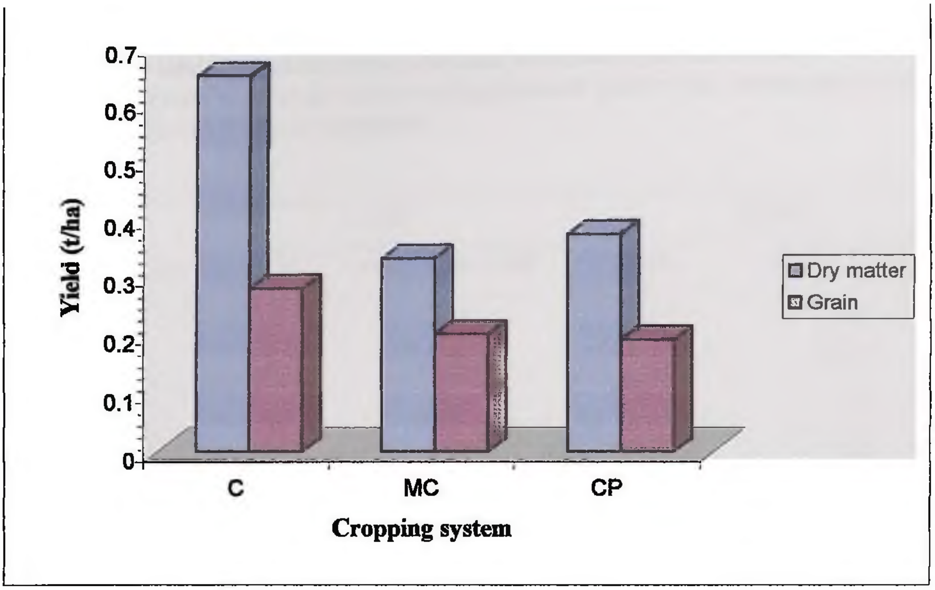


Fig.4.7 Effect of cropping systems on total dry matter and grain yields of cowpea at the end of the first cropping season

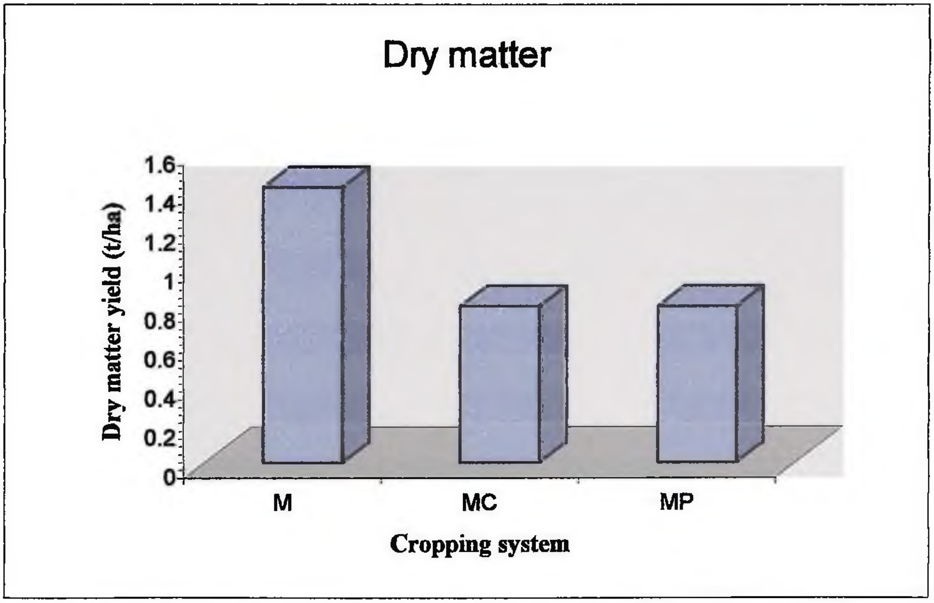


Fig.4.8 Effect of cropping systems on total dry matter yield of maize at the end of the first cropping season

Table 4.2. The land equivalent ratio (LER) and area-time equivalent ratio (ATER) estimated at harvest for total dry matter and grain/tuber yield of the intercropping systems at the minor and major season cropping.

	LER		ATER	
Cropping system	tdmy	grain/tuber yield	tdmy	grain/tuber yield
MC⁺	1.07	n.d	0.89	n.d
CP⁺	1.21	1.34	0.83	0.88
MP⁺	1.01	n.d	0.78	n.d
MC/MC♀	0.93	1.51	0.77	1.26

MC = Maize – cowpea intercrop

CP = Cowpea – potato intercrop

MP = Maize – potato intercrop

MC/MC = Maize – cowpea intercrop preceding maize - cowpea intercrop

tdmy = total dry matter yield

n.d = not determined

+ = Minor season cropping

♀= Major season cropping

4.3.2 Maize

The dry matter yield results for maize at the end of the first cropping season are shown in Fig. 4.8. The onset of drought (Fig. 4.1) just at the tasseling stage of the maize crop seriously affected growth of this crop, hence there was no data on maize grain yield for the first season's crop. In terms of total dry matter yield the observed trend was M > MC = MP. The *LER* (Table 4.2) for both MC and MP were almost unity, again the *ATER* measure gave no advantage of intercropping over sole cropping. The maize dry matter yield reduction as a result of the intercropping was almost 43 %. The data seems to suggest that if sole maize population is maintained in MP and MC intercrop systems (Table 3.1), the superimposed crops are not advantageous in terms of maize dry matter production.

4.3.3 Potato

The influence of cropping system on the total dry matter yield as well as the tuber yield of potato at the end of the first cropping season is shown in Fig. 4.9. In terms of total dry matter yield as well as tuber yields, the treatments ranked from the highest to the lowest as follows: P > CP > MP. Similar to earlier dry matter yields (Figs 4.7 and 4.8), intercropping systems resulted in yields decline; however, potato dry matter yield reduction was less severe in the CP (almost 36 %) intercrop system than the MP (almost 56 %). Tuber yield reduction in the CP intercrop system was 31 % compared to 52 % in the MP cropping system. The ATER estimated less than unity for both MP and CP indicating no beneficial effect of the addition of cowpea and maize to the dry matter yield of potato (Table 4.5). The potato plant population in the intercrop CP was almost 33 % less than the same plant population in the MP intercrop (Table 3.1).

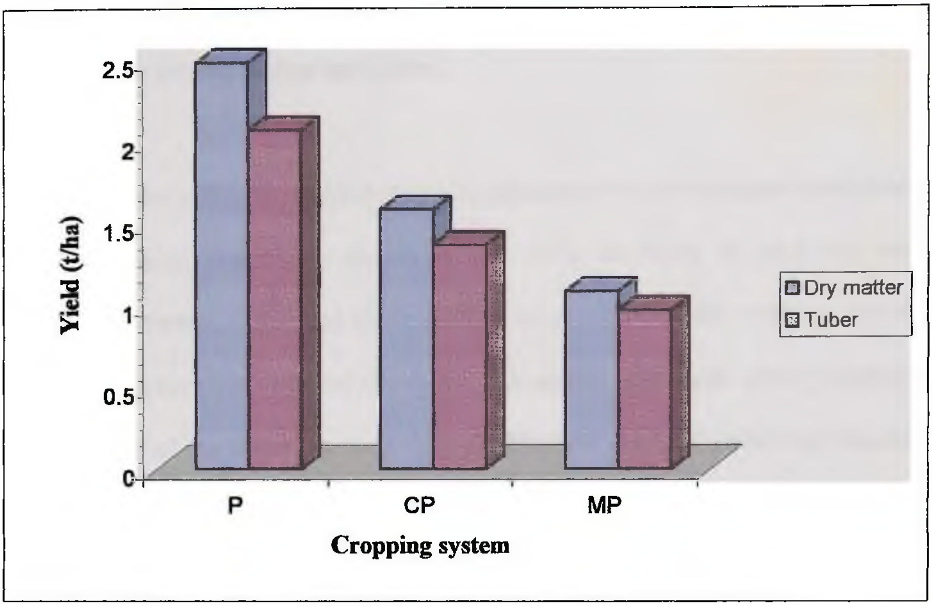


Fig 4.9 Effect of cropping systems on total dry matter and tuber yields of potato at the end of the first cropping season

4.4 Effect of cropping system on dry matter and grain yield of maize and cowpea at the end of the second cropping season.

4.4.1 Maize

The total dry matter and grain yield of maize as influenced by the cropping systems at the end of the second cropping season are shown in Fig. 4.10. In terms of total dry matter yield, statistically, the treatments showed the following trend: M/C = M/M > M/P = M/MC > M/MP >MC/MC. The grain yields parallel the dry matter yields. The maize plant population was the same irrespective of the preceding crop. *LER* for MC/MC was 0.93 indicating that the intercrop was not a productive practice. The grain yield however, indicates the superiority of the intercrop system whether *LER* or *ATER* was used (Table 4.2). The dry matter and grain yields of maize were generally lower in treatments where an intercrop preceded the maize.

4.42.2 Cowpea

The cowpea yield results at the end of the second cropping season are shown in Fig. 4.11. In terms of total dry matter yield, the treatments could be ranked from the highest to the lowest in the following order: C/M > C/C > C/MC > C/CP > C/P >MC/MC. With the exception of C/P, the total dry matter yield of cowpea was generally higher in treatments where cowpea followed a monocrop compared to an intercrop preceding the cowpea. The trend in the grain yield was similar to the total dry matter yield. In terms of dry matter yield, the *LER* and *ATER* indicated no superiority of the MC/MC intercrop system. However, the grain yields were shown to be beneficial under the MC/MC cropping system (Table 4.2).

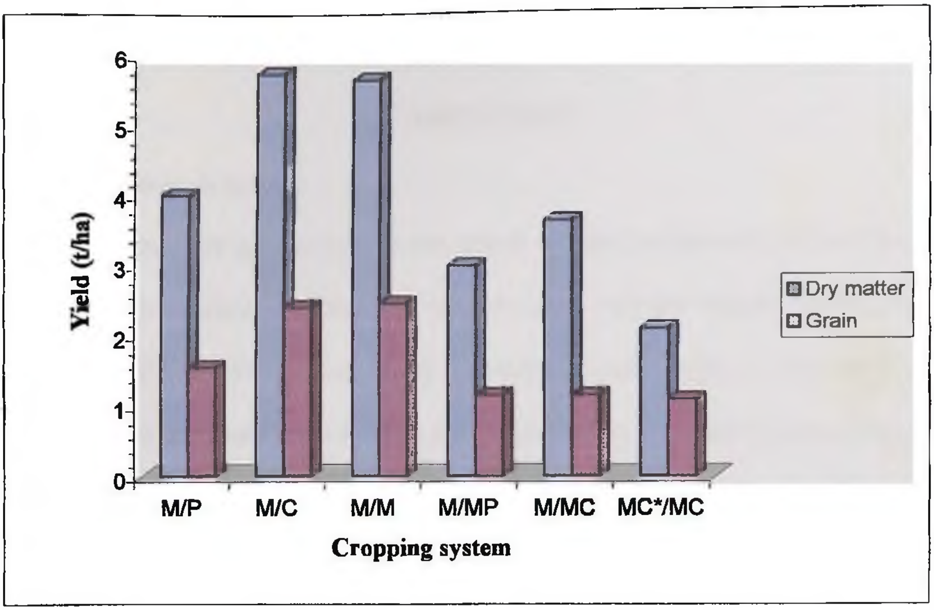


Fig. 4.10 Effect of cropping systems on total dry matter and grain yields of maize at the end of the second cropping season

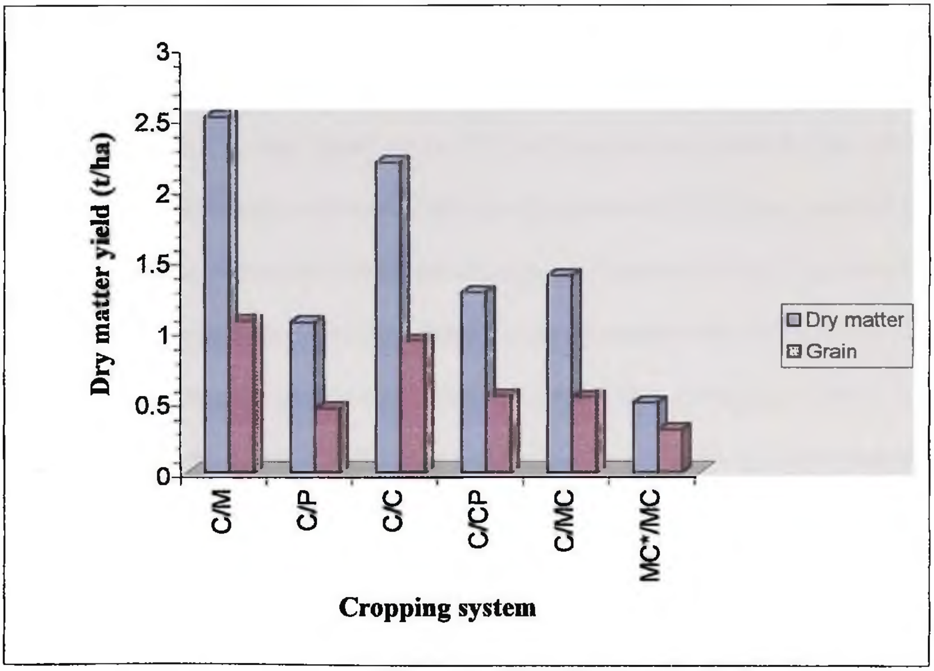


Fig. 4.11 Effect of cropping systems on total dry matter and grain yields of cowpea at the end of the second cropping season

CHAPTER FIVE

DISCUSSION

5.1 Soil nutrient dynamics

Soil nutrients are concentrated in the topsoil and tend to decrease with depth, suggesting that a greater part of these nutrients may be associated with the organic matter present in the topsoil (Aweto, 1988). The maintenance of high organic matter levels in the topsoil is therefore very important for sustainable soil fertility and for enhancing agricultural production. The soil of the study site is inherently low in organic carbon as is common for most tropical soils (Ankomah *et al.* 1995). It is possible that such low levels of organic matter would be expected to be further reduced under cropping with no fertilization (Greacen, 1983). Supplementary application of nutrients from fertilizer or organic matter may under these circumstances be required to provide for optimal nutrition of crops. The contribution of agroforestry could be to attempt to improve the quality of existing soil organic matter derived from *Chromolaena odorata* and *Panicum maximum* with nitrogen rich plant material from leguminous species low in lignin and polyphenol or both. However, application of large quantities of N-rich plant material to acid soils can temporarily raise soil acidification and consequent P unavailability (Yamoah et al., 1991). During the fallow period, the major plant that colonized the plots was *Chromolaena odorata*, one of the most fast growing obnoxious weeds in West Africa (Owusu-Bennoah, 1997). It is possible that the increase in the level of SOM observed during the intervening fallow period may have been caused by *C. odorata* with its rapid organic matter turn over. However, further studies are needed to confirm this, and to determine the proper management of *C. odorata* in farming systems. For example, would it be practical and highly beneficial to incorporate all that much nutrients and organic mass locked up in this plant into the soil? A real quantification of the benefits is needed. Although irrespective of the crop(s) grown, soil organic matter levels declined, the type of crops grown and the cropping system had varying effects. As observed from Table 4.2a and 4.2b the cultivation of the sole crops, in particular cowpea and maize conserved more soil organic matter than the intercrops such as maize-potato intercrop. These findings may appear to have practical implications. Thus, although there are several advantages associated with maximizing the use of land through additive intercropping, sight should not be lost of its potential adverse effect on the stress it may put on some important chemical proprieties such as the soil organic matter. The relative decreases in soil % organic carbon with cultivation are consistent with the findings of Nye and Greenland (1960) who reported a 20 % loss of soil organic carbon after one year of cultivation.

The available P (Bray 1 P) at the start of the experiment was low and compares with that reported by Ankomah *et al*. (1995) on the same soil. Thomas and Peaslee (1973) suggested that most soils containing extractable P of less than 15 ppm as determined by Bray 1 method could be defined as being deficient in available P for optimal plant growth. These are similar to the values suggested by Olson and Engelsted (1972) and Menon *et al*. (1995). The results obtained in this study confirm the findings of Pieri (1986), that P is one of the most limiting nutrients for crop growth in tropical soils. The extremely low P in the subsoil could possibly be due to P fixation by aluminosilicates, since clay generally accumulates in the B horizon of the Bekwai series (Obeng, 1964). Given the high cost of chemical fertilizers and the fact that most peasant farmers cannot afford their purchase, the need to test the efficiency of other sources such as phosphate rock is great. Considering the low pH of the Bekwai series, and the higher solubility of phosphate rock at low than at high pH, this might prove useful. Phosphate-solubilizing microorganisms (PSMs) which are ubiquitous in soils can also play an important role in retrieving the unavailable P and enhance plant growth in an eco-friendly manner (Gyaneshwar et al.,1999). Phosphorus also plays a key role in legume biomass production and symbiotic nitrogen fixation. It is therefore not surprising that the beneficial effect of including legumes in cropping systems was not clearly demonstrated in this study. Therefore for a biological N fixing system such as C, CP and MC to be successful, initial P fertilization is necessary.

The inherently low soil N of the study site, coupled the removal of trash after land clearing could deprive the soil of plant stored nutrients such as N and P that would normally be made available through litter decomposition. Thus residue removal makes the soil relatively more dependent on mineral nutrients. In a soil that have become depleted as a result of continuous low-input cropping with short fallow periods, one can assume nitrogen (N) deficiencies for almost any cropping system, that does not receive chemical inputs. However, small land holdings, poorly developed transport and market infrastructures, and lack of credit all militate against higher use of mineral fertilizers by tropical small holders. Continual supply of N is necessary since it is very difficult to build large N reserves. Legume rotations though common in the tropics, most involve a harvest offtake in grain hence net additions are low or even negative. The early hopes for alley cropping as a solution for N deficiencies have not been realized, and sequential systems such as relay cropping or 1-3- year leguminous fallows now receive greater attention (Smithson and Giller, 1999). Fertilizer additions should be seen as necessary. An organic based system, coupled with judicious use of moderate does of inorganic fertilizers, probably offers the best path to increased agricultural productivity in the tropics.

5.2 Season 1 yield results

Intercropping a non-legume with a legume crop has been a traditional practice of peasant farmers in the subtropical and tropical countries (Dalal, 1974). The yield reduction of cowpea observed as a result of intercropping is consistent with the findings of Dalal, (1974) who observed decline in yield of both cowpea and maize in a tropical condition. It appears that the yield of cowpea is more depressed in MC intercropping (50 %) than maize (43%). Similar findings have been reported by Ofori and Stern, (1987). It is possible that the decrease in yields of either cowpea or maize grown together could be reduced by selecting crops of widely different growth habits. Based on the evidence available (Table 4.5), it is apparent that intercropping is advantageous in many ways, particularly to the peasant farmer where factors other than yield are important, such as ensuring a measure of return, rather than the maximum return. In peasant farming practice where nutrient addition is entirely due to crop residues after crop harvest, CP with LER of 1.21 (tdmy) may be advantageous compared to MC (1.07). However, the extent to which crop residues influence plant growth is determined, in part, by the decomposition and N mineralization rates of the residues, and the concurrent timing of nutrient release and crop demand. Therefore there is a need to understand the C and N dynamics of crop residues to effectively manage these nutrients as a nutrient source (Koenig and Cochran, 1994). The complete failure of maize to produce grain as a result of drought during grain filling is an example of what could happen to a farmer and yet, could obtain the yield of another crop in an intercropped system. For increased productivity in an intercropping system, matching phenological development with growing season is vital, particularly in water limiting environments (Wien and Smithson, 1981). The reduction in yield of cowpea in the intercrops could be due to shading by the companion crop, competition for nutrients and water. Similar findings have been reported by Wahua and Miller (1978). This suggests that the growth environment encountered by a component in an intercrop is often strikingly different from that in the sole crop. The environmental modification had an adverse effect on the growth and yield of cowpea. In the major cropping season, however, the cereal yields were little affected by the associated legume (Table 4.5). Similar interactions between cereal/legume performance and water availability have been found in other combinations by Natarajan and Willey (1980) and Stoop (1986).

The relatively higher yield of potato which was harvested later than cowpea in the cowpea-potato intercrop (1.37 t ha^{-1}) could be due to the ability of the potato to recover quickly from any growth check when the early-maturing cowpea was harvested. The potato had sufficient time to develop a complete canopy and root system to capture as much of the remaining resources as possible. The late-maturing crop (potato) also utilizes resources (e.g. residual water) which might otherwise be wasted, and hence it acts at least as effectively as does a second crop in a double-crop system (Rao and Willey, 1983). It is evident from the potato yields that additive intercropping could be stressful to the associated crops (Fig.4.13). The CP intercrop system which had 33 % less sweet potato plant population (Table 3.1) resulted in 36 % and 31 % decline in dry matter and tuber yields respectively, with respect to sweet potato monocrop. The MP intercrop system however, resulted in 56 % and 52 % decline in total dry matter and tuber yields respectively.

The 43 % yield reduction in intercropped maize (MC and MP) even though the maize plant population in the intercropped and sole crops were th same suggest that competition for nutrients may be responsible for the observed yield decline.

5.3 Season 2 yield results

The population of maize was kept fixed in the intercropping system and thus assuming its yield could be maintained, then the superimposed cowpea crop could be a bonus, in addition to the increased security expected. However, in all cases yields of component crops were reduced possibly due to competition for soil nutrients, water and shading (Wahua and Miller, 1978). The total dry matter and grain yields of component crops were generally lower in intercropping than in sole cropping. This indicated that conditions were not optimal for the best growth of the combined crops i.e., the component crops must have been competing for limited resources under the intercropped condition. Considerable competition between cereals and legumes grown together has already been demonstrated, e.g. in terms of light interception (Natarajan and Willey 1980).

It has often been observed that legumes have a beneficial effect on the yield of cereal crops which are subsequently grown on the same soil (Nambiar *et al.*,1982; De *et al.*, 1983). This residual or carry-over effect is usually attributed to enrichment of the soil with nitrogen due to the fixation of atmospheric N_2 by the legume-*Rhizobium* symbiosis. In this study, the beneficial effect of legumes in crop rotation could not be established since M/M gave a similarly grain yield as M/C (Fig.4.12). That these results were obtained though cowpea absorbed less soil N relative to maize at the end of the first cropping season (Fig. 4.) indicated that factors other than soil N must have accounted for this anomaly. This is supported by the fact that cultivation of maize led to a greater decline of soil N observed by the subsequent cereal crop than when cropped to cowpea. Hence the increased total dry matter yield of maize following cowpea was not due entirely to soil-N conserving effect but also to 'other effects' which enabled the subsequent maize crop to exploit the soil more than when preceded by cowpea. The high yield of cowpea in C/M treatment possibly illustrates the beneficial effect of crop rotation in ensuring higher crop yield and also supporting the report of Tobita *et al*., (1994) that N_2 fixation increases when a preceding cereal depletes the soil of its N. There is strong evidence with respect to grain yield (Table 4.5) that negative interference is minimal in the maize-cowpea preceding maize-cowpea intercrop system. The positive interference responsible for this result may be mutualistic mycorrhizal association between the maize and the cowpea in the intercrop system.

5.4 The effect of rainfall on crop yields

Crop performance in rainfed cropping systems generally is dependent on rainfall amount and distribution. The minor cropping season precipitation in the study area (Fig.4.1) is insufficient for full expression of maize yield potential (Fig. 4.12). The magnitude of the moisture deficit during the minor cropping season may contribute to poor maize performance. Rainfall amount and distribution thus may influence farmer decisions on which crops to plant and cultural practices such as mulching or reduced tillage that conserve soil moisture to adopt. Evidently, November rainfall (Fig.4.1) appears to be most critical in influencing maize yield if planting is done in late September. The practical application of this finding would be most advantageous to farmers who may avoid growing maize and plant a more early maturing crop such as cowpea during the minor cropping season. Cowpea has low water requirement and a shorter growth period (60 days) compared to maize (90 days). Perhaps cowpea took advantage of residual moisture during the high monthly rainfall in September and October (Fig. 4.1) for crop establishment and high yield. Planting of maize in early September may probably be a better option for farmers if crop failure is to be avoided as rainfed farming in the experimental site is not entirely dependable without supplemental irrigation especially in the minor cropping season. Deforestation giving way to agriculture is also on the ascendancy and is believed to be one of the significant causes of low rainfall (Benneh and Agyepong, 1990) and degradation leading to desertification in West Africa. Accordingly, crops suffer from frequent drought even in cropping seasons. Management practices that ensure permanent soil cover minimizes moisture loss and retards soil degradation. Maize stover has been found to reduce moisture loss and improved crop performance (Swift, 1997).

CHAPTER SIX

CONCLUSION AND RESEARCH DIRECTIONS

Results of the study demonstrate the potential of cropping systems in enhancing crop yields in the semi-deciduous forest zone of Ghana. Overall, maize yields were more sensitive than cowpea to variable rainfall patterns during the minor season cropping, thus making cowpea a preferred crop to grow where we have limited rainfall. Rainfed farming in the experimental site is not entirely dependable without supplemental irrigation. Evidently, November rainfall appears to be most critical in influencing maize yield if planting is done in late September. The practical application of this finding would be most advantageous to farmers who may avoid growing maize and plant a more early maturing crop such as cowpea during the minor cropping season. In general, monocrop yields were higher than in intercropped systems. The yield of legumes is more depressed in maize-cowpea intercropping (about 50 %) than the non-legume (about 43%). Additive intercropping could be advantageous if the superimposed plant population is reduced to a level that will minimize competition. The most valuable information for management decisions is the nutrient mining under intercrop systems. This is useful in predicting the productive capacity of a cleared site. The analyses contribute to our understanding of how continuous cropping contrasts with rotation systems and how both respond to variations in weather.

Some suggestions to improve crop production in the study site are:

1. Given the high cost of chemical fertilizers and the fact that most peasant farmers cannot afford their purchase, the need to test the efficiency of other sources such as phosphate rock is great. Given the low pH of the Bekwai series, and the higher solubility of phosphate rock at low than at high pH, this might prove useful.

2. In the minor cropping season, planting of maize in early September may probably be a better option for farmers in the experimental site if crop failure is to be avoided. Intercropping early maturing maize with early maturing cowpea would reduce the risk of total crop failure especially with maize. A better understanding of the influence of other weather factors such as temperature on crop yields would prove worthwhile.

3 Because of the inherently low fertility, the soil of the study site would require longer fallow than the 4 months reported in this study in order to achieve sustained high levels of productivity. What also would be interesting for future studies is, how long it will take to restore these soils to their original fertility if different fallows were to be adapted for soils under the different cropping systems

4 Since the trial was only for two cropping seasons, it would be necessary in future to monitor the nutrient dynamics of specific crop types over a longer period of time in order to establish the useful life span of a cleared site.

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