CARBON. NITROGEN AND PHOSPHORUS DYNAMICS INDUCED BY LONG-TERM CULTIVATION AND MANAGEMENT

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DECLARATION

I hereby declare that this thesis has been written by me, and that it is a record of my own research work. It has not been accepted in any previous application for a higher degree.

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CERTIFICATION

This thesis entitled CARBON, NITROGEN AND PHOSPHORUS DYNAMICS INDUCED BY LONG-TERM CULTIVATION AND MANAGEMENT by GOLADI, J.T. meets the regulation governing the award of the degree of Master of Science (Soil Science) of Ahmadu Bello University, Zaria, and is approved for its contribution to scientific knowledge and literary presentation.

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ABSTRACT

Several studies in the savanna continue to justify the benefits of inorganic fertilizers. Parallel studies on the long-term effects of fertilizers on the soils are scanty. The objective of this study was to determine the impact of inorganic fertilizers with or without farmyard manure on carbon (C), nitrogen (N) and phosphorus (P) in a savanna alfisol after 45 years of continuous cultivation. Soils for the study were fertilized with N,N+P. N+P+K. farmyard manure (FYM) FYM+N. FYM+P_r FYM+NP and FYM+NPK.

Continuous cultivation caused significant losses of C.N and P. The N+P or N+P+K fertilization could not mitigate these losses. Losses of N and P occurred mainly in organic forms. However, combination of farmyard manure with N+P and N+P+K fertilization maintained C.N and P at par with or greater than the native site soil.

Inorganic fertilizers stressed microbial activity, evidenced by the low microbial biomass C.N and P compared to the soil under native vegetation and soils fertilized with FYM+N and FYM+NPK.

The study further examined the dynamics of inorganic P(P,) and organic (P_0) pools of the soils using a modified Medley Fractionation. Continuous cultivation without P, fertilization decreased the concentration of P_1 and P_0pools including residual P fraction. Fertilization with P, or in combination with FYM (P.N+P+K. FYMP+P, FYM+NP and FYM+NPK) increased the concentration of labile P_1 pools, but decreased the concentration of P_0 pools and the residual P fraction. The tendency of the residual P fraction

to decrease along with P_0 pools suggested that the residual P fraction was largely P_0, consistent with the correlation between residual P fraction and total P_0 (r = 0.74**) and with organic carbon (r = 0.47**). Path analysis of the relationships between resin extractable P and the more stable P_t and P_0 pools indicated that 85% of the variations in resin-P were explained by hydroxide extractable P, ($OH\text{-}P_1$) and HC1-P, which acted as sinks for fertilizer-P. The contribution of residual P fraction to resin-P was indirect via bicarbonate extractable P„ ($HC0_3\text{-}P_o$) and $0H\text{-}P_o$ suported by the significant path coefficients between them. Thus, the hypothesis that considers residual P fraction stable and inactive needs to be revised.

The study thus concluded that from the perspective of soil quality maintenance and sustainable landuse systems a rational fertilization strategy in the savanna is one that combines inorganic fertilizers with FYM or organic/crop residue management to maintain SOM.

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DEDICATION

To Mum and Dad

TABLE OF CONTENTS

		PAGE
	Title Page	i
	Declaration	ii
	Certification	iii
	Abstract	iv
	Acknowlcdgcmcnt	vi
	Dedication	viii
	Table of Contents	ix
	List of Tables	xi
	Lifst of Figures	xiii
1.	INTRODUCTION	1
2.	LITERATURE REVIEW	3
	2.1 Introduction	3
	2.2 The interrelationships of C,N and P	3
	2.3 Carbon, N and P dynamics as influenced by cultivation and management	5
	2.4 Aggrcgatc associatcd C,N and P under Cultivation	10
	2.4.1 Management effect on aggregate associate C, N and P	12
	2.5 Changes in soil biomass C,N and P under Cultivation	12
	2.6 Methods of Measuring Microbial Biomass	14
	2.6.1 Fumigation incubation (F1) Method	14
	2.6.2 Fumigation Extraction (FE) Method	15
	2.6.3 Substrate Induced Respiration (SIR) Method	16
	2.6.4 Adenosine Triphosphate (ATP) Method	17
	2.7 Dynamics of soil P fractions	20
3.	MATERIALS AND METHODS	22
	3.1 Site History and Management	22
	3.2 Spatial Variability	23
	3.3 Soil Sampling	24
	3.4 Soil Analysis	26
	3.4.1 Carbon, N and P concentration	26

TABLE OF CONTENTS

		PAGE
	3.4.2 Aggregate size analysis	27
	3.4.3 Organic carbon, N and P_o in aggregates	28
	3.5 Microbial biomass C, N and P in Soils	28
	3.5.1 Microbial biomass carbon and nitrogen	28
	3.5.2 Soil microbial biomass phosphorus	30
	3.6 Sequential Extraction of Phosphorus by the Modified Hedley Procedure	30
	3.6.1 Statistical procedure	33
4	RESULTS AND DISCUSSION	35
	4.1 Carbon, Nitrogen and Phosphorus Dynamics	35
	4.1.1 Carbon, N and P concentration in the soils	35
	4.1.2 Area based losses of C, N and P	39
	4.1.3 General discussions	40
	4.2 Aggregate Associated C, N and P	45
	4.2.1 Aggregate distribution	45
	4.2.2 Organic C, N and P in aggregates	47
	4.2.3 Soil microbial biomass C,N and P	52
	4.3 Dynamics of P Fraction as Influenced by Long-term Cultivation and Management	60
	4.3.1 Effects of cultivation and N and P fertilization	60
	4.3.2 Effects of combination of FYM and inorganic fertilizer	66
	4.3.3 Relationship between P pools	70
5.	SUMMARY AND CONCLUSION	75
	REFERENCES	78

LIST OF TABLES

TITLE		PAGE
3.1	The particle size distribution of the experimental soils....	25
4.1	The mean concentration and standard deviation of C,N and P in the ploughing depth (0–15cm) of an alfisol as influenced by inorganic fertilizers and farmyard manure for 45 years.....	37
4.2	The mean concentration and standard deviation of C,N and P at 0–15cm depth of an alfisol as influenced by inorganic fertilizers and farmyard manure for 45 years.....	38
4.3	Area-bared amounts and standard deviations and losses of C,N and P in a savanna alfisol after 45 years of cultivation.....	41
4.4	Aggregate distribution and stability determined as mean weight diametes (MWD) of aggregates of a savanna alfisol under continuous cultivation.....	46
4.5	The amounts of C,N and P_o (gk^{-1}) in aggregates as influenced by inorganic fertilizers and farmyard manure.....	48
4.6	Net changes of C,N and P in aggregates experessed in percentage as influenced by inorganic fertilizer and FYM.....	49
4.7	The influence of inorganic fertilizer and manure on soil microbial biomass carbon, nitrogen and phosphorus.....	54
4.8	The soil microbial biomass C,N and P as percentages of soil total organic C,N and Phosphorus.....	56
4.9	Selected properties of the soils used in the Study.....	61
4.10	The amounts and changes in P fractions of a savanna alfisol under continuous cultivation for 45 years without fertilization.....	63

LIST OF TABLES

TITLE		PAGE
4.11	The amounts and changes in P fractions of a savanna alfisol under continuous cultivation for 45 years as influenced by inorganic fertilizer application.....	64
4.12	The amounts and changes in P fractions of a savanna alfisol under continuous cultivation for 45 years as influenced by farmyard manure plus inorganic fertilizer combination.....	67
4.13	Factor analysis of the correlation betweenn the amounts of P in various P pools of the soil (r = 33).....	71

LIST OF FIGURES

Figure		PAGE
2.1	Modified schematic illustration of the interrelationships of C,N and P within soil–plant system (McGill & Cole, 1981)	6
3.1	Modified Hedley et al., (1982) sequential extraction of P as adopted by Agbenin and Tussen (1994)	32
4.1	The changes in C,N and P in of the different aggregate sizes in relation to the native site	51
4.2	The relationship between organic carbon and microbial biomass carbon	55
4.3	The relationship between microbial biomass carbon and microbial biomass nitrogen	58
4.4	Relationship between labile and stable P components of the soil P cycle of Ap horizons of a savanna alfisol under continuous cultivation and fertilization Path coefficient are normalized	73

CHAPTER ONE

INTRODUCTION

Shifting cultivation and bush fallowing, traditionally used to regenerate soil fertility in the savanna, had given way to continuous cultivation as a result of increased population. The maintenance of soil fertility under these conditions poses a great challenge Most savanna soils are weathered tropical ferruginous soils, classified as either Alfisols or Ultisols in the soil taxonomy. They are typically kaolinitic, with low organic matter (OM) content, cation exchange capacity (CEC) and low buffer capacity (Jones and Wild, 1975).

Under continuous cultivation, there is a rapid decline of OM, followed by extensive leaching of basic cations and a rapid development of acidity. To maintain acceptable yield levels, there is an increasing use of inorganic fertilizers.

The current global move for sustainable agricultural systems that optimize the use of agricultural resources (FAO, 1989) requires close monitoring of soil quality under continuous cultivation complemented with inorganic fertilizers. The negative effects of inorganic fertilizer application on soil pH, exchangeable bases and soil acidity in the savanna have been documented in several studies (Heathcote, 1970; Jones and Stockinger, 1976). In contrast, the positive effects of farmyard manure (FYM) in increasing nutrient supply, pH, soil organic matter (SOM) and CEC of savanna soils were

reported by Heathcote (1970) and Bache and Heatcote (1969).

Soil organic matter (SOM) is a source of and temporary sink for nutrients (Anderson and Coleman, 1985; Swift and Woomer, 1993), and controls N, P and S availability (Adepetu and Corey, 1976; Stewart and Tiessen, 1987). The importance of SOM in the fertility of savanna soils necessitates investigation into changes in SOM that affect N and P supplying capacities. The results of such a study are useful in predicting the productive capacities of savanna soils under long-term cultivation.

The objective of this study is to determine the changes in, and the pattern of depletion of, nutrients with particular reference to C, N and P under continuous cultivation as influenced by soil management.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

Soil organic matter (SOM) plays vital roles in soil fertility. These roles deal with water retention, nutrient relations and soil structural improvement. Its charge properties provide sites for ion exchange (a very important role in low activity clay soils prevalent in the tropics): its physical and chemical properties facilitate aggregation which in turn modifies soils biota, thus influencing biologically mediated soil processes.

The level of SOM is determined by its rates of formation and breakdown (Swift and Woomer, 1993). The renewal of SOM can be achieved by changing any of the soil variables affecting the rates of formation and oxidation.

2.2. The interrelationship of C, N and P.

Walker and Adams (1958) indicated that the amounts of OM and N of soils are controlled by P. The availability of P, therefore, ultimately controls the OM content of soils (Walker and Syeres, 1976: Tiessen et al., 1984). The cycling of N and P within the soil-plant system requires energy, which is made available by the oxidation of C to CO_2. The energy thus released is utilized in N and P

mineralization.

Attempts have been made to study the quantitative distribution of C, N and P in savanna soils (Jones, 1973) but there are no studies which examine the quality and the organo-mineral associations that regulate C, N and P cycling in the soil. Enwezor (1976) and Lekwa and Whiteside (1986) used stoichiometric ratios of C: N and C: P as a measure of SOM quality; an approach discarded by McGill and Cole (1981) who proposed a dichotomous model for the flows of C, N and P in soils. In this model they proposed that C, N and P might be mineralized together by microbes in the search for energy through C-N bond breakage, a process termed "biological" mineralization, while a "biochemical mineralization", motivated by the need for P and S, catalyzed by enzymes external to the cell, rather than the need for energy, and controlled by the supply of the end product, is central to P and S cycling.

The path of mineralization depends upon whether the element is carbon-bonded such as C-N or ester-bonded such as C-O-P. The C-bonded N is released by the cleavage of the C-N bond, thus releasing the inorganic ion, while C is oxidized to $CO_{2(g)}$ with the release of energy. This explains the considerable relationship between C and N in soils (McGill and Cole, 1981).

The mineralization of ester bonded P (C-O-P) is achieved by the catalytic action of the enzyme phosphatase, a process which takes place external to the cell membrane. Cleavage of the ester-bonded P

requires depolymerization of P bonded to a polymer. Phosphorus is also subject to biological mineralization through C–P bond breakage (phosphonates). These different regulatory mechanisms for the individual elements are all interrelated and integrated within the organism. Thus soil organisms, including plant roots may preferentially hydrolyse any element, if it has the need for it. This leads to a system with variability in C:N:P, ratios. These interrelationships are schematically represented in figure 2.1.

2.3. Carbon, N and P dynamic as influenced by cultivation and management

The light fraction (LF) organic matter consists primarily of OM derived from plant residues in various stages of decomposition, with appreciable amounts of microbial and microfaunal debris (including fungal hyphae and spores), and a high concentration of C and N (Janzen et al, 1992; Feller, 1993). The L.F. has a high mineralization rate, a character attributed to the absence of protection from soil colloids, predisposing it to enzymatic and microbial action (Janzen et al., 1992).

Carbohydrate C is the fraction of OM that is most subject to change, compared to other forms, suggesting that it is the most active fraction (Kinchesh et al. 1995). These changes are greater where OM inputs are correspondingly high. Kinchesh et

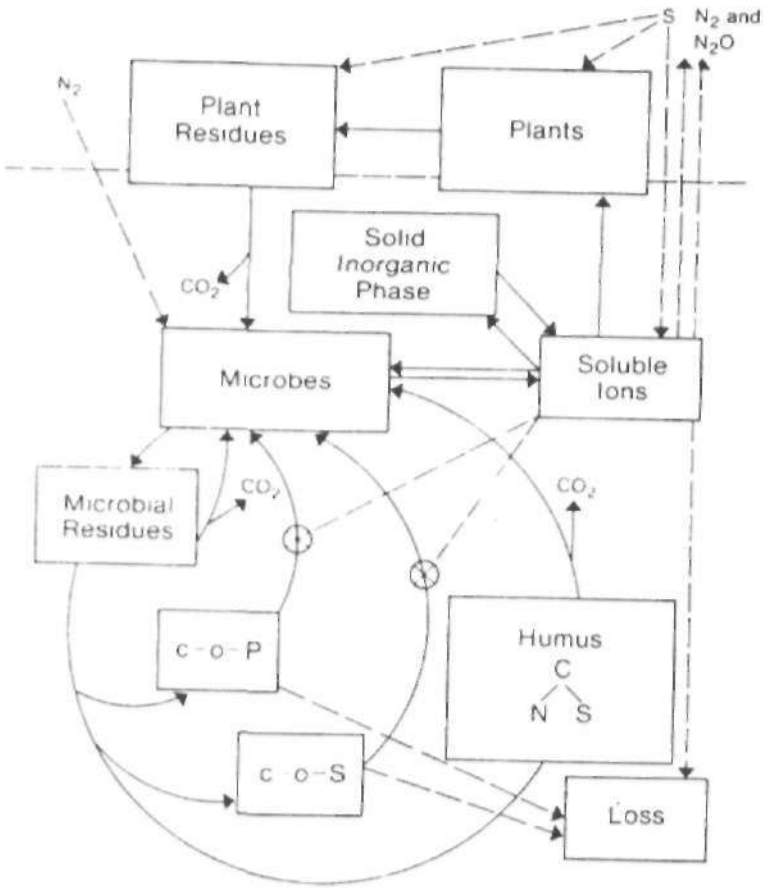


Fig. 2.1: **Modified schematic illustration of the interrelationships of C,N and P within soil-Plant system (McGill and Cole, 1981)**

al, (1995), found that alkyl C increases with increasing C inputs. but that the rate of decrease with decreasing C input is gradual.

There is a relationship between the active fraction of OM and N immobilization and release in soil. Application of glucose (a carbohydrate), an active fraction of 0M increases the immobilization of N (Cadish et al., 1993). The higher the C:N ratio of the residue, the higher the N incorporation into OM (greater immobilization) than organic residue with lower C:N ratio (Cadish et al.,1993).

The equilibrium between adsorbed P and that in solution is to some extent influenced by organic matter (OM) incorporation. Soil organic matter (SOM) when mineralized, releases some organic anions in solution, which can compete with phosphate ions for adsorption sites (Sibanda and Young, 1986), thus increasing P in solution. Biological agencies also provide a small but significant proportion of available P in soils, and thus acting as a reservoir. This highly labile P pool is significant to the P fertility of weathered soils.

Changes in agricultural practices, involving tillage and residue incorporation and fertilizer application have a profound effect on OM dynamics and turn over in soils, and consequently on N and P availability to plants. Tiessen et. el. (1982) showed that the P content of a cultivated soil was 29% less than that of an uncultivated soil and that P was predominantly lost in organic form. Similar observations were made by Anderson and Coleman (1985). Storage of soil P in organic form can be increased by organic residue addition alone, but

for an extremely P-deficient soil, organic residue addition and P fertilization are required to initiate organic P (P_o) build-up in the soil.

A loss of 32% C was observed by Tiessen et al (1982) after 60-70 years of cultivation in a clay and silty loam, with the losses on a sandy loam being greater than silty loam. The losses of C paralleled N and P losses in the same soil.

Cultivation techniques influence SOM. Conventional tillage (CT) leads to greater reduction in OM than zero tillage (Anderson and Coleman, 1985). There is generally an increase in soil organic carbon (SOC) and soil organic nitrogen (SON) under no tillage (NT) or zero tillage (Wood et al, 1991) with increase in cropping intensity. Redistribution of SOC and SON closer to the soil surface occurs under NT than conventional tillage (CT) (Doran, 1980).

Phosphorus application increases SOM accumulation and total N in soils (Russel and Williams, 1982: Murata et al., 1995). In some cases the increase in total N induced by P-fertilization did not correspond to increase in OM (Murata et al., 1995) suggesting that N was not being incorporated into humic materials. This, however, might be related to N retention in the forms of NH_4^+ in the cation exchange complex. Murata et al (1995) further noted that biomass C (BC): biomass N (BN) and BN: total N (N_t) ratios in soils increased with P application, while the stable SOM fraction, HCl/HF-extractable C: total C, and humic N:N_t ratios decreased accordingly. Similarly, fertilization with NPK

increases SOC at the surface compared to an unfertilized site (Schjonning et al, 1994).

Fertilizer P application can also alter the P fraction or status of the soil, depending on the properties of the soil. The fractions enriched by fertilizer P are resin-extractable inorganic P (P_i) and bicarbonate extractable -P_i. Labile P_o is positively influenced by N and P-fertilizers. Applied fertilizer-P accumulated as labile resin extractable-P_i, bicarbonate extractable-P_i and microbial-P despite P export from grain harvest suggesting that the crop P requirements were probably satisfied from organic P pools (Selles et al., 1995).

The addition of farm yard manure (FYM) causes an increase of 32% SOC in a sandy loam (Schjonning et al, 1994), and the accumulation of extractable nitrate (greater than 12.00 mg N kg^{-1}) at 90-150 cm depth (Dick and Christ, 1995) suggesting that mineralization of organic N to NO_3^- exceeded crop requirements. This poses a potential danger to ground water pollution, but with intensive cropping under NT, this danger can be largely averted (Wood et al., 1991).

Application of organic manure might sharply increase the amounts of N and P_i in soils (Sharpley and Smith, 1995). These workers, however, showed that the distribution of N into different fractions was not affected by manure application, but it resulted in a shift of P_o in untreated soils to P_i in treated soils. This makes manure treated soil vulnerable in enriching runoff with P.

Phosphorus enriched run-offs find their way to surface waters such as lakes, streams and ponds (Reddy, 1975). Such P levels could be large enough to endanger the environment, particularly the eutrophication of lakes and streams (Reddy, 1975). The increase in P_i in manure treated soils appears to be concentrated in Ca-P bound pool (Sharpley and Smith, (1995).

2.4. Aggregate associated C, N and P under cultivation.

Soil structure is an important factor in SOM decomposition (Oades, 1988). The SOM is a major agent stabilizating aggregates. Thus decreases in SOM bring about deterioration of soil structure (Tisdall and Oades, 1982; Chaney and Swift, 1984; Haynes et al, 1991). Generally, SOM is lost by cultivation and clearing. These losses are more pronounced in sand-size fractions (Tiessen and Stewart, 1983; Zhang et al., 1988). Similarly higher concentrations of C and N are associated with microaggregates (Elliot, 1986; Gupta and Germida, 1988; Cambardella and Elliot, 1992; Puget et al., 1995) than macroaggregates.

The presence of large amounts of OM in stable aggregate fractions implies that the location of OM within aggregates limits their decomposition, but when aggregates are broken down by tillage and harrowing to pulverize the soil, SOM mineralization flushes are observed (Hansink, 1992). The large C content in stable aggregates is attributed to young C_4-derived organic C. Young OM is the cause

of macroggregate stability (Puget et al, 1995).

Guggenberger et al (1994) showed that carbohydrate and lignin (phenolic and methoxyl C) decreased with decreasing particle size, while alkyl and aromatic C increased in the order; clay > silt > sand. Alkyl C is low in silt humic acid (HA) compared to clay, and aromatic C is highest in silt HA compared to sand and clay. Similar observations were made by Anderson et al. (1981) who showed that OM associated with fine clay (0.2μm) contained high amounts of hydrolyzable N. These results indicate that sand-size separates are rich in plant residue (primary source) while clay size-separates are dominated by microbial resynthesized products (secondary source).

In cultivated and native soils, Elliot (1986) found that there was almost always an increase in the concentration of organic C, N and P in all size classes greater than 0.09 mm, with the least concentration being in the 0.053-0.09 mm size class. The macroaggregates of the native soil had a high OM content than that of the cultivated soil.

Cultivated soils had the highest C:N ratio (12.2) in the microaggregate size-class (4.7mm) and the lowest C:N ratio (9.2) in microaggregate size class (0.053-0.09mm). There was almost a linear change in C:N ratio between the two size classes. The 0.053 mm particles (silt + clay size) have slightly higher C:N ratios than the 0.053-0.09 mm size-class. The C:P ratios were found to follow a similar trend.

2.4.1 Management effect on aggregate associated C, N and P

The effect of cultivation on soil organic matter (SOM) reduction and the attendant losses of N and P_o is reasonably well documented for temperate grassland soils (Tiessen et al, 1982; Anderson and Coleman , 1985; Elliot, 1986). Many factors are responsible for SOM reduction under cultivation. According to Angers et al. (1992), factors such as the dilution of organic matter-rich suface horizon with organic matter-poor subsurface horizons, accelerated mineralization and oxidation due to tillage, induced erosion and the lower amounts of C inputs cause SOM reduction in cultivated soils.

In the Canadian prairies long-term cultivation caused up to 53% C loss, and about 56% N loss in soils (Campbell and Souster, 1982). In the North American Great Plains, 39% of N and 42% C were lost after 36 years of cultivation. In the Nigerian savanna, this study found 38% loss of C and 41% of N in an alfisol after 45 years of cultivation without inorganic fertilizer and farmyard manure. When fertilized with N+P and N+P+K, losses of C, N and P_o were greater than soils receiving a combination of farmyard manure with N+P and N+P+K.

Several studies of long-term cultivated temperate grassland soils suggested that soil degradation under continuous cultivation resulted primarily from deterioration of aggregate stability (Elliot, 1986) due to losses of SOM in macroaggregate fractions (>200 or 250 μm) (Gupta and Germida,1988; Cambardella and Elliot, 1993, 1994). Because soil aggregates are the structural building blocks of arable

or agricultural soils (Fryrear, 1985), aggregate stability has major impact on soil erosion, soil productivity and C, N and P cycling (Tiessen and Stewart, 1983; Gupta and Germida, 1988). Knowledge of aggregate stability and SOM in different aggregate classes is required to determine the changes in aggregation under different soil management techniques that enhance OM accumulation and dissipation (Gupta and Germida, 1988; Beare et al., 1994). These relationships are yet unknown for savanna soils.

Aggregation distribution and stability are sensitive to soil management and cropping systems. Changes in aggregate distribution and stability would have long occurred before detectable declines in SOM are observed when a native grassland soil is broken (Angers et al., 1992). There is no information on aggregate-associated SOM as influenced by inorganic fertilizer and farmyard manure in the savanna. Part of this study would also provide information on the lability of C, N and organic P associated with different aggregate sizes.

2.5. Changes in soil biomass C, N and P under cultivation

The soil microbial biomass performs two important functions: i. oxidation of carbonaceous materials which results in the stabilization of OM and the release of nutrients; ii. the storage of C and mineral nutrients in their living biomass (Anderson and Domsch, 1980; Smith and Paul, 1990). The carbon stored in the living biomass makes up

about 2-5% of the total organic carbon in the soil (Brookes et al, 1982; Witter et al, 1993). Thus soil microbial biomass (SMB) constitutes a very important repository of plant nutrients. The relationship between OM and nutrient cycling is, therefore, through the microbially driven process of immobilization and mineralization (Duxbury et al, 1989). Temporal fluctuations in SMB may have considerable influence on nutrient availability (Granatstein et. al., 1987; Patra et al, 1990).

The SMB is the most labile fraction of SOM, and provides a key site in P_o mineralization in soils (Jenkinson and Ladd, 1981). Brookes et al (1984) reported a linear relationship between soil biomass P and biomass C. Biomass P is more labile than soil P_o with mineralization rates ranging from 0.8 to 8.5 kg P ha^{-1} yr^{-1} (Brookes et al, 1984).

Soil management has noticeable effects on SMB. Crop residue incorporation often leads to increased microbial biomass in soils (Ocio et al, 1991). Alley croppings together with long-term OM addition increase microbial and total C and N (Mazzarino et al, 1993). Soil microbial biomass size is not affected by the type of C input; whether crop residue, green manure, straw, sawdust or FYM (Witter et al, 1993).

Uncultivated grassland soils have higher microbial biomass than cultivated grassland soils (Carter,1986). However, the decline in microbial activity under cultivation can be altered by the addition of fertilizers, crop residues and other sources of OM (Biederbeck et al,

1984; Carter, 1984).

Variations up to 50–70% in biomass C and N can be explained by management practices (Carter, 1986) because of the sensitivity of microbial biomass to management (Powlson and Jenkinson, 1981). Cropping practice may increase or decrease microbial biomass. In cereal–grass rotation, microbial biomass increased significantly compared to continuous–wheat or wheat fallow in Canada (Carter, 1986) suggesting that microbial biomass is to a large extent, controlled by the type of crop grown. Similarly biomass P concentrations are higher and C: P ratios narrower in permanent–grass soils than in arable soils (Brookes et al., 1984).

For soils treated with $(NH_4)_2SO_4$ fertilizer low microbial biomass size was found probably due to stress induced by low pH (Witter et al, 1993). Similar effects of pH on SMB were reported after NH^+_4 addition to soils (Collin et. al., 1992).

When straw and N–fertilizer solution of NH_4N0_3 were used as a treatment, C–mineralization rate decreased, with a corresponding low C availability due to increases in soil acidity (Collins et al, 1992). But the incorporation of FYM produces an increase in microbial biomass. This increase is due to the supply of mineralizable C and N which directly stimulates microbial activity and growth (McGill et al., 1986).

.6. Methods of measuring microbial biomass

Because research into soil microbial biomass is still undergoing refinement it is important to review, in brief, methods of estimating

microbial biomass C, N and P in soils. Several methods are available for the quantitative estimation of soil microbial biomass.

2.6.1. Fumigation-incubation (FI) method

This method introduced by Jenkinson and Powlson (1976), consists principally of killing the soil micro-organism with ethanol-free chloroform ($CHCl_3$), and then decomposing the dead cells by recolonizing the soil with an inoculum of the same soil that has not been treated with $CHCl_3$. This gives a measure of the initial soil biomass. The difference between fumigated and non-fumigated sample is used in the calculation of biomass C and N from the equation:

(i) for Carbon;

$$B_c = \frac{F_c}{K_c} \quad \text{..... Eq. [2.1]}$$

(ii) For Nitrogen:

$$B_N = \frac{F_N}{K_N} \quad \text{..... Eq. [2.2]}$$

where

B_c and B_N = Biomass C and biomass N respectively

F_c = CO_2-C flush produced following fumigation

F_N = Mineralized N flush

K_c = Flush of killed biomass C mineralized to CO_2-C

K_N = Fraction of killed biomass N mineralized under standard conditions

Certain factors have a marked influence on this method.

These are: (a) incubation conditions,

(b) determination of the flush

(c) the K value

2.6.2. Fumigation extraction (FE) method

The underlying principle in this method is the selective action of the fumigant ($CHCl_3$) on the soil microbial biomass, with little effect on the non-living components of the soil. A great advantage of this method is the elimination of the microbial mineralization stages; the avoidance of selecting an appropriate control for calculating the flush, and the potential immobilization of N during the incubation period (Sparling and Ross, 1993). This method can also be used in a wide range of soil types including those with low pH and wide C:N ratios for which the FI method is not suitable (Sparling and Ross, 1993). The soils are usually extracted immediately after fumigation to remove microbial C from the lysed organisms. The extractants usually employed are:

(i) EDTA (MercKx and Martin, 1987)

(ii) 0.5M K_2SO_4 (Tate et al, 1988, Jeorgenson and Brookes, 1990).

(iii) 2M KCl (Amato and Ladd, 1988)

The C extracted by the FE method, unlike that of the FI method,

can react with the soil surface (Jenkinson, 1988), which is often responsible for the variation in values reported in the literature;

B_N = 2.22 extractable N flush (Jenkinson, 1988)

B_N = 3.1 Ninhydrin reactive Nitrogen (NRN) (Amato and Ladd, 1988)

B_C = 21 (NRN) (Amato and Ladd, 1988)

Microbial C =2.64 (extractable C flush) (Vance et al. 1987).

2.6.3 Substrate induced respiration (SIR) method

Substrate availability in the soil is a limiting factor for the respiratory activity of soil organisms. The basic assumption in this method is that the initial rate of respiration after amendment with saturated quantities of the substrate (e.g. glucose solution) is sufficient to permit the direct calibration between respiratory rate and microbial biomass. The application of the glucose in solution, for example, ensures a more precise control of the concentration of the substrate and more even distribution in the soil. It can be used in soils with low initial water content (Sparling and Ross, 1993). Conversion of the SIR into microbial C is calculated from the equation:

Microbial C (μg) = 50 (μl CO_2 h^{-1})..... Eq. [2.3]

2.6.4 Adenosine triphosphate (ATP) method.

There is a close relationship between adenosine 5 – triphosphate (ATP) content of a soil and its microbial biomass content (Oades and

Jenkinson, 1979; Jenkinson et al. 1979; Witter et al, 1993) even though this correlation does not seem to hold where there has been a large substrate application, especially at times of phosphate deficiency.

In this method, moist soil is usually ultrasonified with a suitable extractant. The extractants commonly used are:

(i) Cold 0.3M H_2SO_4 (Lee et al, 1971; Greaves et al, 1973; Karl and La Rock, 1975)

(ii) Butanol-octanol (Conklin and Macgregor, 1972; Anderson and Davis, 1973).

(iii) Boiling Tris-Buffer (Lee et al, 1971, Conklin and Macgregor, 1972; Ausmus, 1973; Karl and La Rock, 1975; Kaczmarek et al, 1976)

(iv) Cold 0.5M $NaHCO_3$-$CHCl_3$ (Paul and Johnson, 1977).

Sometimes, microbial cells of known ATP content are added to the soil to serve as a correction for incomplete recovery during extraction (Lee et al, 1971, Greaves et al, 1973; Paul and Johnson, 1977).

The extract is usually mixed with an asernate buffer in scintillation vials and enzymes added. These are next placed in a liquid scintillation spectrometer. A set of standards are used for calibration from which percentage recovery can be calculated (Jenkinson and Oades, 1979) according to Eq. 2.4.

$$\% \text{ recovery of ATP} = 4(b-a)\ \frac{1+(n-m)}{25} \quad \text{..... Eq. [2.4]}$$

where

'a' = ATP content in P moles read from the calibration curve

n("g") = mass of moist soil with extractant A

b. = mass of moist soil with extractant B

m = mass of oven dry soil

2.7 Dynamics of soil phosphorus fractions

The dynamics of P in soils had been approached from the standpoint that P forms distinct secondary solids with Ca, Al and Fe; an assumption that underlies the sequential P extraction procedure developed by Chang and Jackson (1957) in which different extractants are used to selectively dissolve Ca-P, Al-P and Fe-P. The method ignores P_o pool which may account for up to 80% of total P (P_t) in some soils (Dalal, 1977).

The biological transformation of P is as important as the inorganic transformation in regulating P availability (Stewart and Tiessen, 1987) especially in highly weathered soils (Tiessen et al., 1984). It seems that the apparent neglect of P_o pools when examining P dynamics might be due to methodological difficulty for characterizing labile P_o forms in soils. Hedley et al. (1982) developed a procedure to separate P_i and P_o into different bioavailable forms, and also allowed organization into some chemical groupings. In the sequential extraction, resin P_i and HCO_3-P_i are the labile fractions

consisting of exchangeable P_i, while OH-P_i and P_o are moderately labile and can buffer the resin and HCO_3-P_i. The HCO_3-P_o is the most labile P_o form (Bowman and Cole, 1978), while the more stable P_o forms which are probably involved in long-term P transformation and turnover in soils are extracted with sodium hydroxide (Batsula and Krivonosova, 1973). Finally, the residue from the extraction consists of occluded and non-extractable P, the nature of which is not clearly understood. Tiessen et. al. (1984) followed the Hedley procedure to fractionate P in 168 benchmark soils covering eight taxonomic orders. Path analysis of the relationships between labile and stable P forms indicated that in Ultisols, 80% of the variance in resin-P was explained by HCO_3-P_o suggesting that P_o mineralization is a major determinant of available P, confirming observations in some Nigerian soils (Adepetu and Corey, 1976).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site history and management

The soil samples for analysis were obtained from the long-term DNPK experimental plots at Samaru established since 1950. Samaru lies within the Northern Guinea Savanna on Latitude 11^0 11' N and Longitude 7^0 38' E. It stands at an altitude of about 686m above sea level, with an annual rainfall of about 1100 mm. The long-term plots have four main treatments: farm yard manure (FYM), N,P and K each at three levels.

In the first 10 years of the experiment (1950-1960), the field was cropped to a rotation of cotton, guinea corn and groundnut. From 1961-1970, it was monocropped with cotton and from then on, the plots have been under groundnut rotated with maize prior to sampling in 1995.

The plots were established with the sole aim of determining the best combination of inorganic fertilizer and farm-yard manure (FYM) that could best sustain soil quality and productivity. These long term plots, therefore, offer a unique opportunity for the assessment of soil C,N and P changes under long-term cultivation in the Savanna.

The plots sampled for this study were:

i. Natural vegetation: an uncultivated site adjacent to the

experimental field.

ii. Check plot: cultivated for 45 years with no soil amendment.

iii. NP-plot: cultivated for 45 years and fertilized with 48-135kg N/ha/yr and 18-54kg P/ha/yr.

iv. NPK-plot: cultivated for 45 years with 48-135kg N/ha/yr and 18-54kg P/ha/yr and 29-58kg k/ha/yr.

v. FYM-plot: Cultivated for 45 years with 5 tons/ha/yr of farmyard manure.

vi. FYM+NP-plot; Cultivated for 45 years with 5 tons/ha/yr of farm yard manure and 18-54kg P/ha/yr and 48-135kg N/ha/yr.

vii. FYM+NPK-plot: Cultivated for 45 years with 5 tons/ha/yr of farm yard manure and 48-135kg N/ha/yr and 18-54kg P/ha/yr and 29-58kg K/ha/yr.

3.2 Spatial variability

The effect of soil management on C, N and P was determined by an inferential method involving the comparison of C,N and P concentrations under native site with soils under different management techniques. The validity of this approach depends upon the critical assumption that differences observed between plots and the native site are due to management rather than to inherent variability between plots. The spatial variability of the plots evaluated by 5-cm incremental soil depth augering up to 100-cm depth indicated that soil textures and thickness of Ap horizons were

apparently uniform. This uniformity was adequately reflected in the particle size distribution of the soil (Table 3.1). Because of the apparent site homogeneity, variation in C,N and P were attributed to management rather than to inherent spatial variability between plots.

3.3 Soil sampling

The Ap horizon (0-15 cm depth) and 15-30 cm depth from five plots selected to represent common fertilization practices in the region were sampled for this study. Also a check plot (an unfertilized plot) under continuous cultivation for 45 years, and a native site were sampled. The native site provided the basis for assessing the effect of inorganic fertilization and farmyard manure on the changes in C, N and P of the soils. Since cultivation can alter bulk soil density, and consequently the thickness of the Ap horizon in relation to the thickness of A horizon of the native site, auger points were taken from the Ap horizons of the experimental plots and compared with the thickness of A horizon of the native site soil. The mean thickness of Ap horizons of the experimental plots was 14.8 $\pm$ 0.3 cm which was close to the 15$\pm$0.4 cm thickness of the A horizon of the soil under native vegetation. Similarly, the mean bulk density of 1.53$\pm$0.2 Mg m^{-3} of the experiment plots was only slightly higher than that of the native site soil with bulk density of 1.51$\pm$0.2 Mg m^{-3}. According to Lawes (1965) and Kowal (1968), the effect of cultivation on bulk density of savanna soils is usually short-lived because bulk density

Table 3.1 The particle size distribution of the experimental soils

Treatment	Sand	Silt	Clay
	<----------mg kg^{-1} ---------->		
NP	87.3	6.4	6.3
NPK	89.1	4.6	6.3
FYM	84.3	6.4	9.3
FYM+NP	81.3	8.4	10.3
FYM+NPK	75.1	14.6	10.3
Check	85.1	5.6	9.3
Native	81.8	9.2	9.0

quickly returns to the original value at the end of the growing season. Thus, the narrow range of the bulk density data of the native and the experimental fields is consistent with the uniform thickness of the Ap horizon of experimental field and the A horizon of the native site soil. Twenty core samples were taken from 0-15 and 15-30cm depth. The soils were spread out to dry and then screened through a 2 mm sieve. Sub-samples were fine-ground to 0.5 mm for the determination of organic C, N and P.

3.4 Soil analysis

3.4.1 Carbon, N and P concentration

Organic C was determined by dichromate oxidation (Nelson and Sommers, 1982). Total N and P were determined by sulfuric acid-hydrogen peroxide digestion using Se as a catalyst (Stewart et al., 1974). Total N in the digest was determined by the regular Kjeldahl distillation method (Bremner and Mulvaney, 1982). Organic N was determined by the difference between total N and inorganic N. Inorganic N was extracted by shaking 10 g soil with 100 ml of 2M KCl for 2 h. The NH_4-N and NO_3-N in the extract was determined by steam distillation with Magnesium oxide (Mg0) and Devarda alloy (Keeney and Nelson, 1982). Total P in the digest was determined by Murphy and Riley's (1962) method. Inorganic P was extracted by shaking 5 g soil with 0.5M H_2SO_4 for 18 hours and filtered through Whatman No. 42 filter paper. The total (P_t) in the filtrate was determined by the

Murphy and Riley's method. Mean difference between treatments was partitioned by Kruskal – Wallis non-parametric analysis of variance (Daniel, 1978).

3.4.2 Aggregate size analysis

Twenty core samples were taken from 0-15 cm from each plot. The soil samples were spread out for air-drying.

Aggregate analysis was determined by dry-sieving method. Dry-sieving of the air-dry soil was done manualy following the procedure described by Carter et al. (1994). Briefly, 100-g air-dry soil, placed in a nest of sieves: 2000 μm, 500 μm, 200 μm, 100 μm and 45 μm sieve (20-cm i.d), were gently rotated by hand five times with slight tilting. The procedure adequately distributed the soil throughout the nest of sieves. The proportion of soil remaining in each sieve was collected and weighed. Three replicate determinations were carried out for each soil sample, and the coefficients of variations were less than 5% in all soils. Aggregate stability was characterized by mean weight diameter (MWD) as described by Chaney and Swift (1984) and Carter et al, (1994). The proportion of sand in the aggregates was determined by shaking the aggregates with sodium hexametaphosphate solution for two hours to disperse the soil. The soil suspension was poured through 45 μm sieve to separate the sand fraction from the clay and silt suspension. The sand was washed several times with water, oven-dried overnight and weighed.

3.4.3 Organic carbon, N and P_o in aggregates

Organic C was determined by dichromate oxidation (Nelson and Sommers, 1982). Total N and P were determined by sulfuric acid-hydrogen peroxide digestion using Se as a catalyst (Stewart et al. 1974). Total N in the digest was determined by the regular Kjeldhl distillation method. Organic P was determined by the difference between total P (P_t) and inorganic P (P_i). Inorganic P was extracted by shaking 5 g soil with 0.5M H_2SO_4 for 18 hours and filtered through Whatman No. 42 filter paper. The P_i in the filtate and digest was determined by the molybdate-ascorbic acid method (Murphy and Riley, 1962).

3.5 Microbial biomass C, N and P in Soils

3.5.1 Microbial biomass carbon and nitrogen

The soil microbial biomass carbon (SMB_c) and N (SMB_N) were estimated by the chloroform fumigation-incubation method of Jenkinson and Powlson (1976) with slight modification based on available facilities. Moist soil samples were weighed into 50ml beakers (20 g dry weight) and treated with ethanol-stabilized chloroform ($CHCl_3$) at the rate of 0.5 ml g^{-1} soil in tightly sealed plastic containers for 24 h. Lack of functional distillation facilities made it impossible to remove ethanol from the $CHCl_3$. The C residue, of the ethanol no doubt, would have influenced SMB_C estimates of the soils. The beakers were evacuated under fume hood for six hours and the

fumigated samples were then inoculated with 1.5g moist unfumigated soil thoroughly mixing the soil with the inoculum. The soils were then incubated for 10 d with 20ml portion of 1M NaOH to trap the evolved carbondioxide (CO_2). A control sample treated in the same manner but without $CHCl_3$ fumigation was also incubated. At the end of 10 d, the quantity of $C0_2$ evolution was determined by titrating the Na0H with standard 1.0 M HCl. The SMB_C was determined by Eq. (3.1)

$$SMBC = [(C0_2\text{–}C)_{\text{fumigated}} - (C0_2\text{–}C)_{\text{unfumigated}}]/K_C \text{ -- (3.1)}$$

where K_C=0.41 (Voroney and Paul, 1984). The K_C refers to the fraction of biomass C mineralized to $C0_2$ over a 10 d incubation period.

To determine SMBN, a 10 g portion of the $CHCl_3$ fumigated soil was extracted at the end of 10 d with 2M KCl for 1 h by shaking in a reciprocating mechanical shaker. The soil extract was analyzed for NH_4–N by the Kjeldahl method (Bremner and Mulvaney, 1982)
The SMBN was determined by Eq. (3.2).

$$SMBN = [(NH_4\text{–}N)_{\text{fumigated}} - (NH_4\text{–}N)_{\text{unfumigated}}]/K_N \text{ ---(3.2).}$$

where K_N =0.41 (Carter and Rennie, 1982) and K_N refers to the fraction of microbial N mineralized at the 10 d incubation period.

3.5.2 Soil microbial biomass phosphorus

Soil microbial biomass phosphorus (SMB_p) was determined by the method described by Hedley and Stewart (1982) except that there was no initial removal of resin extractable P prior to $CHCl_3$ fumigation. Briefly, to 2 g moist soil in a 50 ml centrifuge tube was added 2 ml of $CHCl_3$. The $CHCl_3$ fumigated soil was extracted with 30 ml of 0.5 N $NaHCO_3$ for 16 h by shaking overnight. The soil was centrifuged at 10 000 rpm and the extract filtered through Whatman No. 42 filter paper. Phosphorus in the extract was determined by digesting 10 ml aliquot with 0.6 g potassium persulphate ($K_2S_2O_4$) and 10 ml of 1.8 N H_2SO_4. Total P in the digest was determined colorimetrically by the method of Murphy and Riley (1962). The SMBp was determined by eq. 3.3.

$$SMB_p = [(NaHCO_3\text{-}P)_{fumigated} - (NaHCO_3\text{-}P)_{unfumigated}]/Kp \quad -- 3.3)$$

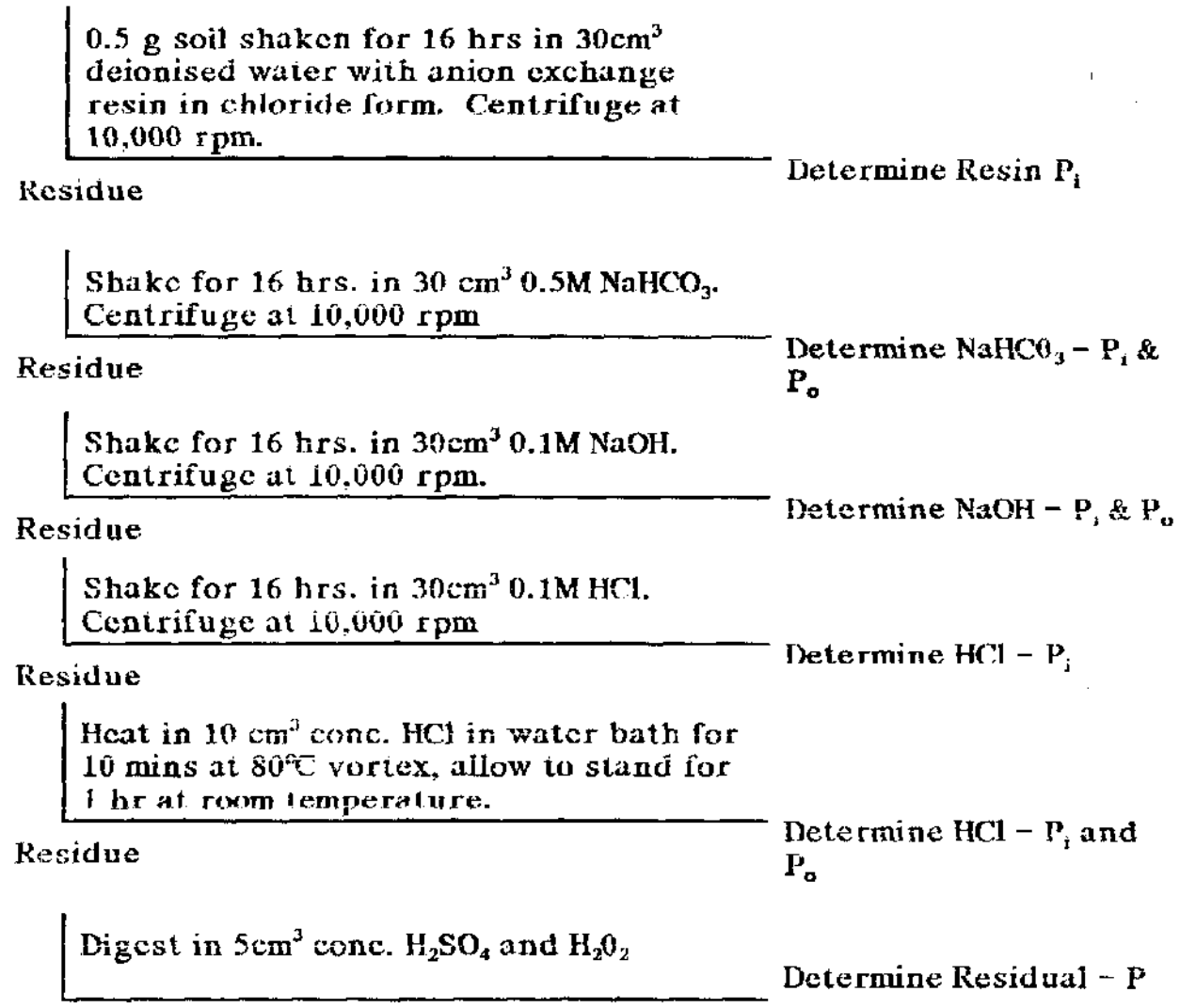
where Kp = 0.40 (Brookes et. al., 1982) and Kp refers to the fraction of microbial P extractable with $NaHCO_3$. Hedley and Stewart (1982) reported a Kp of 0.37 which is not too far from 0.40 used in this study.

3.6 Sequential extration of phosphorus by the modified Hedley procedure

The Ap horizons (0–15 cm) of ten plots from the long-term experimental DNPK field were used for this study.

The soils were spread out to dry and screened through 2 mm

sieve. Sub-samples were ground and passed through 0.5mm sieve for P fractionation and organic carbon analysis. Particle size analysis was determined by the pipette method after dispersing the soils with sodium hexametaphosphate solution. Soil pH was determined in 0.01 M KCl suspension. Organic C was determined by dichromate oxidation (Nelson and Sommers, 1982). Total P (P_t) was determined by concentrated H_2SO_4–H_2O_2 digestion. Total P in the digest was determined by the molybdate-ascorbic acid method (Murphy and Riley, 1962). Total organic P was determined by the difference between P_t and P_i. Inorganic P was extracted by shaking 5 g soil with 1N H_2SO_4 for 18 hours, and the P_i in the extract was determined by Murphy and Riley's method. Phosphorus fractionation was achieved by a modified Hedley fractionation (Fig. 3.1). The P_t and P_o forms in the extracts were determined by the procedure described by Agbenin and Tiessen (1994).



Figire 3.1: Modified Hedley et al, (1982) sequential extraction of P as adopted by Agbenin and Tiessen, (1994).

3.6.1 Statistical procedure

To determine the underlying relationships between different P pools, we grouped the P fractions according to their covariances employing factor analysis. Factor analysis allows the coherence in relationships in a multivariate dataset to be identified. Such relationships reflect the correlation of each variable with mutually orthogonal underlying factors. Factor analysis assumes that the observed variable is influenced by a number of factors or determinants, some of which are shared by other variables. The importance of each factor is deduced from its respective eigenvalue which is calculated from the loading of each variable on the factor. The factor loadings are similar to regression coefficients of the factors in a multiple regression equation to describe a given variable (Johnston, 1978). Varimax rotation was employed to reduce the number of P pools having high loading on any one factor in order to simplify the interpretation without relaxing the orthogonality constraint (Davis, 1973).

The direct and indirect contribution of various P pools to plant available P (resin-P) was also determined. For this purpose, path analysis was used for evaluating causal relationships. Path analysis utilizes multiple regression techniques to measure the direct influence of one variable upon another, and further allows the separation of the correlation coefficients into components of direct and indirect effects (Dewey and Lu, 1959). The basic requirement of

path analysis is that a cause and effect relationship among the variables be established. If a cause and effect relationship can be established independently say Y is caused by variables X_1, X_2 and X_3, the magnitude of the effect of each variable on Y can be evaluated by the sign and magnitude of the normalized regression or beta coefficient (ß) which, when used in path analysis, are called path coefficients. Path coefficients measure the change in a dependent variable (measured in units of standard deviation) that is associated with a unit standard deviation change in an independent variable. Path coefficients were derived among the P fractions in a conceptual model depicting P transformation in the soils. This is to spell out the causation paths in the relationship between plant available P (resin-P) and the other P pools. All statistical analysis were performed on Statview II (Abacus concepts, 1987).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Carbon, nitrogen and phosphorus dynamics

4.1.1 Carbon, N and P concentrations in the soils

Forty five years of continuous cultivation with inorganic fertilization caused significant changes in the concentrations of C, N and P in the Ap horizon (Table 4.1). In some cases the changes extended to 15–50cm depth (Table 4.2). At the AP horizon, N+P and N+P+K fertilization significantly reduced C concentration when compared to the native site (Table 4.1). This drastic reduction in C concentration extended to 15–30 cm depth (Table 4.2). However, combination of N+P or N+P+K with FYM maintained C concentrations at nearly identical levels with the native site soil. Similarly, FYM applied alone did not reduce OC status significantly.

Total N in the Ap horizon ranged from 217 mg kg^{-1} in the check plot to 501 mg kg^{-1} in the FYM+NP plot. Organic N accounted for over 80% of soil total N (Table 4.1). At the AP horizon, N+P and N+P+K fertilization significantly reduced organic N concentration when compared to the native site (Table 4.1). The FYM in combination with N+P or N+P+K maintained organic N concentrations at par with sometimes exceeding the concentrations of organic N in the native site soil. However, N+P+K fertilization increased NH_4-N concentration in relation to the native site. At 15–30 cm depth, inorganic or FYM

fertilization had no effect on organic N concentrations except for increased NH_4-N content (Table 4.2).

Total P in the Ap horizon ranged from 180 mg kg^{-1} in the NP and check plots to 529 mg kg^{-1} in the FYM+NP plot. Application of N+P and N+P+K reduced P_t and P_o in relation to the native site. This is at variance with report by Dalal (1977) and Anderson and Coleman (1985) that N and P_i fertilization increases build-up of P_o and SOM. However, FYM in combination with N+P or N+P+K increased the concentration of P_o above the native site soil.

The C:N and C:P_o ratios were in a narrow range. However, the C:N ratio fairly well exceeded 10 in most of the plots. This is a critical ratio for net N mineralization to occur in soils though C:N ratio fails to recognize the forms of N in organic matter. Mineralizable N is largely the portion that is bound to proteins, while the part bound to lignin is recalcitrant to microbial degradation (Christie, 1987; Collins et al., 1992). The narrow range of C:N and C:P_o ratios indicates similarity in SOM mineralization or decomposition rates.

Table 4.1 The mean concentration and standard deviations of C. N and P in the ploughing depth (0-15cm) of an alfisol as influenced by inorganic fertilizers and farmyard manure for 45 years.

Soil Treat.+	OC (g kg^{-1})	Org.N	NH_4-N	Total N	C:N ratio	P_o	P_i	P_t	C : P_o ratio
		<----------mg kg^{-1} ---------->				<----------mg kg^{-1}---------->			
NP	4.7±0.3d	223±49bc	21.6±1.2b	245±50bc	21	101±17b	79.1±16c	180±9c	46
NPK	3.1±0.3e	224±48bc	40.0±13.4a	264±60bc	14	143±66b	114±1b	257±66c	22
FYM	5.7±0.2c	334±0.3b	28.0±0.6ab	362±85b	17	316±48a	70.2±4.2cd	386±5ab	18
FYM+NP	6.3±0.3bc	280±49b	24.3±2.8b	304±52bc	22	390±51a	140±0.3a	529±51a	16
FYM+NPK	7.0±0.2a	474±128a	26.7±12.6ab	501±120a	15	349±73a	142±4a	490±69a	20
Check	3.5±0.5e	195±48c	22.3±8.0b	217±53c	28	152±39b	27.9±1.5e	180±39c	23
Native	6.9±0.4ab	364±97ab	16.6±0.2b	380±96ab	19	325±48a	56.5±17.8d	381±30b	21

+N = nitrogen. P = phosphorus. K=potassium. FYM=Farm yard manure. control = never received inorganic or farmyard manure treatment for 45 years prior to sampling. Means followed by the same or common letter are not significantly different at 5% probability level.

Table 4.2 The mean concentration and standard deviations of C. N and P at 15-30 cm depth of an alfisol as influenced by inorganic fertilizer and farmyard manure for 45 years.

Soil Treat.+	OC (g kg^{-1})	Org.N	NH4-N	Total N	C:N ratio	P_o	P_i	P_t	C : P_o ratio
		<--------mg kg^{-1}---------->				<-------mg kg^{-1}---------->			
NP	1.5±0.1c	280+48abc	21.1±0.7b	300±47ab	6	122±63d	30.0±1.9cd	153±63c	12
NPK	2.6±0.4cd	195+48bc	35.6±7.6a	231±52bc	13	96±60d	84.6±1.0b	180±60c	27
FYM	4.2±1.3a	252+1.0abc	24.2±3.0ab	276±3bc	17	306±56ab	23.6±1.0cd	330±56b	14
FYM+NP	4.0+1.3ab	308+49ab	22.3+1.2a	330+48ab	22	370+85a	122+2a	492+84a	11
FYM+NPK	3.1±1.0bc	363+128a	25.6±13.4c	391±124a	15	100±36d	73.7±18b	174±51c	31
Check	3.0±0.1bc	167+1c	17.8±7.6bc	185±8c	18	153±32cd	34.9±14c	188±33c	20
Native	3.6±0.7ab	252+84ab	22.2±0.1b	274±84bc	19	299±37bc	15.6±1.0d	245±37bc	16

+N = nitrogen. P = phosphorus. K=potassium. FYM=Farmyard manure. control = never received inorganic or farmyard manure treatment for 45 years prior to sampling. Means followed by the same or common letter are not significantly different at 5% probability level.

4.1.2 Area-based losses of C,N and P

Area-based losses of C, N and P were calculated by multiplying the concentration data with the bulk density and sampling depth. The amounts of C,N and P calculated in this manner were summed up for the two sampling depths. Area-based changes give an estimate of the total amounts of C, N and P lost from a soil due to mineralization, erosion (Tiessen et al., 1982) and possibly leaching. Although, soil fertility data evaluated in this way are prone to relatively large errors because of the complexity of a field (inherent spatial variability), such data do give an idea of field conditions. Thus, the net losses of C, N and P induced by 45 years of N+P and N+P+K fertilization with or without farmyard manure were calculated for the experimental field with respect to the native site (Table 4.4).

Significant losses of C, organic N, P_o occurred in the check plot. Similarly, N+P and N+P+K fertilization induced losses of C, P_o and organic N (Table 4.4). However, net gains of P_i were made with inorganic fertilization. Of interest in this study is that farmyard manure application did not cause losses of C, N and P in the soil under continuous cultivation. The effectiveness of farmyard manure on the maintenance of C, N and P status of the soils increased when applied in combination with N+P and N+P+K. Net gains of P_i, P_o and P_t were made in FYM+NP plot, while a net gain of organic N occurred in the FYM+NPK plot (Table 4.4).

4.1.3 General discussion

In soil ecosystems, C, N and P are closely linked and their transformations are controlled by these linkages and external driving variables that regulate the process which determine soil properties. Changes in C, N and P were used to asses the degradation and aggradation of soil quality under continuous cultivation in this study.

Continuous cultivation without fertilization (check plot) for 45 years reduced C by 38%, organic N and total N by 41% and 39% respectively. When converted to a hectare basis, losses of 10.2 Mg ha^{-1} of C, 630 Kg ha^{-1} of organic N, and 670 Kg ha^{-1} of total N occurred in the check plot in relation to the native site. Similar amounts of P_t and P_o were lost in the check plot (Table 4.3). The effect of continuous cultivation in depleting soil C,N and P is fairly well documented (Tiessen et al. 1982. Ihori et al., 1995). Rapid loss of C induced by cultivation is usually caused by rapid decomposition and erosion due to structural deterioration of soil aggregates (Elliot, 1986).

It is also of interest to note that long-term inorganic fertilization in the savanna has a deleterious effect on soil quality with special reference to C, organic N and P_o. Application of N+P or N+P+K could not arrest the downward slide in C, organic N and P_o in the soils. The continuous loss of organic N and P_o in the soils despite the supply of N and P from inorganic sources seems to imply that SOM

Table 4.3: Area-based amounts and standard deviations and losses of C, N and P in a savanna alfiosol after 45 years of cultivation

Soil property	Native	Soil Management techniques + Check	NP	NPK	FYM	FYM+NP	FYM+NPK
Organic C(Mg ha^{-1})	23.9±2.5	13.7±1.8 (-10.2)**	14.1±0.9 (-8.9)**	13.0±1.4 (-10.9)**	22.6±2.7 (-1.3)NS	23.5±2.7 (-0.4)NS	23.0±1.1 (-0.9)NS
Organic N(kg ha^{-1})	1400±410	830±160 (-630)**	1150±240 (-250)NS	960±210 (-440)*	1340±320 (-60)NS	1340±210 (-60)NS	1910±590 (+510)**
NH_4-N (Kg ha^{-1})	87±10	90±30 (+3)NS	100±10 (+13)NS	171±50 (+83)*	120±10 (+33)NS	100±10 (+13)NS	121±50 (+33)NS
Total N(kg ha^{-1})	1490±410	820±140 (-670)**	1240±220 (-250)NS	1130±260 (-360)*	1455±200 (-35)NS	1450±230 (-40)NS	2030±560 (+540)**
Organic P (kg ha^{-1})	1260±300	540±280 (-720)**	510±200 (-750)NS	700±150 (-560)**	1420±210 (-160)NS	1730±290 (+470)**	1030±670 (-230)NS
Inorganic P (kg ha^{-1})	160±110	140±50 (-20)NS	300±190 (+140)**	540±70 (+290)**	210±120 (+50)NS	600±50 (+340)**	490±180 (+330)**
Total P (kg ha^{-1})	1430±370	840±150 -590)**	760±200 (-670)**	990±320 (-440)*	1630±260 (+200)NS	2320±300 (+890)**	1510±830 (+80)NS

+ N=Nitrogen. P=phosphorus. K=potassium. FYM=Farmyard manure. control=never received inorganic or farmyard manure treatment for 45 years prior to sampling. * and ** indicate significant difference in relation to the native site at 5 and 1 % probability levels respectively.

mineralization was probably fast enough to supply plant available N and P. This is consistent with the hypothesis of Stewart and Tiessen (1987) that in weathered soils, P_o is the reservoir of plant available P corroborating the observations of Adepetu and Corey (1976) in soils of southern Nigeria. Inorganic fertilization (N+P and N+P+K) only increased the extractable inorganic N and P_i of the soils and could not halt the losses of organic N and P_o.

The comparable losses of organic N and P_o especially in the check plot were probably due to similarities in the mineralization rates of N and P from soil organic matter (SOM) consistent with the narrow range of the C:N and C:P ratios. This is rather inconsistent with the view that the mechanisms stabilizing N and P_o in soils might be different from each other (McGill and Cole, 1981). In the dichotomous model proposed by McGill and Cole (1981), C and N are stabilized and mineralized together through C-N bond linkage (biological mineralization) whereas P might be stabilized either through the C-P (phosphonates) or C-O-P (esters) bond linkage. Thus, P is subject to both biological mineralization through C-P bond breakage (phosphonates) brought about by microbial need for C, and by biochemical mineralization through extracellular phosphatase cleavage of C-O-P bond. The production of extracellular phosphatase or this enzymatic catalysis (biochemical mineralization) is in response to P stress (McGill and Cole, 1981). One would have expected that liberal supply of P through N+P and N+P+K fertilization would halt the

production of extracellular phosphatase so that P_o mineralization and losses would be substantially less than N mineralization and losses. This was not the case in the check, NP and NPK plots Table 4.4.

The tendency for N losses to parallel P_o losses in the soils suggests a biological mineralization pathway or mechanism for both elements. Tiessen and Stewart (1983) reported that losses of C, N and P_o in Canadian Prairie soils were similar, further lending credence to biological and non-differential mineralization process. The result of this study is therefore consistent with the hypothesis of Stewart and Tiessen (1987) that SOM mineralization could be fast enough to provide P for crop export, thus avoiding the P limiting condition that leads to biochemical mineralization.

The FYM plot had C, N and P concentrations at approximately the same levels as the native site. Area-based changes in C, and P calculated in relation to the native site were not significant suggesting that FYM was effective in mitigating C, N and P losse When FYM was combined with N+P and N+P+K fertilization, apart from arresting the net loss of C, net increases of organic N and P_o in relation to the native site were observed in the plots. It seems, from the data, that build-up of N and P in a savanna alfisol can be enhanced with FYM. Farmyard manure in combination with N+P and N+P+K fertilization probably stimulated immobilization of N and P at the expense of reactions with soil inorganic constituents.

The beneficial effect of farmyard manure on the physical and

chemical properties of savanna soils had long been recognized (Heathcote. 1970; Bache and Heatcote. 1969). However. the use of farmyard manure for soil fertility improvement is not widespread. The reasons for this include bulkiness. application rate and transportation. Weighing these problems against the degradative effect of inorganic fertilization on SOM. the lifewire of the soil ecosystem. there seems to be no apparent justification for not stimulating research into the integration of farmyard manure into the farming and cropping systems to halt the declining SOM. increase the size of organic matter pools for the sustainability of savanna agroecosystems. In the context of sustainability of the farming systems. inorganic fertilization does not seem to hold any promise. There is the dire need to develop management practices that utilize nutrients cycling through active and moderately active compartments of SOM (Anderson and Coleman. 1985) without the nutrients being tied down in the recalcitrant compartment of SOM. This is where farmyard manure might be indispensable; its bulkiness. application and transportation costs notwithstanding.

In conclusion the soil under native site had significantly higher C.N and P than the check plot. Inorganic fertilization could not halt the losses of C. N and P. With farmyard manure. the amounts of C.N and P were statistically at par with the native site. The effectiveness of FYM in the maintenance of soil fertility with special reference to C. N and P was improved when combined with inorganic fertilization. It

can thus, be concluded that soil degradation under continuous cultivation can be reversed with farmyard manure. Research into management practices that halt the decline of SOM, and increase the size of organic matter pool is required and should be accorded high priority.

4.2 Aggregate associated C, N and P.

4.2.1 Aggregate distribution

In the check plot, significant reduction of macro-aggregates (> 200 μm) occurred compared to the native site (Table 4.4). Except for the check plot, the amounts of macro-aggregates were slightly more than micro-aggregates in all soils. Detailed separation of the macro-aggregate class indicated that the 200-500 μm size accounted for 25-33% of the whole soils while the 45-100 μm micro-aggregate size accounted for 25-36% of the whole soils. Sand content ranged from 63 to 80% of the weight of macro-aggregates, and from 54 to 79% of micro-aggregates (Table 4.4) Normalizing the aggregates on sand-free basis, the FYM-fertilized soil had the highest amount of macro-aggregate due probably to the dependence of soil structural stability on SOM (Tisdall and Oades, 1982). Organic C explained 67% of the variations in MWD between soils (MWD = 0.72 + 0.02 (OC) r^2 = 0.67). Aggregate stability of the fertilized plots was at par with the uncultivated site due probably to increased crop residue biomass returned to the soil.

Table 4.4: Aggregate distribution and stability determined as mean weight diameters (MWD) of aggregates of a savanna Alfisol under continuous cultivation.

Soil treatment	>200 µm macro-aggregates		45-200 µm micro-aggregates		<45 µm silt+clay	Mean weight diameter (mm)
	<---------- % of total soil ------->					
NS	49.0	(80)[a]	43.3	(74)	7.6	0.85
Check	43.7*	(78)	44.4	(73)	11.9**	0.77*
NPK	48.6	(82)	42.8	(54)**	8.6	0.82
FYM	49.8	(63)*	40.7	(73)	9.5	0.88
FYM+NPK	50.3	(67)*	41.2	(54)**	8.5	0.90

* and ** significantly different from the native site at $P < 0.05$ and 0.01 respectively. a = Values in parentheses are percent sand in the aggregate sizes.

4.2.2. Organic C, N and P in aggregates

The amounts of C, N and P_o in aggregates was compared on sand-free basis since sand had the effect of diluting the C,N and P_o of intact aggregates thus making comparisons, across aggregate size difficult. The FYM+NPK-fertilized soil had higher concentrations of N and P_o in the macro-aggregate class, while the other soils contained more N and P_o in the micro-than macro-aggregates (Table 4.4). The 500-2000 μm size fraction contained more C, N and P_o than the 200-500 μm size macro-aggregates , while the 45-100 μm micro-aggregate size contained more C, N and P_o than the 100-200 μm size aggregate.

The net percent changes in the concentrations of C, N and P_o in aggregates of the cultivated soils in relation to virgin soil were assessed (Table 4.6). Implicit in this assessment is the assumption that without cultivation, the concentrations of C, N and P_o in the aggregates would have been at par with the uncultivated soil aggregates. The concentration of C in macro aggregates decreased significantly in the check and N+P+K fertilized soils when compared to the native site soil (Table 4.6). Addition of FYM with or without NPK fertilizer maintained C concentration of macro-aggregates at par with, or higher than, the native site. The P_o concentration in macro-aggrates decreased significantly in the check- and FYM-plots compared to the native site. In contrast to macro-aggregates.

Table 4.5: The amounts of C, N and P_o (g kg^{-1}) in aggregates as influenced by inorganic fertilizers and farmyard manure

Soil aggregates	Native	Check	NPK	FYM	FYM+NPK
Macro-aggregates					
C	20.1	12.7	20.0	17.0	34.9
N	2.3	2.1	2.4	1.4	4.25
P_o	2.8	1.7	2.5	1.0	2.7
Micro-aggregates					
C	56.6	10.6	12.6	17.9	18.8
N	6.3	2.5	1.7	2.0	2.3
P_o	4.9	1.6	2.0	1.6	1.7
Silt + Clay					
C	9.5	5.6	7.1	9.5	7.6
N	0.9	0.8	0.8	0.8	1.0
P_o	0.6	0.6	0.7	0.7	0.5

Table 4.6: Net changes of C, N and P in aggregates expressed in percentages as influenced by inorganic fertilizer and FYM

Soil Aggregates	Check	NPK	FYM	FYM+NPK
	<---------- △ %[a] ---------->			
Macro-aggregates				
C	-37	NS	NS	+74
N	NS	NS	NS	+88
P_o	-38	NS	-46	NS
Micro-aggregates				
C	-81	-78	-68	-67
N	-60	-71	-68	-64
P_o	-67	-73	-67	-65
Silt + Clay				
C	-41	-37	NS	-20
N	NS	NS	NS	NS
P_o	NS	NS	NS	NS

[a] NS denotes non-significant changes. Percent changes were calculated when 't' test indicated significant changes between a treatment and the native site.

net losses or decreases in the concentration of C,N and P_o occurred in micro-aggregates of all soils when compared to the native site. Net increases in N and P_o occurred in the <45 μm sized fraction (silt + clay) due probably to their stabilization. In the macro-aggregates class, losses in the concentrations C, N and P_o occurred mainly in 500-2000 μm size aggregates, while losses in C, N and P_o in micro-aggregates occurred predominantly in 45-100 μm size (Fig. 4.1), suggesting that these two aggregate sizes contained a pool of stabilized but mineralizable C, N and P_o important to the medium-term supply of nutrient by SOM mineralization. It seems that the 200-500 μm and the 100-200 μm aggregate sizes contained physically protected or occluded OM.

Models of SOM turnover from temperate grassland soils consistently suggested that SOM associated with macro-aggregates is more labile than SOM in micro aggregates (Elliot and Coleman, 1988) with turnover of one to three years (Buyanovsky et al., 1994). The macro-aggregate-associated SOM consists of temporary binding agents made up of roots and hyphae, binding micro-aggregates into macro-aggregates (Tisdall and Oades 1982). During cultivation of grassland soils, much of the SOM lost is derived from the mineralization of these temporary binding agents which bind micro-aggregates into macro-aggregates (Gupta and Germida, 1988). The results of this study suggest that the labile and nutrient-rich SOM was associated with 45-100 μm size. The C:N ratios (data not shown) were similar across aggregate sizes suggesting that

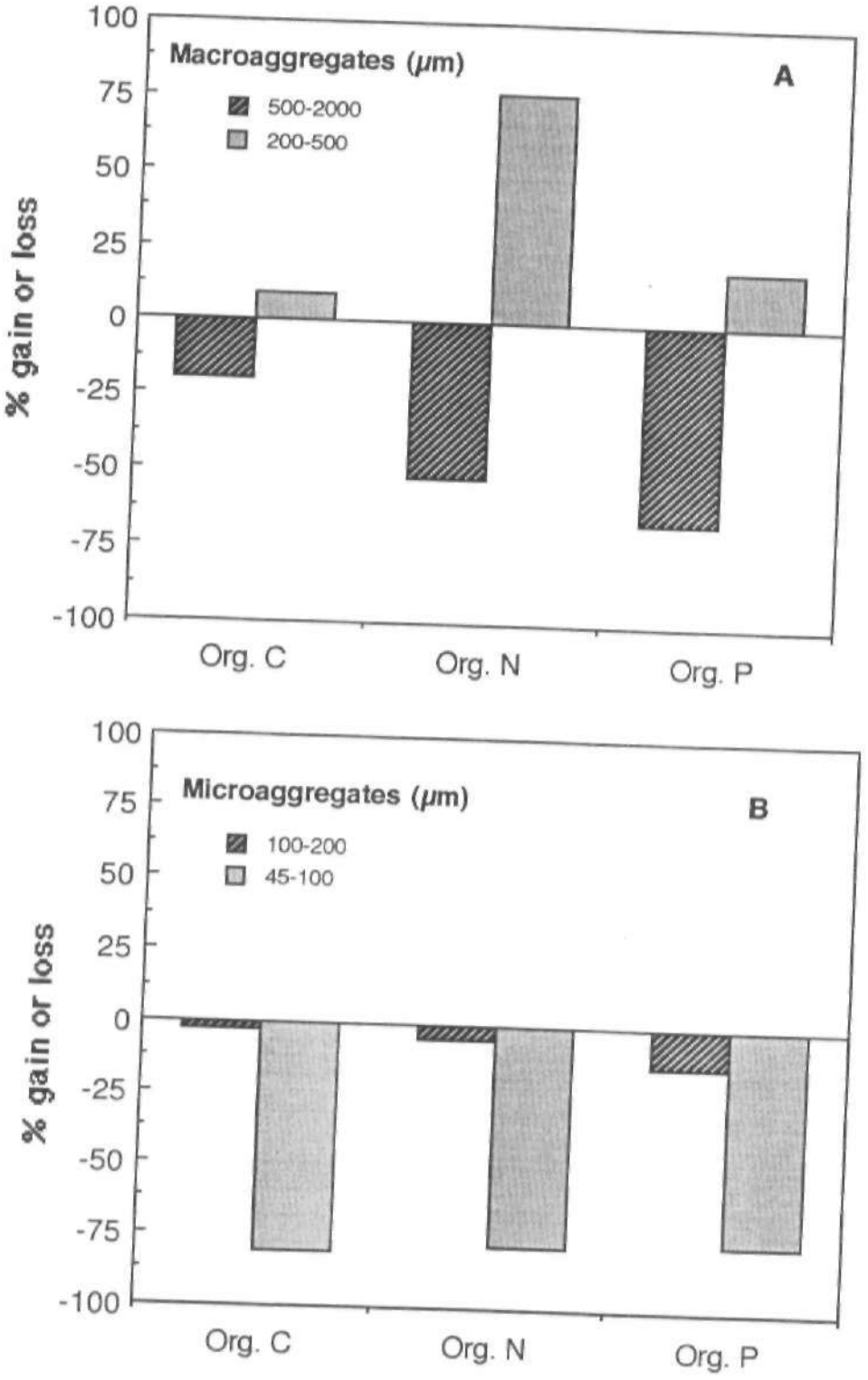


Figure 4.1: The changes in C,N and P in percentage of the different aggregate sizes in relation to the native site

there might not be clear-cut differentiation in the degree of SOM humification associated with different aggregate sizes even though other studies indicated that micro-aggregate-associated OM is highly humified, nutrient-poor and structurally complex humic acid with high aromatic contents (Elliot and Coleman, 1988) and slow turnover (Buyanovsky, et al., 1994).

The results of this study support the idea that cultivation reduces C, N and P_o even with N+P+K fertilization. Losses of C, N and P_o were confined to 500-20000 μm size macro-aggregate, and the 45-100 μm micro-aggregates irrespective of fertiiization practices. However, higher loses of C, N and P_o in 45-100 μm size (micro-aggregates) than 500-200 μm size suggesting that macro-aggregates are important mechanisms of SOM sequestration or protection.

4.2.3 Soil microbial biomass C, N and P

The "health" of the soil ecosystem can be assessed by its biological activities involving the flows of C, N and P through the soil microbal biomass (Carter and Rennie, 1982). Visser and Parkison (1992) for instance showed that low microbial activity is an indication of a stressed ecosystem. This study, therefore, used soil microbial biomass carbon (SMBC), soil microbial biomass nitrogen (SMBN), and soil microbial biomass phophorus (SMBP), to asses the "health" of the soil under continuous cultivation.

Soil microbial biomass carbon (SMBC) was 522 mg kg^{-1} in the

native site as against 100 mg kg^{-1} in the NPK fertilized plot (Table 4.7). This might be attributed to the low pH in the NPK plot which inhibited microbial activity. Application of FYM or FYM + N tended to stabilize SMBC, probably due to the supply of N as nutrient and C as a source of energy from the FYM consistent with the relationship between SMBC and soil OC ($r = 0.84$) Fig. 4.2. The SMBC accounted for 3.5 - 7.8% of soil organic carbon (SOC) (Table 4.8) which is higher than the 1-4% of Anderson and Domsch (1989). This range, however is reasonably close to the 4.0 - 6.5% reported for soils under long-term cultivation by Franzluebbers et al., (1995).

It is commonly suggested that a higher proportion of SOC as SMBC is an indication of an enlarging SOM (Witter et.al., 1993). This study cannot claim this because of the use of ethanol-stabilized chloroform ($CHCl_3$) as the fumigant. Metabolism of residual C from the ethanol during the 10 day incubation period could have increased CO_2 evolution (Vance et al. 1987). But the findings of Deluca and Keeney (1993) showed no significant error in SMBC estimation by ninhydrin-reactive N method, using ethanol-stabilized $CHCl_3$ as a fumigant. Despite the probable error in the estimation of SMBC by the use of ethanol-stabilized $CHCl_3$, the results indicated that continuous cultivation with inorganic fertilizers stressed SMBC, which was relieved by FYM.

Table 4.7 The influence of inorganic fertilizer and manure on soil microbial biomass carbon,nitrogen and phosphorus

Soil treatment	Biomass C	Biomass N	C/N	Biomass P	C/P ratio
	-----mg kg_{-1})------			(mg kg_{-1})	
Native	522[a]	71.7	7.3	8.6	60.7
Check	166	ND	ND	ND	ND
N	322	61.0	5.3	7.1	5.3
NPK	110	25.2	4.4	ND	ND
FYM	293	22.0	13.3	1.5	195
FYM+N	477	58.6	8.1	6.0	79.5
FYM+NPK	373	32.9	11.3	10.9	34.2

[a] = No statistical analysis was carried out because measurements were done on one sample from each treatment.

ND = not determined.

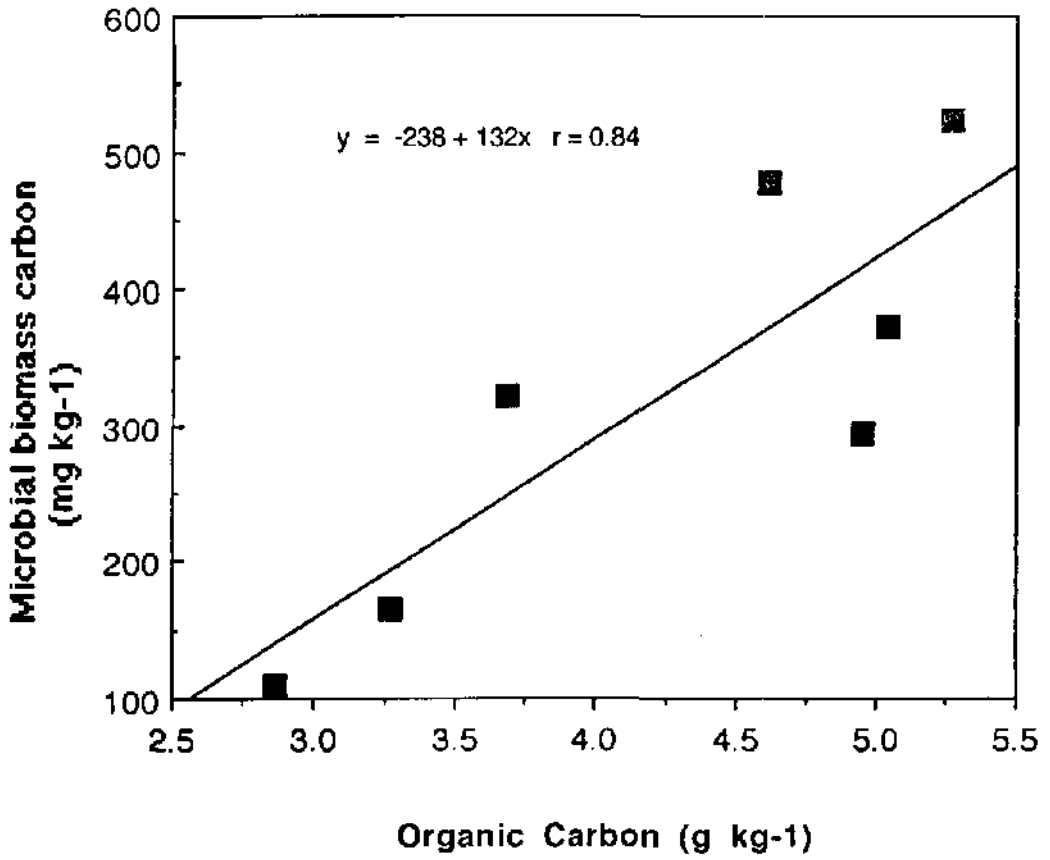


Figure 4.2: The relationship between organic carbon and microbial biomass carbon

Table 4.8: The Soil microbial biomas C.N and P as percentages of soil total organic C. N and Phosphorus

Soil treatment	Biomass C	Biomass N	Biomass P
	<---------- % ---------->		
Native	7.5	22.4	2.6
Check	4.7	ND	ND
N	7.8	16.8	2.6
NPK	3.5	11.3	ND
FYM	5.2	6.6	0.5
FYM	7.8	17.5	1.6
FYM+NPK	5.4	6.9	3.1

Some linear relationship was observed between SMBN and SMBC, indicating the dependence of soil N on microbial activity (Fig.4.3). The soil microbial biomass C:N ratio varied from 7:1 - 13:1 (Table 4.7), which is lower than the 14:1 to 17:1 reported by Mazzarino et al (1993) for some tropical agroecosytems due probably to differences in crop residue management.

The SMBP ranges from 1.5 mg kg^{-1} in the FYM fertilized plot to 10.9 mg kg^{-1} in the FYM + NPK plot. The SMBP was low in all soils except the FYM + NPK fertilized plot whose high value may be attributed to OC addition from the FYM and fertilizer - P which might have been immobilized by microbial biomass.

There is the possibility of under-estimation of P held by the soil microbial biomass because the K_p value used (0.40) was obtained from the literature (Bookes et el., 1982; Hedley and Stewart, 1982). Because of variations arising from the capacity of soils to adsorb phosphate, Hedley and Stewart (1982) cautioned that separate Kp values must be determined for each soil. The probability of under-estimation of SMBP is apparent from the calculated C:P ratios of SMB ranging from 34:1 - 195:1, which is far from 15:1 for P-sufficient and P-deficient soils under laboratory conditions (Chauhan et al. 1981).

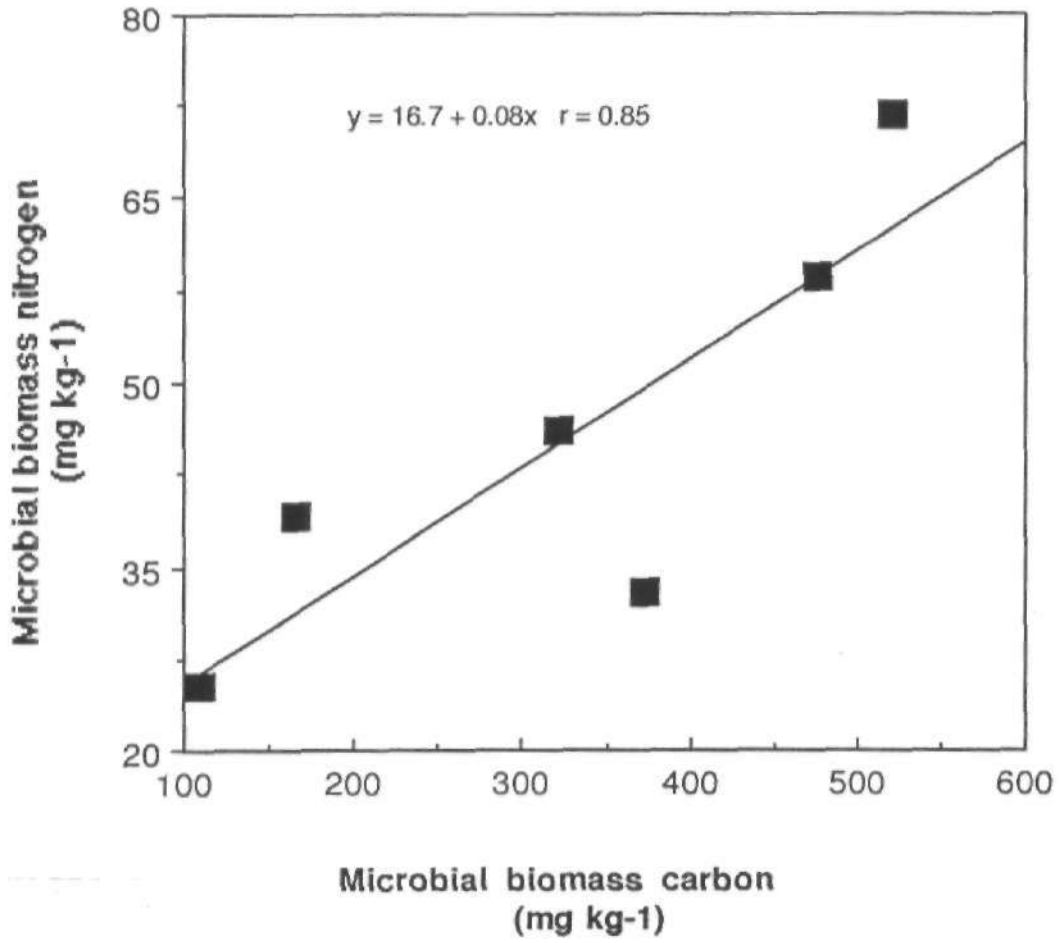


Figure 4.3: The relationship between microbial biomass carbon and microbial biomass nitrogen

The result of this work showed that SMBP can be maintained at the same level with that of the native site with N, FYM + N and FYM +NPK fertilization (Table 4.7). The source of inorganic N is critical so as to prevent the development of soil acidity which has deleterious effects on microbial activity (Kowalenko et al. 1978). This necessitated the change to calcium ammonium nitrate ($CaNH_4(NO_3)_3$) as a source of N from 1969 – 1994 instead of ammonium sulfate ($(NH_4)_2SO_4$) applied from 1950 – 1968 in the DNPK experimental plots at Samaru.

There was no relationship between SMBC and SMBP. This might be attributed to the different stabilization mechanisms for N and P in soil OM (McGill and Cole 1981).

In conclusions, this study demonstrated that cultivation and management practices did not influence aggregate size distribution. However, aggregate stability, characterised by MWD, was higher in soil fertilized with FYM or FYM+NPK than soils receiving inorganic fertilizers alone. A major cause of soil degradation is the deterioration of soil aggregate stability. Even though, savanna soils are predominantly sandy and poorly aggregated, their erodibility is minimal because of the relatively stable aggregates. Thus management practices that induce destruction of aggregate stability will increase erodibility of the soils. The limited data presented here showed that the inherent structural stability of soils can be preserved with FYM or by the combinations of FYM with inorganic fertilizers.

The higher losses of C, N and P in the microaggregate compared to macro-aggrates suggested that macro-aggregates are effective mechanisms of OC sequestration. As cultivation destroys macro-

aggegates. OC becomes susceptible to rapid oxidation becuase of exposure arising from increased surface areas. From the perspective of soil maintenance, it is the conclusion of this study that a rational fertilizer strategy must combine organic residue management with inorganic fertilizer use. Reliance on inorganic fertilizer alone has long-term degradation consequences not only for the soil physico-chemical fertility but also on the biological fertility criteria assessed in this study.

4.3 Dynamics of P fractions as influenced by long-term cultivation and management

4.3.1 Effect of cultivation and N and P fertilization

To compare the size of P pools in the soils, the concentrations of P_i and P_o were normalized on the basis of soil fines (silt + clay fractions) because of textural variability of the soils, and to remove the dilution effect of sand. The amounts of soil fines ranged from 9% in the native site to 15% in the FYM+NPK fertilized plot (Table 4.6). Under continuous cultivation with no manurial treatment, significant decreases occurred in all P pools when compared with the native site (Table 4.10). The residual P pool declined by 82%, the HCO_3- P_o decreased by 77% and 0H-P_o by 75%. The resin-P pool had the lowest net decrease of 39% due probably to its replenishment by the other pools.

Table 4.9 Selected properties of the soils used in the study

Soil treatment	pH		Sand	Soil fines[a]	Org. C	Org. P	Total P
	H_2O	KCl		---(g kg^{-1})---		---(mg kg^{-1})---	
Native	5.5	4.9	882	118	6.93	325	381
Check	5.3	5.0	851	149	3.51	152	180
N	4.3	4.0	813	187	4.11	274	337
P	5.0	4.7	863	137	3.19	327	458
NP	4.2	3.8	871	147	4.67	79	280
NPK	4.8	4.4	891	109	3.14	143	257
FYM	5.2	5.1	843	157	5.67	316	386
FYM+N	5.1	4.8	863	137	6.32	366	429
FYM+P	5.1	4.9	831	169	5.96	332	467
FYM+NP	4.4	4.2	813	187	6.29	390	529
FYM+NPK	4.8	4.4	861	149	6.94	349	490

[a]Soil fines = (silt + clay fractions).

Continuous cultivation complemented with P_1 fertilization increased P_1 pools above that of the native site (Table 4.11). In the N and N+P fertilized soils, all P pools decreased. It is not apparent in the study why fertilization with N+P caused decreases in the concentrations of all P pools. However, fertilization with N+P+K increased the concentration of P_1 pools ranging from 31% in $0H-P_1$ to 80% in the $HCl-P_1$ pool. Increasing concentrations of P_1 pools from P_1 fertilization are likely due to adsorption. The HCO_3-P_1 and $0H-P_1$ are supposedly P_1 forms adsorbed to the surfaces of crystalline and non-crystalline Al and Fe oxides (Mattingly, 1975; Williams et al., 1980), the major P sinks in weathered soils. Similarly increases in $HCl-P_1$ with P_1 fertilization is likely due to the effect of exchangeable Ca^{2+} or Ca^{2+} + Mg^{2+} which can exert tremendous influence on P adsorption in tropical soils (Smillie et al., 1987) including savanna soils (Agbenin, 1996). The enrichment of labile P_1 pools simply indicates that P_1 fertilization had been in excess of crop requirement.

In contrast to the increases in P_1 pools, P_1 fertilization could not halt the decreases in P_0 pools and residual P fraction. In P_1 fertilized soil, HCO_3-P_0 decreased by 51%, $OH-P_0$ by 36% and the residual P pool by 43% compared to the native site. Similar decreases in P_0 pools and the residual P fraction are apparent in the N+P+K fertilized soil. Decreases in P_0 concentration under P_1 fertilization are at variance with studies cited by Beck and Sanchez (1994) which found increases in extractable P_0 after few months of fertilizing Oxisols. Also, Williams and Donald (1957) reported that 26 years of superphosphate

Table 4.10 The amounts and changes in P fractions of a savanna alfisol under continuous cultivation for 45 years without fertilization.

Phosphorus fraction (mg kg^{-1} soil fines)[a]	Native	Cultivated	△ %[b]
Resin-P_i	173 ± 8.3	105 ± 3.5	-39
HCO3-P_i	189 ± 10.1	65 ± 3.2	-66
HCO3-P_o	206 ± 20.8	47 ± 1.5	-77
OH-P_i	335 ± 5.0	130 ± 5.8	-61
OH-P_o	558 ± 35.0	146 ± 9.9	-75
HCl-P_i	172 ± 8.7	110 ± 5.9	-40
Residual P	2245 ± 168	461 ± 18.4	-82
ΣP fractions	3878 ± 176	1064 ± 29.3	-74

[a]Amounts of P fractions on the basis of soil fines. Soil fines were determined as 100-sand (%).

[b]Percent changes in P fractions are all significant at 1% probability level.

Table 4.11: The amounts and changes in P fractions of a savanna alfisol under continuous cultivation for 45 years as influenced by inorganic fertilizer application.

Phosphorus fractions (mg kg^{-1})	Inorganic fertilizer treatment							
	N	△ %[a]	P	△%	NP	△ %	NPK	△ %
Resin-P_i	55±1.3	-68	290±2.3	+68	144±3.1	-17	302±8.7	+75
HCO_3-P_i	62±3.6	-38	407±18.8	+115	206±1.3	+9NS	326±4.4	+72
HCO_3-P_o	50±1.1	-76	101±4.3	-51	27±1.1	-87	64±3.8	-69
OH-P_i	106±6.2	-65	320±9.7	-25	303±6.4	NS	440±8.9	+31
OH-P_o	211±6.2	-62	357±15.9	-36	418±12.1	-25	482±6.8	NS[b]
HCl-P_i	73±2.0	-58	338±16.9	+97	220±5.6	+57	309±7.9	+80
Residual P	439±13.1	-80	1279±61.7	-43	549±13.0	-76	515±10.3	-173
ΣP fractions	996±29.3	-74	3092±91.6	-20	1917±26.4	-51	2438±48.8	-37

[a]Percent change in concentrations of P fractions were calculated with respect to concentrations of P fractions in native site given in Table 2.
[b]NS = not significant at 5% probability level.

application to a pasture of subterranean clover in podzolic soils increased P_o from 53 to 96 μg g^{-1} soil. Annual addition of plant residues to soils is greater under pasture than under crops hence SOM build-up is usually high in soils under pasture (Tisdall and Oades, 1982). The high plant residues addition coupled with faecal or animal droppings will increase the soil organic residue load, thus stimulating microbial immobilization of P_i in pasture fields.

Studies from North America Great Plains and elsewhere reviewed by Stewart and Sharpley (1987) showed that soils under cultivation maintained approximately similar P_i levels with uncultivated soils, but P_o continued to decline, suggesting P_o mineralization and losses despite P_i fertilization. Accumulation of P_o in tropical semi-arid soils may not depend so much on P_i fertilization as it is on the soil temperature, aeration, moisture, leaching potential, availability of carbon and macronutrient substrate and the tillage systems. It seems that the failure of P_i fertilization to increase P_o pool in the soils might be partly explained by rapid mineralization due to tillage. In addition, N and P_i fertilization probably provided the macronutrient substrate for rapid growth of microbial population, thus facilitating SOM mineralization (Beck and Sanchez 1994) consistent with 0M losses of between 60-70% of these plots. In their review, Stewart and Tiessen (1987) rightly argued that P_i fertilization could only lead to P_o accumulation if adequate C and N supplies are available, whereas P_i is likely to accumulate in rapidly degrading soils especially under

continuous cultivation. Furthermore, the possibility of P_o loss through erosion under the high kinetic energy load of savanna rainfall (Kowal and Kassam, 1978) cannot be entirely discounted in explaining the decreasing concentration of P_o pools in the soils. Hannapel et al. (1964) showed that P loss and movement through soils occurred mostly in organic form. Similarly, Ryden et al., (1973) reported that substantial amounts of P losses which occur through surface run-off and sub-surface flows are in P_o form.

4.3.2 Effect of combination of FYM and inorganic fertilizer

The effects of FYM application, and its combination with N and P_i fertilizer sources (FYM+N, FYM+P, FYM+NP and FYM+NPK) on the amounts of, and changes in, P_i and P_o pools are given in Table 4.12. Fertilization with FYM or FYM+N caused decreases in the concentration of all P fractions. Farmyard manure applied in combination with P, N+P and N+P+K increased the concentrations of extractable P_i pools in all the soils. Despite the increased concentrations of P_i pools, significant decreases occurred in P_o pools and the residual P fraction (Table 4.12). One would have expected that FYM addition would stimulate microbial immobilization and incorporation of P_i into organic macromolecules or their body tissues.

The failure of FYM and the FYM+N fertilization to enhance build-up of P_o is consistent with the view expressed by Stewart & Sharpley (1987) that organic residue incorporation may lead to higher OM

Table 4.12 The amounts and changes in P fractions of a savanna alfisol under continuous cultivation for 45 years as influenced by farmyard manure plus inorganic fertilizer combination.

Phosphorus fraction (mg kg_{-1})	Farmyard manure + inorganic fertilizer combination									
	FYM	△%[a]	FYM+N	△%	FYM+P	△%	FYM+NP	△%	FYM+NPK	△%
Resin-P_i	121±3.5	-30	187±2.7	NS[b]	279±3.2	+61	189±2.0	NS	197±6.7	NS
HCO_3-P_i	93±2.3	-51	138±7.4	NS	248±6.6	+31	249±4.7	+32	312±3.4	+65
$HC0_3$-P_o	68±3.2	-67	60±1.8	-71	110±4.8	-47	169±7.8	NS	104±4.2	-50
OH-P_i	174±6.3	-48	203±3.2	-132	393±14.4	+17	321±9.2	NS	414±10.4	-24
OH-P_o	480±11.2	NS	281±10.7	-50	270±11.4	-52	385±9.2	-31	425±9.4	-2
HC1-P_i	149±6.4	NS	163±7.1	NS	313±6.4	+82	226±1.9	+31	334±9.3	+94
Residual P	1234±57.3	-45	1696±42.3	-24	270±12.3	-88	897±56.7	-60	1531±58	-32
ΣP fractions	2319±91.2	-40	2728±59.1	-30	1883±48.9	-51	2436±60.8	-37	3217±72.9	-17

[a]Percentage change in concentrations of P fractions were calculated with respect to concentrations of P fractions in native site given in Table 5.2.
[b]NS = Not significant at 5% probability level.

status in a soil without enhancing P_o accumulation in a P-deficient condition. To this hypothesis, one may add that residue incorporation and P_i fertilization may not actually lead to P_o build-up under field condition in the savanna if conventional tillage practices which promote rapid oxidation and mineralization of SOM and P_o are employed. Decreases in the concentration of P_o pools in FYM+P, FYM+NP and FYM+NPK fertilized soils support this hypothesis. Chauhan et. al. (1982) showed that P_i fertilization combined with labile carbon sources such as cellulose stimulated P_o build-up under laboratory incubation. It is also likely that FYM application could not stimulate P_i immobilization because of its relatively low C contents and C:N ratio compared to undecomposed plant residues with wider C:N ratio since FYM is partially humified and processed in the cow rumen or digestive system.

Recognizing the role of P_o in replenishing available P_i in weathered soils (Acquaye, 1963; Adepetu and Corey, 1976; Tiessen et al. 1984), management practices which maintain or increase P_o pools are likely to be advantageous. One such management practice that might increase P_o in weathered soils, suggested by Stewart and Sharpley (1987) is zero tillage that returns crop residues to the surface complemented with P_i fertilization. With conventional tillage, in which residue incorporation and P_i fertilization are achieved by ploughing and harrowing, P_o build-up is unlikely because of rapid mineralization induced by improved soil aeration and temperature.

especially in tropical semi-arid region.

A common thread running through the differently managed soils analyzed in this study is the declining residual P pool along with P_o pools with or without P_i fertilization. The continued decrease in the residual P fraction, a hitherto considered stable and inactive P pool (Stewart and Mckercher, 1982; Hedley et al., 1982) is rather surprising. However McLaughlin and Alston (1986) and Ball-Coelho et al. (1993) reported changes in the residual P fraction with time. The results of this study are therefore consistent with these reports. The present data had demonstrated that this P pool was active in the soils contrary to previous hypothesis suggesting otherwise (Hedley, et al., 1982; Stewart and McKercher, 1982). The residual P fraction may be responsible for long-term P availability (Ball-Coelho et al., 1993) even when soil tests indicate extreme P deficiency. Thus, research into methods to further characterize the residual P fraction is highly warranted.

Hypothesis about the nature of residual P in soils varied from being P_i encapsulated in, or in the structural lattices of, resistant minerals which is only accessible by destroying the structural integrity of these minerals, to being apatite inclusions that are resistant to acid attack (Syers et al., 1968, 1969). Recently, Ball-Coelho et. al. (1993) suggested that the residual P fraction in some Brazilian soils might be P_o. The tendency of decreasing P_o concentrations to parallel decreases in the concentration of residual

P fraction suggests that the residual P pool may be largely P_o consistent with the correlation between residual P and organic C (r = 0.47**) and with the soil total P_o (r = 0.74**).

4.3.3 Relationships between P pools

To determine the underlying coherence in the relationships between different P pools, the P fractions were grouped according to their coveriances employing factor analysis. The P pools which have high loading on the same factor are said to be covariant, and are influenced by the same factor. From the variance-covariance matrix, two factors were extracted (Table 4.13). Resin-P_i, HCO_3-P_i, OH-P_i and HCl-P_i loaded highly on factor I suggesting clearly that this factor represented secondary P_i. Thus, the HCl-P_i in these soils cannot be considered to be of primary origin (apatite), but of secondary origin such as P_i bound to exchangeable Ca or Ca+Mg, probably adsorbed as $CaH_2PO_4^+$, $CaHPO_4^o$, or as a balancing anion for exchangeable Ca or Ca + Mg or surface Ca-phosphate precipitates (Smillie et al., 1987; Agbenin, 1996). The moderate loading of OH-P_o on factor 1 suggests that part of this P_o pool is probably adsorbed to, and stabilized by, inorganic colloids. The HCO_3-P_o and residual P fraction loaded highly on factor 2 consistent with the hypothesis of this study that the residual P fraction in these soils is largely

Table 4.13 Factor analysis of the correlation between the amounts of P in various P pools of the soils (n = 33).

Phosphorus fraction (mg kg_{-1})	Factor 1	Factor 2	Variable communality
	Factor loading[a]		
Resin-P_i	0.94	-	0.90
$HC0_3$-P_i	0.93	-	0.87
OH-P_i	0.95	-	0.97
HC1-P_i	0.97	-	0.95
HCO_3-P_o	-	0.81	0.75
OH-P_o	0.54	0.43	0.48
Residual P	-	0.90	0.81

[a]Factor loading explaining less than 10% of the variance was excluded.

of organic origin.

Path analysis was used to test the relationships between different P fractions with a view to determining the pools that interact with and maintain resin-P or plant available P pool. The P cycling model that developed from the results of the path analysis (Fig. 4.4) resembled that depicted for Mollisols by Tiessen et al. (1984) and for fertilized Ultisols by Beck and Sanchez (1994). The model did not, however, clearly support the hypothesis that P_o played a more dominant role in replenishing resin-P in weathered soils such as these apparently because of the perturbation of the natural P cycle by P_i fertilization. The variance in resin-P was explained up to 85% by OH-P_i and HCl-P_i in this fertilized alfisol (Fig. 4.4). However part of the labile P_i pool was furnished by P_o mineralization as indicated by the significant path coefficient between HCO_3-P_o and OH-P_i. In a fertilized Ultisol, Beck and Sanchez (1994) reported that up to 96% of the variation in resin-P was explained by OH-P_i and HCl-P_i. The residual P makes an indirect contribution to resin-P through P_o mineralization consistent with the significant path coefficients between residual P fraction and P_o pools. Path analysis was consistent with our hypothesis that the residual P fraction is largely inextractable P_o.

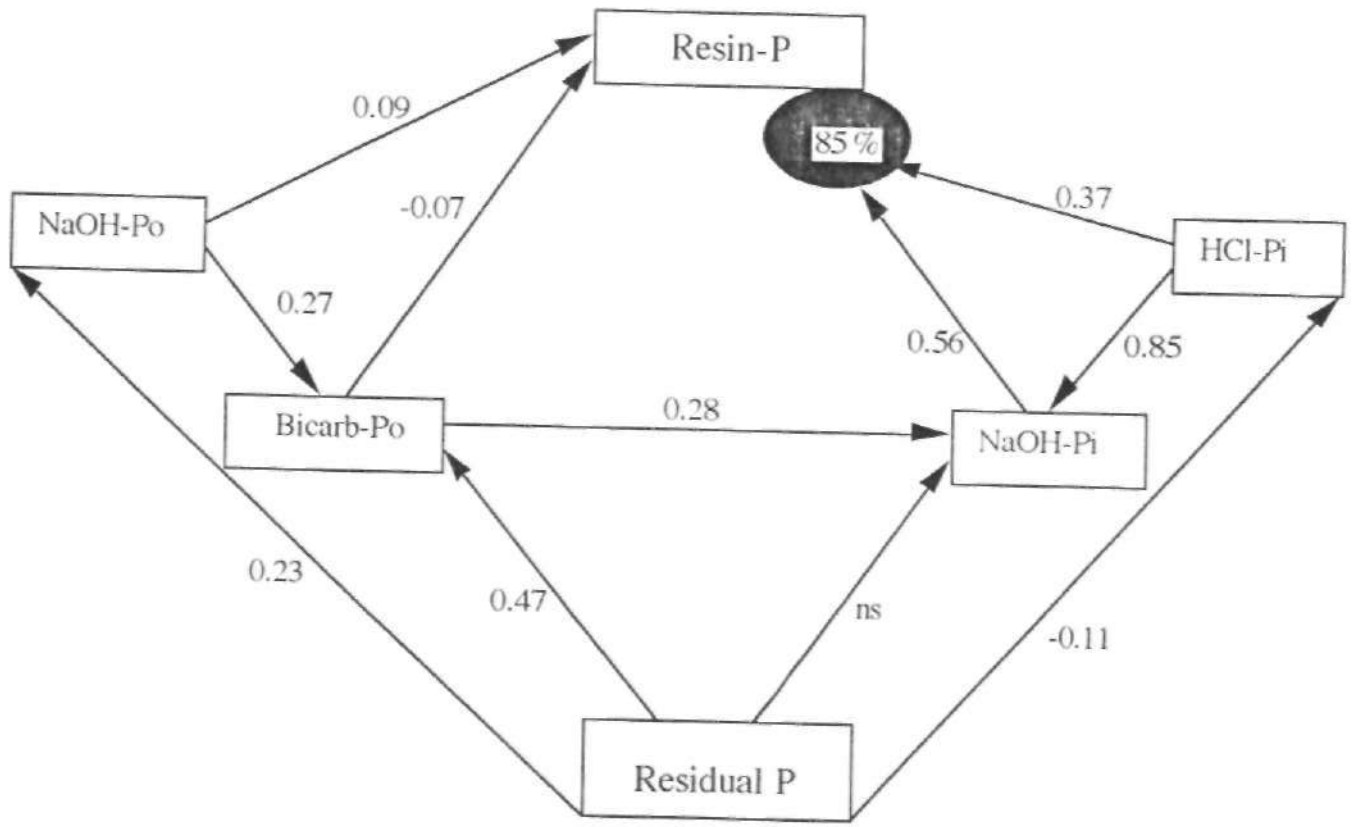


Figure 4.4: Relationships between labile and stable P components of the soil P cycle of Ap horizons of a savanna alfisol under cultivation and fertilization. Pathway coefficients are normalized.

In conclusion, the sizes and changes in labile P_i pools were dependent on P_i fertilization. Under P_i fertilization with or without FYM, increases in OH-P_i and HCl-P_i pools were observed suggesting that these pools acted as sinks for fertilizer-P. The net increase in labile P_i pools suggested that fertilizer-P had been applied in excess of P requirement for maize, sorghum, cotton and groundnut cultivated in these plots over the years. Total P input in the 45 years of cultivation was 1890 kg/ha. Under high to moderate production levels in the savanna, total P uptake ranges from 10 to 15 kg/ha for sorghum, cotton and groundnut, and 15 to 20 kg/ha for maize grain and about 4 to 5 kg/ha for stover (Kowal and Kassam, 1978). Assuming a net P export of 25 kg/ha/yr from the field, this still leaves an estimated net P balance of 765 kg/ha after 45 years of cultivation.

The results of this study also clarify why previous attemtps to find the best extraction method for estimating available P, that is well correlated and calibrated with yield and plant P uptake in the savanna, have given inconsistent results (Bache and Rogers, 1970; Audi, 1987). Mokwunye (1977) observed that some soils which had low available P did not respond to fertilizer-P addition, suggesting that the extraction method did not adequately reflect the available P status. The contributions of labile P_o fractions (HCO_3-P_o and OH-P_o) and the residual P fraction, hitherto considered stable and inactive, to P availability are not measured by conventional soil tests.

CHAPTER FIVE

SUMMARY AND CONCLUSION

Studies in the savanna region have continued to justify the benefits of inorganic fertilizers with little attention given to their long-term effects on soil property changes. The deletarious effects of inorganic fertilizers, especially the nitrogenous fertilizers such as ammonium sulfate [$(NH_4)_2SO_4$] and urea [$(CO(NH_2)_2$] in the region have been demonstrated (Bache and Heathcote, 1969).

This calls for management technologies and cultivation practices that rely on low fertilizer inputs and maintain soil organic matter (SOM). Development of such technologies is possible only with the proper documentation of changes in soil properties associated with long-term cultivation involving inorganic fertilization. The DNPK experimental plots in Samaru established since 1950 with the aim of determining the best combination of inorganic fertilizer and farmyard manure (FYM) that will maintain soil quality and productivity, provides a unique opportunity for this assessment.

In the present study, changes in C, N and P of cultivated and uncultivated soils under different inorganic fertilizer and farmyard manure (FYM) treatment combinations were determined. The results showed that continuous cultivation with N+P and N+P+K resulted in losses of C, N and P compared to the native site. Application of FYM

and FYM+NPK maintained C. N and P concentrations at the same level with or higher than the native site.

To determine the "health" of the soil ecosystem. the cycling of C. N and P through soil microbial biomass was measured. The results showed that the soils receiving inorganic fertilizers had low microbial activity. evidenced by the low SMBC. SMBN and SMBP. Combination of FYM with N+P and N+P+K maintained SMBC. SMBN and SMBP at par with the native site.

To determine the pattern of depletion of the soil C.N and P. their distribution and concentrations in different aggregates were assessed. The 500–2000μm size macroaggregates contained more C. N and P_o than the 200–500μm macroaggratages. while the 45–100μm microaggregates had higher concentrations of C. N and P_o than the 100–200 μm microggragate size fraction. Higher losses of C. N and P occurred in the 500–2000 μm size macroaggregates and the 45–100μm microaggregate size fractions than the other size aggregates. The result further showed that the 45–100 μm size fraction incurred more losses of C. N and P than the 500–2000 μm size aggregates indicating that the 45–100 μm fraction contained labile N and P that mineralize to supply plant needs.

Because P plays a central role in SOM cycling. detailed characterization was carried out to determine the relationships that exist among the various fractions under long-term cultivation. Phosphorus fertilization with or without FYM caused an increase in

the P_i pools, but could not stop the declining P_o pools and the residual-P fraction. It seems that the residual-P fraction makes an indirect contribution to available P pools. Previous hypotheses which suggest that the residual - P fraction does not make any contribution to available P pools were not validated by the data presented.

In conclusion, the data presented in this thesis clearly support the idea that for sustainable landuse, reliance on inorganic fertilizers alone is inappropriate for long-term soil quality and fertility maintenance in the savanna. Despite the increased yield, the degradative effect of in-organic fertilizers on soil quality, if quantified in economic terms, will outweigh the yield increases obtained. It is not the contention of this thesis that inorganic fertilizers are not required in the cropping system but that their use must be augmented with organic/plant residue management.

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