Direct and residual effects of organic and inorganic fertilizers on soil chemical properties, microbial components and maize yield under long-term crop rotation

by

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Abstract

Management-induced degradation of soil chemical and microbial quality is one of the most pressing concerns and a considerable threat to the sustainability of agroecosystems. However, information on this important issue is limited and largely based on short-term studies. A long-term experiment initiated in 1939 at the University of Pretoria provided a unique opportunity to assess the direct and residual effects of manure and inorganic fertilizers on soil chemical properties, microbial components and maize yield in rotation with field pea.

Long-term addition of manure resulted in increased total organic C (TOC), total N and available P levels in the soil. Seasonally, these nutrients exhibited variations that appeared to be related to influences of crop rotation. Soil N content in an adjacent native site remained relatively constant but tended to increase in the control and manured plots. Soil microbial biomass C, N and P and microbial populations were affected by previous manure application as well as by crop rotation. Microbial biomass and numbers were generally higher in the manured plots. Manure application also had substantial residual effects and resulted in maize grain yields higher than in the control.

Long-term NPK application resulted in decreased TOC and basic cation contents, and lowering of soil pH. The decrease in TOC was greater in single fertilizer treatments whereas basic cation contents and pH declined more in the balanced fertilizer treatments. Soil microbial biomass and numbers were influenced by, and exhibited qualitative changes in response to, long-term fertilization. Crop rotation also exerted effects on chemical and microbial properties of the soil. Maize grain yield showed significant increases in response to balanced fertilizer treatments. Response of maize to simple fertilizer applications was not beneficial in terms of yield returns. These results suggest that judicious use of inorganic fertilizers may, in the long-term, maintain soil quality and productive capacity.

A comparison of the effects of residual manure and NPK fertilizers on the content of selected nutrients, microbial properties, C and N inputs, tissue nutrient concentration and crop yield showed differences due to treatments. TOC, total N and available P levels were increased due to residual manure alone or in combination with NPK fertilizers. C and N inputs and tissue P concentration were also generally higher in manured than in the NPK treatment. However, the higher increase in nutrient contents of manured plots was not reflected in microbial properties of the soil. Despite lower nutrient levels, the NPK treatment resulted in relatively greater increases in microbial properties of the soil. The differential responses were largely due to differences in quality and decomposability of organic material. Organic material in the NPK treatment appeared to have a higher decomposition and turnover rate than in other treatments, suggesting that C limitation in soils of low C but good nutrient supply may be compensated by high turnover rates of the available organic materials.

The beneficial effect of residual manure on microbial properties and crop yield was decreased by application of supplemental N fertilizer but remained unaffected by application of supplemental K fertilizer. The depressive effect of excess soil P levels on soil microbial properties and crop yield was exacerbated by supplemental N fertilizer and mitigated by supplemental manure and K fertilizer applied to residual P. The decrease in available P levels due to supplemental K application implies that this may serve as a viable alternative to ameliorate soils with excess P levels.

Key words: C and N inputs, inorganic fertilizers, maize yield, microbial biomass, microbial number, residual manure, soil chemical properties.

Direkte en indirekte invloed van organiese en anorganiese misstowwe op die chemiese eienskappe, mikrobiologiese samestelling van gronde en mielieopbrengs onder 'n langtermyn gewasrotasiestelsel

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Samevatting

Degradasie in die chemiese en mikrobiologiese eienskappe van grond as gevolg van bestuurspraktyke is 'n ernstige probleem vir die volhoubare gebruik van die agri-ekosisteem. Inligting oor die belangrike aspek is beperk en hoofsaaklik gebasseer op korttermynstudies. 'n Langtermyn veldproef sedert 1939 op die Universiteit van Pretoria se proefplaas het 'n unieke geleentheid gebied om die direkte en residuele effek van kraalmis en anorganiese kunsmistoedienings te evalueer ten opsigte van chemiese grondeienskappe, mikrobiologiese samestelling, asook mielie- en ertjieopbrengste wat in rotasie verbou is.

Langtermyn kraalmisoedienings het die totale organiese C, totale N en beskikbare P-vlakke in die grond verhoog. Seisoensvariasies het voorgekom in die voedingselementinhoud van die grond wat verband gehou het met die gewasrotasie. Oor die langtermyn het die N-inhoud van die grond op 'n aanliggende onversteurde area konstant gebly, terwyl dit in die kontrole en kraalmispersele verhoog het. Die mikrobe biomassa C, N, P en mikrobe populasie is beïnvloed deur vorige kraalmistoedienings en

gewasrotasie. Die mikrobiologiese biomassa en mikroflora getalle was gewoonlik hoër op die persele waar kraalmis toegedien is. Kraalmistoedienings het mielie opbrengste verhoog en ‘n aansienlike residuele effek getoon.

Langtermyn NPK-toedienings het die organiese C, basiese katiooninhoud en pH van die grondverlaag. Die afname in die totale organiese C-inhoud van was meer waar enkel misstowwe toegedien is terwyl die basiese katiooninhoud en pH meer gedaal het waar 'n meer gebalanseerde bemesting toegedien is. Die biomassa en getalle van die mikro - organismes in die grond is beïnvloed deur die langtermyn bemestingsprogram. Gewasrotasie het die chemise en mikrobiologiese eienskappe beïnvloed. Mielieopbrengs het betekenisvol verhoog met 'n gebalanseerde bemestingsprogram terwyl die toediening van enkelmisstowwe nie opbrengs bevoordeel het nie. Die resultate dui daarop dat met oordeelkundige bemesting die kwaliteit en produktiwiteit van die grond instand gehou kan word.

'n Vergelyking tussen die invloed van residuele kraalmis en NPK-bemesting op sekere voedingselemente en mikrobiologiese eienskappe van grond asook C en N bydraes, voedingselemensamestelling van die plante en opbrengs toon duidelike verskille. Totale organismes C, N en beskikbare P-vlakke het verhoog as gevolg van die residuele effek van kraalmis alleen of in kombinasie met NPK-bemesting. Die C en N bydrae en blaar P-inhoud was ook oor die algemeen hoër by die kraalmis in vergelyking met die NPK-persele. Die groter toename in die voedingselemente van die kraalmispersele het nie die mikrobiologiese eienskappe in die grond verander nie. Ten spyte van die laer voedingselementvlakke, het die NPK-behandeling groter toenames in die mikrobiologiese eienskappe van die grond teweeg gebring. Die verskille in reaksie kan grootliks toegeskryf word aan die kwaliteit en verteerbaarheid van die organiese materiaal. Die organiese materiaal in die NPK-persele het 'n hoër tempo van mineralisasie getoon in vergelyking met die ander behandeling wat aandui dat lae C vlakke in grond maar goeie voedingselementvoorsiening as gevolg van die vinnige mineralisasie van organiese materiaal daarvoor vergoed.

Die invloed van residuele kraalmis op die mikrobiologiese eienskappe van die grond en opbrengs is verlaag deur die byvoeging van N-kunsmis, maar nie deur die K-kunsmis nie. Die onderdrukkende effek van oormaat P in die grond op die mikrobiologiese eienskappe en opbrengs is vererger deur die byvoeging van N-kunsmis maar verminder deur K-bemesting. Die afname in P as gevolg van die byvoeging van K was betekenisvol, wat aandui dat dit 'n manier is om grond met hoë P vlakke te behandel.

Sleutelwoord: C en N toedienings, organiese kunsmis, mielieopbrengs, mikrobiologiese biomassa, mikro organisme getalle, residuele kraalmis, grond chemiese eienskappe.

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Abbreviations and acronyms used

AP	available P
B	boron
C	carbon
Ca	calcium
CEC	cation exchange capacity
cm	centimetre
Cu	copper
E	east
EC	electrical conductivity
FAO	Food and Agriculture Organization of the United Nations
Fe	iron
FYM	farm yard manure
g	gram
ha	hectare
K	potassium
kg	kilogram
l	litre
m	metre
µg	microgram
Mg	magnesium
mg	milligram
mm	millimetre
Mn	manganese
N	nitrogen
Na	sodium
P	phosphorus
S	south
SAR	sodium adsorption ratio
SMB	soil microbial biomass

SMB-C	soil microbial biomass C
SMB-N	soil microbial biomass N
SMB-P	soil microbial biomass P
TN	total N
TOC	total organic C
TSBF	Tropical Soil Biology and Fertility
USDA	United States Department of Agriculture
yr	year
Zn	zinc

Chapter 1
General background

1.1 Introduction

Soil quality, which refers to the soil's capacity to support crop growth without resulting in soil degradation or otherwise harming the environment (Gregorich & Acton, 1995), is a critically important component of sustainable agriculture (Miller & Wali, 1995; Warkentin, 1995; Subbian *et al*., 2000). It is vital both to the production of food and fibre, hence to the soil's productive capacity, as well as to the health of the ecosystem (Pierzynski *et al*., 1994). Maintenance and improvement of soil quality may, therefore, be a key strategy to meet the ever-growing demand for food and to address the increasing concern of environmental quality (Carter *et al*., 1997).

Soil quality is a composite of, and to a large extent determined by, chemical and biological properties of the soil. These properties not only are important for the soil's function as a medium for plant growth, but also influence its service as a buffer in the formation and destruction of hazardous compounds (Larson & Pierce, 1994). They are essential attributes on which the soil's productive capacity and its role as an environmental moderator depend (Acton & Padbury, 1993; Bezdick *et al*., 1996). Consequently, maintenance and enhancement of soil quality are, in essence, dependent upon improvement of chemical and biological properties of the soil. As any alteration in quality of the soil is manifested in these properties, they are also useful indicators of quality change (Doran *et al*., 1996).

Soil quality is highly influenced by soil management practices (Larsen & Pierce, 1994). Management-induced deterioration in soil quality has affected nearly 40% of the World's agricultural land (Oldeman, 1994) and is one of the basic agricultural problems today threatening the long-term sustainability of agroecosystems (FAO, 1990). Decline in soil quality is often a result of management practices that cause loss of organic matter, depletion of nutrients and/or reduction in activity and species diversity of microorganisms (Oades & Walters, 1994; Riffaldi *et al*., 1994; Giller *et al*., 1997). Soil quality can be maintained or enhanced by appropriate restorative measures such as legume-based crop rotation, manure addition and other management practices that improve chemical and biological properties of the soil (Lal, 1997; Carter, 1998).

Concerns about the adverse effects of management practices on soil quality arose as recently as the late 1980s (Brundtland, 1987; Bentley & Leskiw, 1984). As a result, information on management-induced changes in soil quality is scarce, incomplete and of low standard (Wang *et al*., 1997). Moreover, while changes may not be evident over short time periods, much of the available data are based largely on short-term experiments (Larson & Pierce, 1991; Fragoso *et al*., 1997).

Soil quality is temporal in dimension, with changes occurring gradually and difficult to detect over short periods of time. Many of the chemical and biological attributes of soil quality are stable and their manifestation is experimentally verifiable only over extended periods (Arnold *et al*., 1990). For reliable answers, soil quality problems therefore need to be addressed using extended experiments. In other words, any effect of a management system on soil quality and productive capacity is best evaluated using long-term trials (Subbian *et al*., 2000).

A long-term cropping and fertilization experiment that has been ongoing for over 60 years at the University of Pretoria, South Africa, provided a unique opportunity for such a study. The experiment is one of the oldest long-term field experiments in southern Africa (Nel *et al*., 1996), and probably on the African continent at large. In the course of the experiment, investigations were conducted on growth, development and water use efficiency of maize (*Zea mays* L.) (Verwey, 1974; Steynberg, 1986), variability of certain individual treatments (Stoch, 1983), and long-term grain yield trends during the period between 1939 and 1990 (Nel *et al*., 1996). Few attempts have been made to study the soil quality changes that might have occurred in response to the long-term management practices imposed. The present study investigated the direct and residual effects of organic and inorganic fertilizers on soil chemical properties, microbial components and maize yield under long-term crop rotation.

1.2 Hypothesis

Long-term application of manure and inorganic fertilizers under legume-based crop rotation improves soil chemical properties, microbial components and crop yield thereby maintaining and/or enhancing soil quality and productive capacity.

1.3 Specific objectives

1. To investigate the dynamics of selected nutrients, changes in microbial properties and maize yield under long-term crop rotation as influenced by residual manure.

2. To assess the long-term effect of direct N and K and residual P fertilizers on chemical and microbial properties of soil and grain yield of maize in rotation with field pea (*Pisum arvense* Poir.).

3. To compare the effect of residual manure and NPK fertilizers on selected soil nutrient contents, microbial components, C and N input and turnover, tissue nutrient concentration and maize yield under long-term crop rotation.

4. To investigate the effect of supplemental N and K fertilizers on the residual value of manure and P to soil chemical properties, microbial components and maize yield under long-term crop rotation.

The experimental work (presented in Chapters 3-6) is preceded by a brief review (Chapter 2) of the available literature emphasizing long-term impacts of crop rotation and fertilization and their interactive effects on soil chemical properties, microbial components and crop yield. Based on observed changes in soil properties and maize yield responses, an assessment of the effects of the different management practices on soil quality and productive capacity is provided in the discussion of each experimental work chapter and as a general summary in Chapter 7.

1.4. References

Acton, D.F. & Padbury, G.A. 1993. A conceptual framework for soil quality assessment and monitoring. In: D.F. Acton (ed.), A program to assess and monitor soil quality in Canada: Soil quality evaluation program summary, pp. 21-27. Centre for Land and Biological Resources Research., Research Branch, Agriculture Canada, Ottawa.

Arnold, R.W., Zaboles, I & Targulian, V.C. 1990. Global soil change. Report of an IIASA-ISSS-UNEP task force on the role of soil in global change. International Institute for Applied Systems Analyses. Laxenburg, Austria.

Bentley, C.F. & Leskiw, L.A. 1984. Sustainability of farmed lands: current trends and thinking. Canadian Environmental Advisory Council, Environment Canada, Ottawa.

Bezdick, D.F., Papendick, R.I. & Lal R. 1996. Introduction: Importance of soil quality to health and sustainable land management. In: J.W. Doran & A. Jones (eds.), Methods for assessing soil quality, pp.1-8. SSSA Spec. Publ. No. 49, Madison, WI.

Brundtland, G.H. 1987. Our common future. World Commission on Environment and Development. Oxford Univ. Press, NY.

Carter, M.R. 1998. Micronutrient concentrations in barley and soybean under minimum tillage on podzolic soils in a cool climate. *Acta Agriculturae Scandinavia* 47:7-13.

Carter, M.R., Gregorich, E.G., Anderson, D.W., Doran, J.W., Janzen, H.H. & Pierce, F.J. 1997. Concepts of soil quality and their significance. In: E.G. Gregorich & M.R. Carter (eds.), Soil quality for crop production and ecosystem health, pp.1-19. Dev. Soil Sci. 25. Elsevier Sci. Publ., Amsterdam.

Doran, J.W., Sarrantonio, M. & Liebig, M.A. 1996. Soil health and sustainability. *Adv. Agron*. 56:1-54.

FAO (Food and Agriculture Organization of the United Nations). 1990. Integrated plant nutrient systems: state of the art. Commission on fertilizers, 11th session, 4-6 April, 1990. Rome.

Fragoso, C., Brown, G.G., Patron, E., Blanchart, P., Lavelle, P., Pashanasi, B., Senapati, B. & Kumar, T. 1997. Agricultural intensification, soil biodiversity and agroecosystem function in the tropics: the role of earthworms. *Appl. Soil Ecol*. 6:17-35.

Giller, K.E., Beare, M.H., Lavelle, P., Izac, A.M.N. & Swift, M.J. 1997. Agricultural intensification, soil biodiversity and agroecosystem function. *Appl. Soil Ecol*. 6:3-16.

Gregorich, L.J. & Acton, D.F. 1995. Understanding soil health. In: D.F. Acton & L.J. Gregorich (eds.), The health of our soils- towards sustainable agriculture in Canada, pp. 5-10. Centre for Land and Biological Resources Research, Research Branch, Agriculture and Agri-Food Canada, Ottawa.

Lal, R. 1997. Long-term tillage and maize monoculture effects on a tropical Alfisol in western Nigeria. II. Crop yield and soil chemical properties. *Soil Tillage Res*. 42: 161-174.

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Larson, W.E. & Pierce, F.J. 1991. Conservation and enhancement of soil quality. International Board for Soil Research and Management, Technical Paper Vol. 2, No. 12(2). Bangkok, Thailand.

Larson, W.E. & Pierce, F. J. 1994. The dynamics of soil quality as a measure of sustainable management. In: J.W. Doran, D.C. Coleman, D.F. Bezdicek, & B.A. Stewart (eds.), Defining soil quality for a sustainable development, pp. 37-51. Soil Sci. Soc. Am. Spec. Publ. 35, Madison, WI.

Miller, F.P. & Wali, M.K. 1995. Soils, land use and sustainable agriculture: a review. *Can. J. Soil Sci*. 75:413-422.

Nel, P.C., Barnard, R.O., Steynberg, R.E., De Beer, J.M. & Groeneveld, H.T. 1996. Trends in maize grain yields in a long-term fertilizer trial. *Field Crops Res*. 47:53-64.

Oades, J.M. & Walters, L.J. 1994. Indicators of sustainable agriculture: policies to padlock. In: C.E. Pankhrust, B.M. Doube, V.V.S.R. Gubta & P.R. Grace (eds.), Soil biota: Management in sustainable farming systems, pp. 219-223. CSIRO Press, Melbourne.

Oldeman, L.R. 1994. The global extent of soil degradation. In: D.J. Greenland & I. Szabolics (eds.), Soil resilience and sustainable land use, pp. 99-118. CAB Inter., Wallingford, Oxon.

Pierzynski, G.M., Sims, J.T. & Vance, G.F. 1994. Soils and environmental quality. Lewis/CRC Press, Boca Raton, FL.

Riffaldi, R., Saviozzi, A., Levi-Minzi, R. & Menchetti, F. 1994. Chemical characteristics of soil after 40 years of continuous maize cultivation. *Agric. Ecosyst. Environ*. 49:239-245.

Steynberg. R.E. 1986. Groei, ontwikkeling en waterverbruiks-doeltreffendheid van mielies (*Zea mays* L.) by verskillende grondvrugbaarheidspeile. M.Sc. (Agric.) diss., University of Pretoria, Pretoria.

Stoch, E.J. 1983. The dynamics of the soil system under cultication. D.Sc. (Agric.) thesis., University of Pretoria, Pretoria.

Subbian, P., Lal, R. & Subramanian, K.S. 2000. Cropping systems effects on soil quality in semi-arid Tropics. *J. Sust. Agric*. 16:7-38.

Verwey, J.F. 1974. Die groei en opbrengs van mielies (*Zea mays* L.) by verskillende peile van bemesting en vogvoorsiening. M.Sc. (Agric.) diss., University of Pretoria, Pretoria.

Wang, C., Walker, B.D. & Rees, H.W. 1997. Establishing a benchmark system for monitoring soil quality in Canada. In: E.G. Gregorich & M.R. Carter (eds.), Soil quality for crop production and ecosystem health, pp. 323-337. Elsevier Sci. Publ. Amsterdam.

Warkentin, B.P. 1995. The changing concept of soil quality. *J. Soil Water Conserv*. 50:226-228.

Chapter 2
Soil chemical and microbial properties in relation to crop rotation and fertilization: a review

2.1 Introduction

Unlike natural systems in which biomass production is in equilibrium with nutrient reserves, agricultural systems are characterized by continual loss and net removal of nutrients (Nair, 1996). The flow of nutrients in and out of agricultural systems is usually much greater, with lower nutrient storage capacity and less nutrient cycling efficiency (Hendrix *et al*., 1992). The sustainability of agricultural systems is therefore greatly dependent on optimizing the balance between inputs and outputs of nutrients. One way of achieving this balance is by ensuring that nutrients removed from the soil are returned to the system. In this manner, a nutrient cycling mechanism that is essential for the sustainability of the production system can be established (King, 1990).

In any agricultural system, the harvested produce is the major avenue of nutrient removal from the soil (Magdoff *et al*., 1997). For instance, a cereal crop like wheat (*Triticum aestivum* L.) can, in the grain alone, remove up to 200 kg N and 40 kg P ha^{-1} $season^{-1}$(Mengel, 1985). This removal can greatly offset nutrient cycling and affect the sustainability of the agricultural system, thus necessitating substitution of the nutrients exported with crops from the field. Conventionally, these nutrients are replenished by promoting such practices as legume-based crop rotation or applying organic and inorganic fertilizers. Legume-based crop rotation is an effective and often profitable way of supplying N and improving soil properties. Organic and inorganic fertilizers are also important not only in elevating the nutrient status of the soil and stimulating microbial activity and plant growth but, by altering the pools and fluxes of C and other chemical elements, may bring about changes in the chemical and microbial properties of soils.

In this chapter, the effects of crop rotation, manure and inorganic fertilizers and their interactive impacts on soil chemical properties, microbial components and crop yield are briefly reviewed. Emphasis is particularly placed on examples and results from long-term experiments.

2.2 Crop rotation and its effect on chemical and microbial properties of soil

Crop rotation – a system of the repetitive cultivation of a sequence of crops in an orderly and recurrent succession on the same land (Francis, 1989) – has been practiced for more than 3000 years and is known to many cultures and civilizations (Karlen *et al*., 1994). Its beneficial effect in maintaining productivity has been recognized throughout history although the underlying reasons behind such effect were unknown until the recent past (Paine & Harrison, 1993). For instance, it was not understood why crops grown in rotation often yielded more than those in monoculture until the later part of the 19th century when the ability of legumes to fix atmospheric nitrogen was uncovered. As a result of this discovery and the coming to light of other beneficial effects of crop rotation in subsequent years, the practice became more popular and its use increased (Karlen *et al*., 1994). However, with the innovation and development of modern farming techniques and price support systems in the 1950s through late 1970s, specialized cropping increased dramatically at the expense of crop rotation (Reeves, 1994). Increased availability of chemical inputs such as nitrogen fertilizers, herbicides and pesticides, resulted in diminished popularity and use of crop rotation (Crookston, 1984) as did the introduction of improved crop varieties, mechanization, marketing practices and policies (Power & Follette, 1987; Bullock, 1992).

In the 1980s, renewed interest in crop rotation evolved due mainly to concerns over the impact of agriculture on environmental quality, decreased commodity prices, and the need to increase farm profitability through diversification (Francis, 1989). As a result of its beneficial effects in reducing chemical inputs and improving soil properties, crop rotation has now received significant attention and its role in environmental protection and sustainable agriculture is ever increasing.

2.2.1 Effect on soil chemical properties

Crop rotation is known to beneficially influence many soil chemical properties including organic C content, N supply and transformation, pH and amount and availability of P, K, Ca and Mg (Wilson *et al*., 1982; Power, 1990).

Crop rotation generally results in increased organic matter content compared to continuous cropping or fallow. This was demonstrated on the Morrow plots in Illinois where more than a century of research revealed a significant increase in soil organic matter content under crop rotation (Aref & Wander, 1998). Organic matter contents were highest in a maize (*Zea mays* L.)-oat (*Avena sativa* L.)-hay rotation, intermediate in a maize-oat rotation and lowest in a continuous maize rotation (Figure 2.1). Similarly, in several long-term experiments (some dating from the early 1900s) at many localities in semi-arid regions of the US Pacific Northwest, greater increases in soil organic matter content of rotation soils compared to continuously cropped or fallowed soils were reported by Monreal *et al*.(1997).

The effect of crop rotation on soil organic matter content is greatly dependent on rotation length and the inclusion of legumes in the rotation sequence (Karlen *et al*., 1994). Crop rotations for periods of four or more years generally increase soil organic matter content while shorter rotations tend to result in organic matter levels slightly higher than continuous cropping. This has been shown on the Breton plots in Alberta where a 60-yr study on different soils showed the organic matter of a 5-yr rotation to be higher than that of a 2-yr rotation (Juma *et al*., 1993). In another long-term experiment at Saskatchewan, Campbell *et al*. (1991), investigating the effects of crop rotations and various cultural practices on the quantity and quality of soil organic matter, found increased organic matter content with increasing frequency of cropping and the inclusion of legumes as green manure or hay crop in the rotation. They observed the organic matter content to be directly related to cropping frequency and found that the inclusion of sweet clover (*Melilotus officinalis* L.) green manure or lucerne (*Medicago sativa* L.) hay in cereal rotations increased soil organic C content compared to 2-year and 3-year fallow rotations.

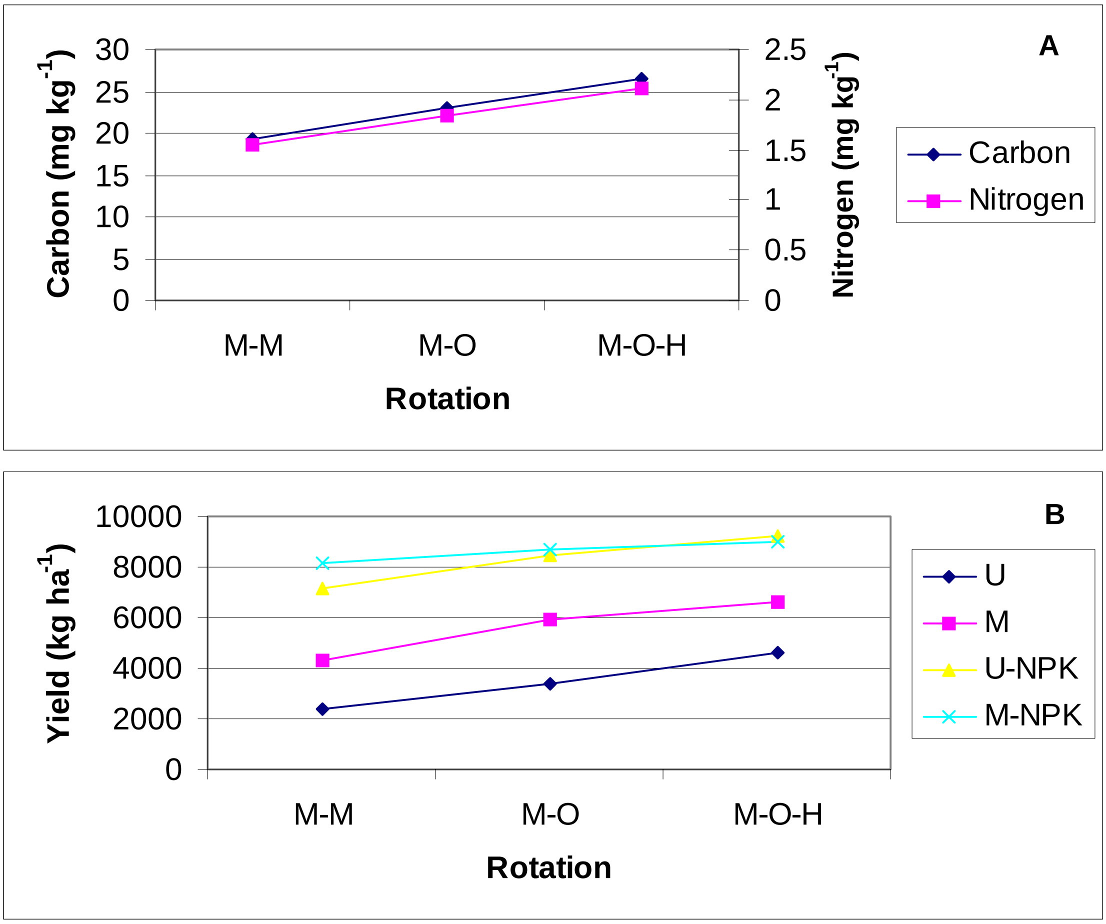

Figure 2.1. Mean soil carbon and nitrogen contents(A) and maize yield (1888-1996) (B) in the Morrow Plots in relation to rotation (M-M = maize-maize; M-O = maize-oat; M-O-H = maize-oat-hay) and fertilization (U=unfertilized; M=manure; U-NPK=NPK only; M-NPK=manure+NPK). From Aref & Wander (1998).

Likewise, Janzen (1987), showed that a 6-yr hay-containing rotation had slightly higher organic carbon content than a 3-yr green-manure-containing rotation. These differences in organic matter content between the longer and shorter rotations are due primarily to differences in the amount of biomass production. It may also be due to higher inputs of residue N relative to residue C which could have resulted in the conservation of C during decomposition (Campbell *et al*., 1991).

Soil N content under crop rotation is increased in two major ways: N input from legume crops in the rotation and reduced leaching of N. On the Morrow plots in Illinois, soil N content in the maize-oat-hay rotation was significantly higher than in the maize-oat rotation and continuous maize cropping (Figure 2.1). The increase was attributed to the inclusion of legumes in the rotations. Contributions of N from legumes in rotation are well-documented (Bruulsema & Christie 1987; Harris & Hesterman 1990; Arshad *et al*., 1998). As much as 10% of the rotation effect on grain yield of a subsequent cereal may be due to N benefits from the legume crop in the rotation (Stevenson & Van Kessel, 1996). Ebelhar *et al*. (1984) and Hargrove (1986) estimated that the contribution of legume cover crops as source of N to subsequent non-leguminous crops may be as high as 120 kg N ha^{-1}. McVay *et al*. (1989) studied the effects of winter legume cover crops on soil properties and nitrogen fertilizer requirements at two localities in the Coastal Plain region of Georgia (USA) and concluded that an adapted winter legume cover crop can replace all the fertilizer N required for optimal rain-fed grain sorghum (*Sorghum bicolor* (L.) Moench) and up to two-thirds of that required for maize production.

Leaching of NO_3-N under crop rotation is reported to be considerably lower than under continuous cropping or fallow. In two separate long-term crop rotation experiments in Saskatchewan, deep-core soil sampling and analysis showed that NO_3-N leaching from legume-containing rotations was significantly lower than either fallow or continuous cropping (Campbell *et al*., 1997). Other studies also observed lower NO_3-N leaching under rotation than under continuous cropping (Grant & Lafond, 1994; Anderson *et al*., 1997; Arshad *et al*., 1998; Simmelsgaard, 1998). A reduction in NO_3-N leaching is essential not only to maintain the available nitrogen level in the soil but also to reduce potential environmental contamination.

With increases in organic matter returns and availability of N, microbial activity can be stimulated thereby enhancing the decomposition process and release of P, K, Ca, Mg and various micronutrients (Groffman *et al*., 1987; Bullock, 1992). Inclusion of legumes in the rotation may be particularly important in facilitating the decomposition and nutrient release processes by reducing the C:N ratio of organic materials returning to the soil (Karlen *et al*., 1994). Additionally, legumes in rotation can increase available P levels by altering the pH of the rhizosphere (Wilson *et al*., 1982) and exchangeable K level through relocation of the ion to the soil surface from deeper in the soil profile (Hargrove, 1986). Increased availability of micronutrients, including Fe, Cu, and Zn because of microbiologically enhanced chelation may also be a beneficial effect of legume-based crop rotation (King, 1990).

2.2.2 Effect on soil microbial properties

Crop rotation generally supports greater soil microbial biomass and numbers than monoculture. The difference is often related to changes in C input and may vary depending on crop type, frequency of cropping and rotation length. This has been demonstrated in several long-term experiments conducted for 28 to 64 years in major ecological zones of the Canadian prairies (Campbell *et al*., 1997) as well as in the midwest and Pacific northwest regions of the USA (Martyniuk & Wagner, 1978; Collins *et al*., 1992; Kirchner *et al*., 1993).

Collins *et al*. (1992) examined the inclusion of summer fallow and a legume crop in a long-term rotation experiment ongoing since 1931 at Pendleton, Oregon. They reported that soil microbial biomass C and N as well as populations of bacteria, fungi and actinomycetes were significantly higher under monoculture wheat than under wheat-fallow rotation. Further increases occurred as a result of the inclusion of a legume crop in the system. Microbial biomass and numbers under wheat-pea (*Pisum sativum* L.) were higher than under wheat-wheat or wheat-fallow. In a study conducted on the Appalachian Piedmont near Raleigh, North Carolina, Kirchner *et al*. (1993) also found soil microbial biomass C and N, *Bacillus* spp., actinomycetes and total culturable bacteria to be significantly higher in soil with maize-sweet clover rotation than with continuous maize.

The differences in soil microbial biomass and numbers due to the inclusion of fallow and a legume crop in a rotation are closely related to the amount of organic C returned to the soil. This was demonstrated by Campbell *et al*. (1991) in a long-term crop rotation experiment at Indian Head, Saskatchewan. Variables examined in the investigation included cropping frequency, green manuring and the inclusion of a grass-legume hay crop in a predominantly spring wheat production system. It was noted that soil organic C and microbial biomass C and N increased with increasing frequency of cropping and with the inclusion of the legume as green manure or hay crop in the rotation. Microbial biomass C and N were positively correlated with the amount of crop residues (including roots) returned to the soil over the period of the study. Similarly, a significant decrease in soil microbial biomass and numbers as a result of the inclusion of summer fallow in a rotation was observed in a separate long-term experiment at Swift Current, Saskatchewan, and attributed to differences in carbonaceous residues returned to the soil (Biederbeck *et al*., 1994).

The effect of rotation length on microbial properties of soil was investigated by McGill *et al*. (1986) in the long-term Breton Plots in Alberta. A two-year fallow-wheat rotation was compared with a five-year rotation consisting of spring wheat-oat-barley (*Hordeum vulgare* L.)-forage-forage. The amount and turnover rates of microbial biomass in the five-year rotation were significantly higher than in the two-year rotation. The five-year rotation contained 117% more microbial biomass than the two-year rotation. It was concluded that the longer rotation practice exerted a greater effect on the amount of organic matter by controlling both input of C and biomass turnover. Martyniuk & Wagner (1978), in a study at the Sanborn field experiment established in 1888 on the University of Missouri campus, also found higher numbers of bacteria and actinomycetes in a rotation including maize, oats, wheat and red clover (*Trifolium pratense* L.) than in either continuous maize or continuous wheat. The rotation soil contained 2.1% organic matter, a significantly higher level than that of the maize or wheat soils, which contained 1.3 and 1.5% organic matter, respectively. The difference in microbial populations was therefore attributed to differences in organic substrate effects that were brought about by the rotation length and the inclusion of red clover in the rotation sequence and the N fixed by the legume. The residues from red clover and from subsequent crops that benefited from the fixed N were presumed to have provided more organic substrate for the micro-organisms.

Unlike frequent annual cropping which reduces loss of soil organic C, fallow in rotation is known to accelerate C loss (Biederbeck *et al*., 1984). A decrease in microbial biomass and numbers by the inclusion of fallow in crop rotation is therefore because of the negative impact of fallow on the C content of the soil. On the other hand, the inclusion of legumes in a crop rotation and prolonging the length of the rotation are advantageous since they enhance and/or maintain the organic C level, thereby impacting favourably on microbial properties of the soil.

2.3 Fertilization and its effect on chemical and microbial properties of soil

Fertilizers are defined as organic or inorganic materials of natural or synthetic origin which are added to soil to supply certain elements essential to the growth of plants (Soil Conservation Society of America, 1982). Two such materials that are commonly used and routinely applied to soils are manure and inorganic NPK fertilizers.

Manure refers to faeces and urine excreted by cattle, dairy, poultry or other domestic livestock, including the bedding material. Use of manure for crop production is an ancient practice and an important way of recycling nutrients. Though the composition and amount of nutrients in manure are variable depending on the type of animal, ration fed, amount and type of bedding material, collection system, and management between production and use (Eck & Stewart, 1995), manure contains all the essential chemical elements needed by plants and its potential nutrient contribution is quite considerable.

The use of inorganic fertilizers began with the development of the synthetic fertilizer industry in the 19th century and vastly expanded during the post-world war II era. It has since been an integral part of modern agriculture and a major contributing factor towards the dramatic increase in food production in the last century (Brown *et al*., 1994). Inorganic fertilizers are now the most widely used sources for supplying nutrients to crop plants and have become an economic necessity in many production systems. Unlike manures which are composed of much C and relatively small percentages of several plant nutrients, inorganic fertilizers contain one or two elements in a proportion required for the production of high yields of crops. The bulk of inorganic fertilizers consist of materials containing the three principal plant nutrients N, P and/or K in concentrations much higher than in manure. For instance, the concentrations of N, P and K in commonly used fertilizer materials such as urea, superphosphate and potassium chloride are, on average, 44, 15 and 45%, respectively, and these levels are 15-20 times higher than in manure.

When manure and NPK fertilizers are applied to the soil, a complex series of chemical and microbial reactions may take place that not only influence plant growth and development but also cause various short- and long-term changes in the chemical and microbial properties of the soil, as discussed below.

2.3.1 Effect of manure

2.3.1.1 Soil chemical properties

The bulk of the solid matter in manure is composed of organic compounds and partially degraded plant material (Jarvis *et al*., 1996). Of the total dry matter content of manure, which ranges from 420-500 g kg^{-1}, C accounts for about 150 g kg^{-1} (30%) (Rasmussen & Collins, 1991). Manure addition to soils can therefore result in substantial C inputs and significant increases in organic C levels of soils. In the classical experiment at Hoosfield (Rothamsted), annual application of manure at a rate of 35 tonne ha^{-1} to continuous spring barley for over 140 years resulted in an exponential increase in soil organic C levels of about three-fold over that in the unfertilized soil (Figure 2.2) (Johnston, 1986). Under tropical conditions in the northwest of India, yearly applications of 45 tonne ha^{-1} manure increased the soil organic C level from an initial value of 0.47% in 1967 to 1.8% in 1995 (Gupta *et al*., 1996). In the experiment at Hoosfield, manured plots contained about 50% higher organic C than unfertilized plots 104 years after manure addition had been discontinued (Johnston, 1986), thus showing the stability and persistence for many years of organic material derived from manure. Several other researchers have observed similar soil organic C increases and substantial residual effects as a result of manure additions (Mathers & Stewart, 1974; Meek *et al*., 1982; Kanazawa *et al*., 1988; Sommerfeldt *et al*., 1988).

Manure is well known as a valuable source of N, P, K and other nutrients. On average, manure contains 2.0, 0.5 and 1.5 % (on dry-mass basis) of N, P and K, respectively, and significant amounts of Ca, Mg, Na and many trace elements (Eck & Stewart, 1995). When added to the soil, manure can furnish the nutrients it contains and elevate soil nutrient levels. Significant increases in total N and NH_4- and NO_3- N with increasing rates and number of annual manure applications have been reported (Sommerfeldt *et al*., 1988; Warman & Cooper, 2000). Manure also increases the availability, persistence and movement of P (Meek *et al*., 1982; Dormar & Chang, 1995; Eghball & Power, 1995) and results in a substantial build-up of exchangeable K, Na and Mg (Mathers & Stewart 1974; Dormaar & Chang, 1995; Eghball & Power, 1995; Warman & Cooper 2000). With a single manure application, Eghball & Power (1995) found an increase from 81 to 114 mg kg^{-1} in available P levels. In the exhaustion land trials at Rothamsted, P and K residues from previous manure application had remained in forms available to plants for more than 50 years (Johnston & Poulton, 1977). Similarly, in the Hoosfield continuous barley experiment, P and K residues from 20 applications of manure were still available to plants after 100 years (Johnston & Poulton, 1992).

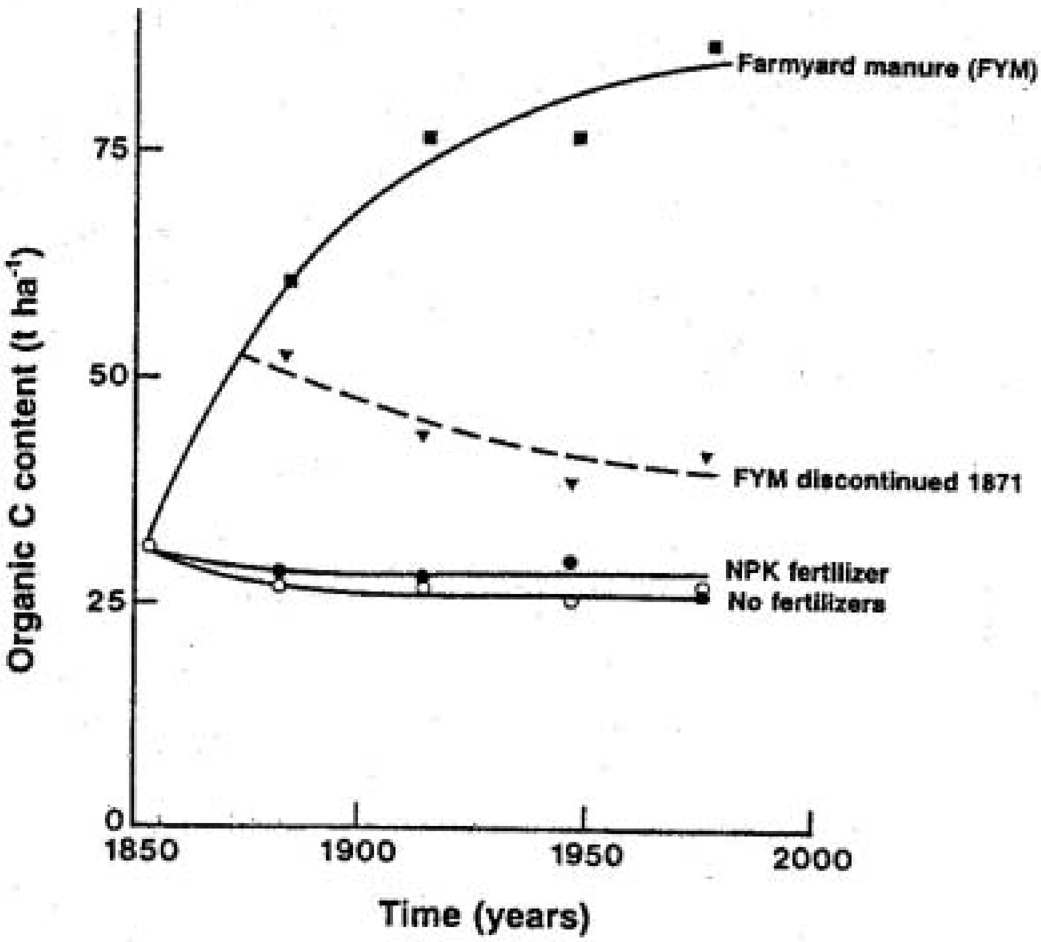

Figure 2.2. Changes in soil organic C content in the Hoosefield continuous barley experiment at Rothamsted. Treatments: no fertilizer applied, NPK fertilizer applied annually, farmyard manure (FYM) applied annually at 35 tonne ha^{-1}, and FYM applied 1852-1871 and none since. From Johnston (1986).

The significance of manure as a source of micronutrients was shown by Warman & Cooper (2000) who found higher levels of B, Cu, Fe, Mn and Zn in manured than in unmanured treatments after 3 years of fresh and composted manure applications at rates ranging from 5 to 10 tonne ha^{-1}.

Manure amendments can increase the pH of acid soils and decrease that of calcareous soils. The pH of acid soils (pH 5.4, top 15 cm) receiving manure annually for 11 years increased by 0.4 to 0.5 units (King *et al*., 1990) while that of a calcareous soil (pH 7.8, top 15 cm) declined by 0.3 to 0.7 units (Chang *et al*., 1990). The effect of manure on soil pH may persist for several years as demonstrated by Bickelhaupt (1989) who observed that an increase in the pH of acid soil from pH 5.7 to between 6.7 and 7.3 due to manure remained undiminished for 12 years after manure application was discontinued.

Other soil chemical properties that are influenced by manure addition include the cation exchange capacity (CEC), electrical conductivity (EC) and sodium adsorption ratio (SAR). These properties have been reported to increase with increasing rates and number of manure applications (Ndayegamiye & Cote, 1989; Chang *et al*, 1990).

2.3.1.2 Soil microbial properties

Because soil is a C-limited environment, the supply and availability of additional mineralisable and readily hydrolysable C due to manure application characteristically results in increased biomass, activity and abundance of soil microbes (McGill *et al*., 1986; Ocio *et al*., 1991). In the Northern Guinea savanna zone of Nigeria, microbial biomass C of a Typic Haplustalf manured for 45 years with cow dung showed an increase of more than 76% over the unmanured control (Goladi & Agbenin, 1997). Many other studies, conducted under both tropical and temperate conditions, have also shown significant increases in microbial biomass C, N and P in soils receiving manure (Hasebe *et al*., 1985; McGill *et al*., 1986; Collins *et al*., 1992; Goyal *et al*., 1992). The positive impact of manure addition on the density of microbes was demonstrated in the long-term field plots at Sanborn. Soils from treatments that received manure had higher numbers of bacteria and actinomycetes than those that did not (Martyniuk & Wagner, 1978).

2.3.2 Effect of NPK fertilizers

2.3.2.1 Soil chemical properties

The purpose of inorganic fertilizer applications generally is to increase soil fertility and enhance crop production. The resultant enhanced plant productivity and associated greater returns of organic material in the form of decaying roots, litter and crop residues often give rise to higher soil organic C levels. As illustrated in Figure 2.2, long-term NPK fertilizers on a yearly basis to the Hoosfield continuous barley experiment resulted in an organic C level that was 15% higher than in the unfertilized treatment (Johnston, 1986). Similar increases in soil organic C levels due to long-term NPK applications have been observed in other studies (Edwards & Lofty, 1982; Mihaila & Hera, 1994). There are, however, reports of decline or no change in organic C content of soils receiving prolonged applications of NPK fertilizers. For example, in the long-term Morrow plots, Aref & Wander (1998) observed significant soil C losses throughout the history of the trial as a result of continued NPK applications. In Ranchi, India, annual applications for over 20 years of 100, 60 and 40 kg ha^{-1} of N, P_2O_5 and K_2O, respectively, did not cause any change in the organic C level of the soil (Prasad & Goswami, 1992). It appears, therefore, that information on the impact of prolonged NPK applications on soil organic C content is inconsistent, probably due to influences of crop, soil and environmental factors.

Application of NPK fertilizers can result in a substantial build-up of the total and readily available levels of soil nutrients. Shen *et al*. (1989) reported that a soil at the Broadbalk long-term experiment which had received 144 kg ha^{-1} fertilizer N each year for 137 years contained 3600 kg ha^{-1} organic N in the top 23 cm, compared to 2900 kg ha^{-1} in the soil receiving no N. A long-term soil fertility monitoring programme at 11 major agroclimatic regions in India revealed that the availability and concentration of readily soluble P and K were much higher where these nutrients were applied (Prasad & Goswami, 1992). Similar increases in total and extractable N, P and K contents were observed in another long-term experiment at the Research Institute for Cereals and Industrial Crops, Fundulea, Romania. After 26 years of annual application of 160 kg ha^{-1} fertilizer N, total N in the fertilized soil was 13% higher than in the unfertilized control. After the same period, plots receiving 160 kg P_2O_5 ha^{-1} yr^{-1} contained 126 mg kg^{-1} readily soluble P compared to 10 mg kg^{-1} P in unfertilized plots. Exchangeable K in the unfertilized plots declined from an initial level of 234 to 218 mg kg^{-1}, while it increased to 327 mg kg^{-1} in plots that had been receiving 120 kg K_2O annually (Mihaila & Hera, 1994).

Nutrient balances calculated for several of the Rothamsted long-term experiments have demonstrated considerable carry-over effects of continued NPK applications. It was shown that up to 85% of the P and 40% of the K added as inorganic fertilizers over the last 100 years or so had been retained in the soil and were plant-available (Johnston & Poulton, 1992). The increase in organic N, however, was equivalent to only 3% of the fertilizer N applied over a period of more than a century, thus showing that the net retention and residual value of fertilizer N is relatively small (Glendining & Powlson, 1995).

Most N-containing inorganic fertilizers, unless specially treated, tend to acidify soil. This is mainly due to the impact of certain carriers that supply ammonia or result in its production when added to the soil. Upon oxidation, the ammonia compounds can release H^+ ions which are potential sources of soil acidity (Magdoff *et al*., 1997). Several reports refer to declines in soil pH as a result of continued use of N-containing inorganic fertilizers. Prasad & Goswami (1992) found that continuous application for 18 years of N as ammonium sulphate, whether or not applied along with P and K fertilizers, decreased the pH of a soil from 5.5 to 3.9. A decrease of 0.4 pH units in the soil at the Fundulea long-term experiment described above occurred as a result of annual application of 160 kg ha^{-1} ammonium nitrate (Mihaila & Hera, 1994). Such soil pH declines as well as decreased nitrification and nutrient mineralization that may result from the use of nitrogenous fertilizers could be unfavourable for soil microbial growth and activity (Hauck, 1981).

2.3.2.2 Soil microbial properties

Reports on the effects of inorganic NPK fertilizers on soil microbial biomass and numbers are inconsistent. In some cases microbial biomass and numbers were stimulated while in other cases there were the opposite or no effects. In the long-term experiment in Saskatchewan, significant increases in soil microbial biomass and numbers due to fertilization were reported (Biederbeck *et al*., 1984). Studies in India (Goyal *et al*., 1992) and Japan (Kanazawa *et al*., 1988) also found similar responses to continuous applications of NPK fertilizers. The increases were attributed to improvements in soil fertility and the associated enhanced plant growth and higher rhizodeposition.

By contrast, McGill *et al*. (1986), studying the dynamics of soil microbial biomass C and N in the long-term Breton Plots, observed decreased microbial biomass due to NPK application. Experiments conducted for more than 10 years at two sites in Kansas also showed that soil microbial biomass C and N of plots fertilized with 224 kg N ha^{-1} yr^{-1} were significantly lower than that of the unfertilized control plot (Omay *et al*., 1997). In a study at the Saskatchewan long-term experiment, the amount of soil microbial biomass C in plots that received continuous NPK fertilizers was not significantly different from that in the unfertilized control (Campbell *et al*., 1991). The lack of response or decrease in microbial biomass and activity could be due to acidifying effects of the fertilizers and the resultant impairment of the survival capacity of many of the soil microorganisms (Domsch, 1986).

Generally speaking, information on the impact of NPK fertilizers on soil microbial biomass and numbers, in addition to being conflicting, is also very limited and more research in this regard is needed.

2.4 Interactive effects of crop rotation and fertilization.

The interaction of crop rotation and fertilization practices in influencing soil chemical and microbial properties is often positive. Application of organic and/or inorganic fertilizers to crops in rotation results in increased plant biomass and hence greater return of organic material and increased soil organic C content (Juma *et al*., 1993). In addition to its nutritional value and enhancement of plant biomass, manure addition to crops in rotation is especially important in directly contributing to the organic matter of the soil by returning organic C.

Soil nutrient levels are also elevated when manure and inorganic fertilizers are applied to crops in rotation due to both the favourable impact of crop rotation as well as additional inputs from the fertilizers. In a rotation system consisting of finger millet (*Eleusine covacana* (L.) Gaertn.)-cowpea (*Vigna unguiculata* (L.) Walp.)-maize in Tamil Nadu, India, the available N status of the soil was maintained at a high level of 240 kg ha^{-1} with a combination of manure plus NPK fertilizers compared to 154 kg N ha^{-1} without fertilization during 14 years of continuous cultivation (Subramanian & Kumaraswamy, 1989). In this study, the available P content in the fertilized treatment was 21 kg ha^{-1} against 5 kg ha^{-1} in the unfertilized treatment. Prasad & Goswami (1992) observed that the available K content of a soil cropped to maize-wheat rotation with application of manure and NPK fertilizer annually for over 28 years was higher by about 20 mg kg^{-1} than the unfertilized rotation soil. These data are consistent with those of other long-term experiments (Hedge, 1996; Omay *et al*, 1997; Aref & Wander, 1998).

Improvements in soil microbial biomass and numbers as a result of the use of fertilizers together with crop rotation have been reported by several researchers. In the long-term Breton Plots, soil microbial biomass C and N of soils cropped to wheat-oats-barley-forage-forage rotations were 320 and 21 mg kg^{-1} without fertilization and 390 and 41 mg kg^{-1} with manure application, respectively (McGill *et al*., 1986). In a two year rotation consisting of maize, soybean (*Glycine max*. (L.) Merr.) and barley, Kanazawa *et al*. (1988) observed that biomass C and populations of bacteria, actinomycetes and fungi in soil that received chemical fertilizers and manure, either separately or together, were significantly higher than in soil receiving no fertilizer. Many other studies have indicated similar responses to the combined use of crop rotation and fertilization practices (Martyniuk & Wagner, 1978; Goyal *et al*., 1992; Kirchner *et al*., 1993).

With improvements in soil chemical and microbial properties, it should be expected that productivity of the soil would be enhanced, resulting in substantial crop yield increases. Yields of crops from rotations, which are often higher than those in monoculture, have been found to be further enhanced by manure and NPK fertilizer applications. In the long-term Morrow Plots, for example, yields of continuous maize plots have always been much lower than yields of maize-oat and maize-oat-hay rotations, and fertilization with manure and/or NPK resulted in greater yields than unfertilized rotations (Figure 2.1) (Aref & Wander, 1998). In two long-term experiments that have been ongoing since 1923 at Skierniewice (Poland), yields of several field and vegetable crops were highest in legume-based crop rotation with manure, considerably lower in rotation without legumes or manure and lowest in unfertilized monoculture (Mercik, 1994). Other long-term studies have also shown similar yield increases and favourable influences of crop rotation and fertilization (Mihaila & Hera, 1994; Campbell *et al*., 1997; Yadav, 1998).

In conclusion, it is apparent from this brief review that the chemical and microbial quality of a soil and productivity of crops can be enhanced by crop rotation, manure addition and appropriate use of NPK fertilizers. The positive interaction and additional benefits accrued by crop rotation and fertilizer application emphasize the importance of integrated crop and nutrient management systems to the maintenance and improvement of the quality and productive capacity of soils.

2.5 References

Anderson, I.C., Buxton, D.R., Karlen, D.L. & Cambardella, C. 1997. Cropping system effects on nitrogen removal, soil nitrogen, aggregate stability and subsequent maize grain yield. *Agron J*. 89:881-886.

Aref, S. & Wander, M.M. 1998. Long-term trends of corn yield and soil organic matter in different crop sequences and soil fertility treatments on the Morrow Plots. *Adv. Agron*. 62:153-197.

Arshad, M.A., Gill, K.S. & Izaurralde, R.C. 1998. Wheat production, weed population and soil properties subsequent to 20 years of sod as affected by crop rotation and tillage. *J. Sust. Agric*. 12:131-153.

Bickelhaupt, D.H. 1989. The long-term effect of a single application of horse manure on soil pH. *Tree Planters' Notes* 40:31-33.

Biederbeck, V.O., Campbell, C.A. & Zenter, R.P. 1984. Effect of crop rotation and fertilization on some biological properties of a loam in Southwestern Saskatchewan. *Can. J. Soil Sci*. 64:355-367.

Biederbeck, V.O., Janzen, H.H., Campbell, C.A. & Zenter, R.P. 1994. Labile soil organic matter as influenced by cropping practices in arid environment. *Soil Biol. Biochem*. 26:1647-1656.

Brown, L.R., Kane, H. & Roodman, D.M. 1994. Vital signs 1994: The trends that are shaping our future. Worldwatch Institute, W.W. Norton & Co., NY

Bruulsema, T.W. & Christie, R.B. 1987. Nitrogen contribution to succeeding corn from alfalfa and red clover. *Agron. J*. 79:96-100.

Bullock, D.G. 1992. Crop rotation. *Crit. Rev. Plant Sci*. 11:309-326.

Campbell, C.A., Biederbeck, V.O., Zenter, R.P. & Lafond, G.P. 1991. Effect of crop rotations and cultural practices on soil organic matter, microbial biomass and respiration in a thin black chernozem. *Can. J. Soil Sci*. 71:363-376.

Campbell, C.A., Janzen, H.H. & Juma, N.G. 1997. Case studies of soil quality in the Canadian prairies: Long-term field experiments. In: E.G. Gregorich & M.R. Carter (eds.), Soil quality for crop production and ecosystem health, pp.351-397. Elsevier Sci., Amsterdam.

Chang, C., Sommerfeldt, T.G. & Entz, T. 1990. Rates of soil chemical changes with eleven annual applications of cattle feedlot manure. *Can. J. Soil Sci*. 70:673-681.

Collins, H.P., Rasmussen, P.E. & Douglas, C.L., Jr. 1992. Crop rotation and residue management effects on soil carbon and microbial dynamics. *Soil Sci. Soc. Am. J.* 56:783-788.

Crookston, R.K. 1984. The rotation effect. *Crops Soils* 36:12-14.

Domsch, K.H. 1986. Influence of management on microbial communities in soil. In: V. Jensen, A. Kjoller & L.H. Sorensen (eds.), Microbial communities in soil, pp.355-367. Elsevier Appl. Sci. Publ., Cambridge.

Dormaar, J.F. & Chang, C. 1995. Effects of 20 annual applications of excess feedlot manure on labile soil phosphorus. *Can. J. Soil Sci*. 75:507-512.

Ebelhar, S.A., Frye, W.W. & Blevins, F.L. 1984. Nitrogen from legume cover crops for no-tillage corn. *Agron. J.* 76:51-55.

Eck, H.V. & Stewart, B.A. 1995. Manure. In: J.E. Rechcigl (ed.), Soil amendments and environmental quality, pp. 169-199. Lewis Publ., Boca Raton.

Edwards, C.A. & Lofty, J.R. 1982. Nitrogenous fertilizers and earthworm populations in agricultural soils. *Soil Biol. Biochem*. 14:515-521.

Eghball, B. & Power, J.F. 1995. Composted and non-composted beef feedlot manure effects on corn production and soil properties under conventional and no-till systems. In: C.C. Ross (ed.), Proceedings of 7th International Symposium on Agricultural and Food Processing Waste. 18-20 June 1995. Chicago, IL. ASAE, St. Joseph, MI.

Francis, C.A. 1989. Biological efficiencies in multiple-cropping systems. *Adv. Agron*. 42:1-42.

Glendining, M.J. & Powlson, D.S. 1995. The effects of long continued applications of inorganic nitrogen fertilizer on soil organic nitrogen- A review. Adv. In Soil Sci. Soil Mgt: Experimental basis for sustainability and environmental quality, pp.385-446. IACR, Rothamsted.

Goladi, J.T. & Agbenin, J.O. 1997. The cation exchange properties and microbial biomass carbon, nitrogen and phosphorus in savanna Alfisol under continuous cultivation. *J. Sci. Food Agric*. 75:412-418.

Goyal, S., Mishra, M.M., Hooda, I.S. & Singh, R. 1992. Organic matter-microbial biomass relationships in field experiments under tropical conditions: Effects of inorganic fertilization and organic amendments. *Soil Biol. Biochem*. 24:1081-1084.

Grant, C.A. & Lafond, G.P. 1994. The effects of tillage systems and crop rotations on soil chemical properties of a black chernozemic soil. *Can. J. Soil Sci*. 74:301-306.

Groffman, P.M., Hendrix, P.F. & Crossley, D.A., Jr. 1987. Nitrogen dynamics in conventional and no-tillage agroecosystems with inorganic fertilizer or legume nitrogen inputs. *Plant Soil* 97:315-332.

Gupta, A.P., Narwal, R.P. & Antil, R.S. 1996. Savings in fertilizer N with the use of farm yard manure in pearl millet-wheat cropping sequence. In: D.S. Powlson, P. Smith & J.U. Smith (eds.), Evaluation of soil organic matter models, pp.345-350. Springer-Verlag, Berlin.

Hargrove, W.L. 1986. Winter legumes as a nitrogen source for no-till grain sorghum. *Agron. J*. 78:70-74.

Harris, G.H. & Hesterman, O.B. 1990. Quantifying the nitrogen contribution from alfalfa to soil and two succeeding crops using nitrogen-15. *Agron. J*. 82:129-134.

Hasebe, A., Kanazawa, S. & Takai, Y. 1985. Microbial biomass in paddy soil. II. Microbial biomass measured by Jenkinson's fumigation method. *Soil Sci*. *Plant Nutr*. 31:349-359.

Hauck, R. 1981. Nitrogen fertilizer effects on nitrogen cycle processes. In: F.E. Clark & T. Rosswall (eds.), Terrestrial nitrogen cycles, pp.551-562. Ecol. Bull. 62, Swedish Natural Sci. Res. Council, Stockholm.

Hedge, D.M. 1996. Long-term sustainability of productivity in an irrigated sorghum-wheat system through integrated nutrient supply. *Field Crops Res*. 48:167-175.

Hendrix, P.F., Coleman, D.C. & Crossley, D.A., Jr. 1992. Using knowledge of nutrient cycling processes to design sustainable agriculture. *J. Sust. Agric*. 2:63-81.

Janzen, H.H. 1987. Soil organic matter characteristics after long-term cropping to various spring wheat rotations. *Can. J. Soil Sci*. 67:845-856.

Jarvis, S.C., Stockdale, E.A., Shepherd, M.A. & Powlson, D.S. 1996. Nitrogen mineralization in temperate agricultural soils: Processes and measurement. *Adv. Agron*. 57:187-235.

Johnston, A.E. 1986. Soil organic matter effects on soils and crops. *Soil Use Mgt*. 2:97-105.

Johnston, A.E. & Poulton, P.R. 1977. Yields on the Exhaustion Land and changes in the NPK contents of the soils due to cropping and manuring, 1852-1975. Rothamsted Exp. Station Rep. 1976, Part 2, 53-85.

Johnston, A.E. & Poulton, P.R. 1992. The role of phosphorus in crop production and soil fertility: 150 years of field experiments at Rothamsted, United Kingdom. In: J.J. Schultz (ed.), Phosphate fertilizers and the environment, pp. 45-64. Intl. Fertilizer Dev. Center, Muscle Shoals, USA.

Juma, N.G., Izaurralde, R.C., Robertson, J.A. & McGill, W.B. 1993. Crop yield and soil organic matter trends over 60 years in a Typic Cryoboralf at Breton, Alberta. In: The Breton Plots, pp. 31-46. Dep. Soil Sci., Univ. Alberta, Edmonton.

Kanazawa, S., Asakawa, S. & Takai, Y. 1988. Effect of fertilizer and manure application on microbial numbers, biomass and enzyme activities in volcanic ash soils. *Soil Sci. Plant Nutr*. 34:429-439.

Karlen, D.L., Varvel, G.E.; Bullock, D.G. & Cruse, R.M. 1994. Crop rotations for the 21st century. *Adv. Agron*. 53:1-45.

King, L.D. 1990. Sustainable soil fertility practices. In: C.A. Francis, C.B. Flora & L.D. King (eds.), Sustainable agriculture in temperate zones, pp. 144-177. John Wiley and Sons, Inc. NY.

King, L.D., Burns, J.C. & Westerman, P.W. 1990. Long-term swine lagoon effluent applications on coastal bermudagrass. II. Effect on nutrient accumulation in soil. *J. Environ. Qual*. 19:756-760.

Kirchner, M.J., Wollum, A.G., II, & King, L.D. 1993. Soil microbial populations and activities in reduced chemical input agroecosystems. *Soil Sci. Soc. Am. J.* 57:1289-1295.

Magdoff, F., Lanyon, L. & Liebhardt, B. 1997. Nutrient cycling, transformations and flows: Implications for a more sustainable agriculture. *Adv. Agron*. 60:1-73.

Martyniuk, S. & Wagner, G.W. 1978. Quantitative and qualitative examination of soil microflora associated with different management systems. *Soil Sci*. 125:343-350.

Mathers, A.C. & Stewart, B.A. 1974. Corn silage yield and soil chemical properties as affected by cattle feedlot manure. *J. Environ. Qual*. 3:143-147.

McGill, W.G., Cannon, K.R., Robertson, J.A. & Cook, F.D. 1986. Dynamic of soil microbial biomass and water-soluble organic C in Breton L after 50 years of cropping to two rotations. *Can. J. Soil Sci*. 66:1-19.

McVay, K.A., Radcliffe, D.E. & Hargrove, W.L. 1989. Winter legume effects on soil properties and nitrogen fertilizer requirements. *Soil Sci. Soc. Am. J.* 53:1856-1862.

Meek, B., Graham, L. & Donovan, T. 1982. Long-term effects of manure on soil nitrogen, phosphorus, potassium, sodium, organic matter and water infiltration rate. *Soil Sci. Sci. Am. J*. 46:1014-1019.

Mengel, K. 1985. Dynamics and availability of major nutrients in soils. *Adv. Soil Sci*. 2: 65-131.

Mercik, S. 1994. Long-term agricultural experiments in Eastern Europe. II. Long-term continuous experiments in Poland, Bulgeria, Czech Repulic and Slovakia. In: R.A. Leigh & A.E. Johnston (eds.), Long-term experiments in agricultural and ecological sciences, pp.211-219. CAB Intl., Wallingford.

Mihaila, V. & Hera, C. 1994. Long-term agricultural experiments in Eastern Europe. II. Some recent results from the long-term experiment at Fundulea, Romania. In: R.A. Leigh & A.E. Johnston (eds.), Long-term experiments in agricultural and ecological sciences, pp.220-227. CAB Intl., Wallingford.

Monreal, C.M., Zentner, R.P, & Robertson, J.A. 1997. An analysis of soil organic matter dynamics in relation to management, erosion and yield of wheat in long-term crop rotation plots. *Can. J. Soil Sci*. 77:553-563.

Nair, K.P.P. 1996. The buffering power of plant nutrients and effects on availability. *Adv. Agron*. 57:237-287.

Ndayegamiye, A. & Cote, D. 1989. Effect of long-term pig slurry and solid cattle manure application on soil chemical and biological properties. *Can. J. Soil Sci*. 69:39-47.

Ocio, J.A., Martinez, J. & Brooks, P.C. 1991. Contribution of straw derived N following incorporation of cereal straw to soil. *Soil Biol. Biochem*. 23:655-659.

Omay, A.B., Rice, C.W.; Maddux, L.D. & Gordon, W.B. 1997. Changes in soil microbial and chemical properties under long-term crop rotation and fertilization. *Soil Sci. Soc. Am. J*. 61:1672-1678.

Paine, L.K. & Harrison, H. 1993. The historical roots of living mulch and related practices. *Hort. Techn*. 3:137-143.

Power, J.F. & Follette, R.F. 1987. Monoculture. *Sci. Am*. 256:78-86.

Power, J.F. 1990. Legumes and crop rotations. In: C.A. Francis, C.B. Flora & L.D. King (eds.), Sustainable agriculture in temperate zones, pp. 178-204. Wiley, NY.

Prasad, R. & Goswami, N.N. 1992. Soil restoration and management for sustainable agriculture in South Asia. *Adv. Soil Sci*. 17:37-77.

Rasmussen, P.E. & Collins, H.P. 1991. Long-term impacts of tillage, fertilizer and crop residue on soil organic matter in temperate semiarid regions. *Adv. Agron*. 45:93-133.

Reeves, D.W. 1994. Cover crops and rotations. In: J.L. Hatfield & B.A. Stewart (eds.), Advances in soil sciences-Crop residue management, pp.125-172. CRC Press, Boca Raton, FL.

Shen, S.M., Hart, P.B.S.; Powlson, D.S. & Jenkinson, D.S. 1989. The nitrogen cycle in the Broadbalk wheat experiment: ^{15}N-labelled fertilizer residues in the soil and in the soil microbial biomass. *Soil Biol. Biochem*. 21:529-533

Simmelsgaard, S.E. 1998. The effect of crop, soil type and drainage on nitrate leaching from Danish soil. *Soil Use Mgt*. 14:30-36.

Soil Conservation Society of America. 1982. Resource conservation glossary. SCSA, Ankeny, IA.

Sommerfeldt, T.G., Chang, C. & Entz, T. 1988. Long-term annual manure applications increase soil organic matter and nitrogen, and decrease carbon to nitrogen ration. *Soil Sci. Soc. Am. J*. 52:1667-1672.

Stevenson, F.C. & Van Kessel, C. 1996. The nitrogen and non-nitrogen benefits of peas to succeeding crops. *Can. J. Plant Sci*. 76:735-745.

Subramanian, K.S. & Kumaraswamy, K. 1989. Effects of continuous cropping and fertilization on chemical properties of soil. *J. Indian Soc. Soil Sci*. 37:171-173.

Warman, P.R. & Cooper, J.M. 2000. Fertilization of a mixed forage crop with fresh and composted chicken manure and NPK fertilizer: Effects on dry matter yield and soil and tissue N, P and K. *Can. J. Soil Sci*. 80:337-344.

Wilson, G.F., Lal, R. & Okigbo, B.N. 1982. Effects of cover crops on soil structure and on yield of subsequent arable crops grown under strip tillage on an eroded Alfisol. *Soil Till. Res*. 2:233-250.

Yadav, R.L. 1998. Factor productivity trends in a rice-wheat cropping system under long-term use of chemical fertilizers. *Exp. Agric*. 34:1-18.

Chapter 3

Influence of residual manure on selected nutrient elements, microbial properties and maize yield under long-term crop rotation*

3.1 Introduction

The current emphasis on low-chemical-input, sustainable agricultural systems has led to a renewed interest in adopting old farming practices such as crop rotation and use of manure as organic fertilizer. These practices are important not only in enhancing crop yields at reduced external inputs but also in maintaining the natural resource base.

Crop rotation is known to beneficially influence the physical (Bullock, 1992; Karlen *et al*., 1994), chemical (Stevensen & Van Kessel, 1996; Aref & Wander, 1998), and biological (Fyson & Oaks, 1990; Karlen *et al*., 1994) properties of soil, thereby improving its quality. The significance of manure in improving the physical, chemical and biological quality of soil is also well documented (Meek, *et al*., 1982; McGill *et al*., 1986; Sharpley & Smith, 1995). Regular manure additions may increase soil organic matter content or reduce its rate of loss (Russell, 1961). Decomposition of the manure and mineralization of the nutrients contained in it is normally fairly slow and may take a few months to several years depending on environmental factors (Paul & Beauchamp, 1993). As a result, long-term manure addition can have residual effects lasting several years (Lund & Doss, 1980; Dilz *et al*., 1990)

Most of the work on long-term effects of crop rotation and manuring on soil properties and crop yield has been done in Europe and North America, and comparative data for much of Africa are lacking due to few or no long-term field experiments in the continent at large. Extended field experiments provide the unique opportunity to investigate long-term influences and interactions of treatments as well as the sustainability of a particular production system. They allow a comprehensive investigation of overall trends and cumulative impacts of different factors and management systems on soil quality (Mitchel *et al*., 1991; Nel *et al*., 1996).

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Long-term effects of a management system on soil quality can be evaluated by using biological attributes such as total organic C and N, microbial biomass, and soil fauna and flora as these characteristics are sensitive and respond quickly to both natural and human-induced changes (Gregorich *et al.*, 1997). The microbial biomass, being an agent of biochemical processes and pool of labile nutrients, is especially important in determining the quality and health of the soil (Kennedy & Papendick, 1995; Fernandes *et al.*, 1997). It is, therefore, regarded as a good indicator of soil quality changes (Gregorich *et al.*, 1997). The aim of this study was to investigate the dynamics of some nutrients and changes in microbial properties of soil under long-term crop rotation as influenced by residual manure.

3.2 Materials and methods

3.2.1 Site description

The study was conducted in a long-term field experiment at the University of Pretoria, South Africa (25^0 45’ S; 28^0 16’ E). The experiment was established in 1939 with the aim of investigating the long-term effects of organic and inorganic amendments on soil properties and on yield of maize rotated with field pea. Average total annual rainfall and potential evapotranspiration (class A pan) are 680 and 1756 mm, respectively, with a mean annual temperature of 17.9 ^{0}C. It lies at an altitude of 1372 m above sea level and has a warm, temperate, summer-rainfall climate.

The soil is a silt clay loam of the Hutton form and belongs to the Suurbekom family (Soil Classification Working Group, 1991). According to the USDA Soil Taxonomy System (Soil Survey Staff, 1990), the soil is classified as a loamy, mixed, thermic Rhodic Kandiudalf (Nel *et al.*, 1996). Information on the soil’s characteristics prior to the initiation of the experiment is not available. However, analysis of an adjacent undisturbed soil in 1990 (Nel *et al.*, 1996) showed that the clay and silt contents of the plow layer were 23 and 13%, respectively, with an organic carbon (Walkley-Black) content of about 6 g kg^{-1}. The pH (H_2O) in the top 20 cm was 6.0 and water-holding capacity (field capacity-wilting point) in the upper 120 cm was 134 mm. Between 1921 and 1938, the site was used for maize production under dryland cropping without fertilization (Marais, 1948).

3.2.2 Experimental design

Details of the experiment have been given by Nel *et al*. (1996). The experiment consists of five factors, namely water, N, P, K and manure, each factor at two levels. It is thus a 2^5 factorial experiment comprising 32 treatment combinations on 128 plots laid out in a randomized complete block design with four replicates. Plot size is 7.5 by 4.9 m and each plot is surrounded by a 20cm-high soil dike to prevent run-off.

In the present investigation, only the control (receiving no amendment) and manure treatments were considered and compared with an adjacent native site which had supported natural grassland since the experiment was established. The manure, a mixture of cattle dung and compost, on average contained 10.7, 1.6 and 5.4 kg tonne^{-1} N, P and K, respectively (Nel, 1972). Manure had been applied at a rate of 4470 kg ha^{-1} season^{-1} until 1965 and at twice that rate from 1966 onwards until it was discontinued in 1989. Manure was applied to the plots and mixed uniformly while preparing the seedbed using a rotovator.

Maize (*Zea mays* L cv. Pioneer 6431) has been grown in summer alternated with field pea (*Pisum arvense* Poir. cv. Swartbekkie) in winter. Plant population for maize was 55 000 plants ha^{-1} in rows 0.91 m apart. Seeding rate for field pea is 136 kg ha^{-1}. Field pea has been grown in rotation with maize until 1999, but pea residues were incorporated into the soil only until 1983. The crops received supplemental irrigation during periods of low rainfall. Maize yield for 1993 was not considered in the analysis due to crop failure and erratic yield in many of the plots.

3.2.3 Sampling and analysis

Soil samples were collected from the selected treatments and an adjacent native site on three sampling dates, viz. 1) October 13, 1998 after harvesting field pea and before planting maize, 2) January 6, 1999 at tasseling stage of maize, and 3) July 13, 1999 at budding stage of field pea. Samples were taken from the top 20 cm of soil at three or more random positions in each plot and the samples from each plot were pooled and mixed. After sieving (< 2 mm), approximately 250 g of each sample was stored at 5 ^{0}C and subsequently used for microbiological assays. The remaining soil was air-dried for chemical analysis.

Total organic C, total N and available P were determined by wet redox titration, Kjeldahl digestion followed by steam distillation, and extractable P (Bray-I) methods, respectively (Soil Science Society of South Africa, 1990; Canadian Society of Soil Science, 1993). Soil microbial biomass C, N and P were estimated by the chloroform fumigation-extraction methods described in the Handbook of Tropical Soil Biology and Fertility (TSBF, 1993). Enumeration of microbial populations was done by dilution plating using tryptic soy agar (Lawley, *et al.*, 1983) for bacteria, water-yeast extract agar (Crawford *et al.*, 1993) for actinomycetes, and potato-dextrose agar supplemented with 50 µg l^{-1} rifampicin for fungi. Plates were incubated at 28 ^{0}C in the dark and counting was done after 7-10 days of incubation.

Data were subjected to statistical analysis and variances between treatments were compared using Duncan's multiple range test or Student's t-test. The relationship between maize grain yield and total N, biomass C and biomass N was determined by linear regression.

3.3 Results and discussion

3.3.1 Total organic C, total N and available P

Total organic C in the manured plots was significantly higher than in the native site and control by more than 40% (Table 3.1). Total N content in manured plots was nearly double and significantly higher than in both the native site and control. Bray-I P of manured plots was also significantly higher than that of the native site and control, the latter having significantly the lowest P content.

Long-term addition of manure can have residual effects that may last several years (Lund & Doss, 1980; Dilz *et al*., 1990). The high C, N and P contents of the manured plots, observed in the present study, could thus be attributed to the continued application of manure over many years and its residual effect lasting nearly 10 years after discontinuation. These observations regarding the persistence of elevated nutrient levels in previously-manured soils are in agreement with other reports (Meek *et al*., 1982; Sommerfeldt *et al*., 1988; Sharpley *et al*., 1993; Sharpley & Smith, 1995). While native, undisturbed soil is expected to contain a higher soil organic C content than continuously-cultivated arable land, the comparable C content in the control plots indicates a positive contribution of crop rotation towards the maintenance of soil organic matter. Since the manure was a mixture of cattle dung and compost, it would be expected to contain more humified and resistant components which, unlike the readily degradable native grass, could remain unaffected and persist for long periods. As a result of this, as well as the continuous input of plant matter from both the legume and maize crops throughout the year, organic C levels in the manured plots may be higher than in the native site.

Levels of the nutrients showed differences (but not statistically significant) according to season (Figure 3.1). Total C, N and Bray-I P contents in all treatments, especially in the manured plots, were relatively higher when the soil was under or after field pea than when under maize. Total C content showed an increase of about 10% in soil under or after field pea whereas increases in total N and Bray-I P contents were higher by 20% or more.

Table 3.1 Influence of residual manure on total organic C, total N and Bray-1 P levels of soil under long-term crop rotation*.

Treatment	organic C	total N	Bray-1 P
	I------------------------- mg kg^{-1}	------------------	-I
Native	6300^b	690^b	27.8^b
Control	5840^b	591^b	1.70^c
Manure	8890^a	1051^a	58.8^a

*Means in columns followed by the same letter do not differ significantly according to Duncan's multiple range test (P=0.05)

*Values are means of three sampling dates

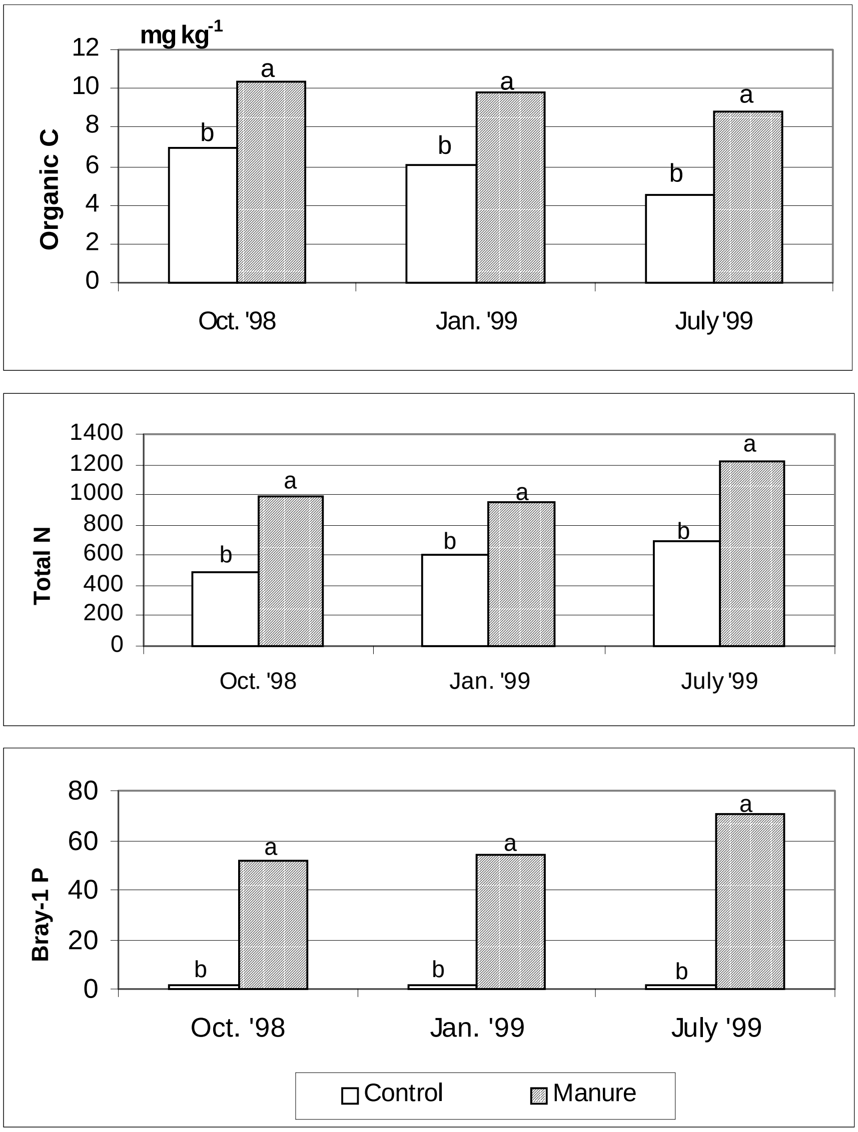

Figure 3.1 Seasonal variations in total organic C, total N and available P contents of soil under long-term crop rotation as influenced by residual manure. [Means with the same letter at each date within each parameter do not differ significantly according to Student's t-test (P=0.05)].

Long-term changes in total organic C, total N and available P in selected treatments are presented in Figure 3.2. Total organic C in the native site showed an increase of 500 mg kg^{-1} (±9%) in the last 10 years whereas total N decreased slightly during the same period. In the control treatment, total N content increased by 38% from 438 mg kg^{-1} in 1984 to 591 mg kg^{-1} in 1999. Total N content of manured plots was almost twice as high in 1999 as in 1990. In the latter two treatments, available P content decreased by nearly 50% in the last 10-15 years.

The seasonal variations in all soil properties considered and the stability of soil N level in the control plots during the past 10-15 years indicate not only N inputs from, but also positive effects of, crop rotation on overall nutrient dynamics and biological properties of the soil. Nitrogen contribution from legume crop rotation and its favourable effect on rhizosphere microbial populations can enhance mineralization and availability of soil nutrients (Fyson & Oaks, 1990; Bullock, 1992; Stevenson & Van Kessel, 1996).

3.3.2 Soil microbial biomass C, N and P and microbial numbers

Microbial biomass C of the control was significantly lower than that of both the native site and manured plots (Table 3.2). Microbial biomass N in the manured plots was 68 and 86% higher than in the control and native site respectively, but differed significantly only from the latter. Manure application has, therefore, favourably influenced soil microbial biomass C and N in agreement with other reports (McGill *et al*., 1986; Goyal *et al*., 1992; Goladi & Agbenin, 1997). As in the case of total N, microbial biomass N content of the control plot was close to that of the native site, corroborating the positive effect of crop rotation on soil microbial biomass.

Biomass C represented 4.6, 2.4, and 2.7% of the total organic C in the native site, control and manured plots, respectively. Biomass N accounted for 2-2.5 % of the total soil N level. The manured plots and control had a microbial biomass C to microbial biomass N ratio of 9.4 and the native site a ratio of about 22. Microbial biomass C and N have been reported to constitute 1-4% and 2-6% of total C and N, respectively (Adams & Laughlin, 1981; Jenkinson & Ladd, 1981; Brookes *et al*., 1985). Values obtained in the present

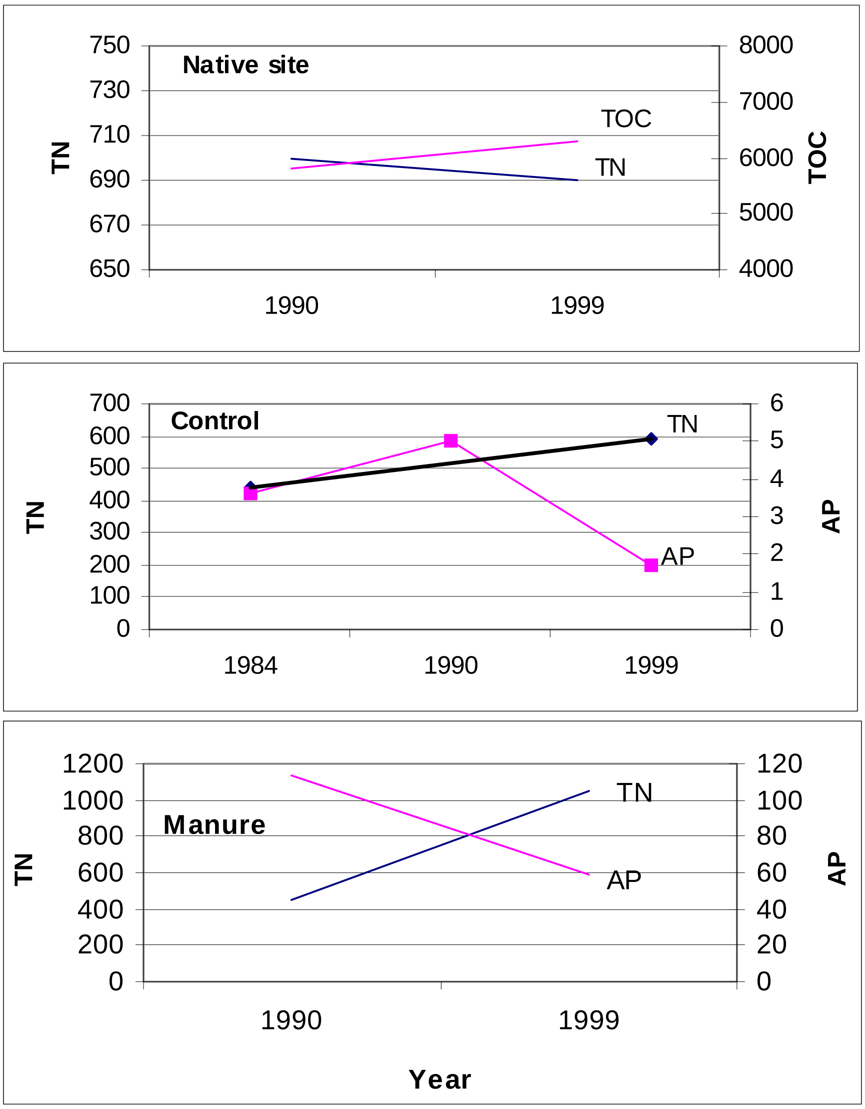

Figure 3.2 Long-term changes in total organic C (TOC), total N (TN) and available P (AP) contents of soil under long-term crop rotation as influenced by residual manure. [Data for 1984 from Steynberg (1986) and for 1990 from Nel *et al.* (1996)]

Table 3.2 Influence of residual manure on microbial biomass C, N and P and microbial numbers of soil under long-term crop rotation*.

Treatment	Microbial biomass C	Microbial biomass N	Microbial biomass P	Bacteria ($x10^5$)	Actinomycetes ($x10^4$)	Fungi ($x10^3$)
	I--------- mg kg^{-1}-------I			I----------------- g^{-1} dry soil--------------I		
Native	292[a]	13.5[b]	0.03[a]	6.9[a]	2.9[b]	39[a]
Control	140[b]	14.9[ab]	0.08[a]	7.0[a]	5.1[a]	8.0[b]
Manure	236[a]	25.1[a]	0.09[a]	7.5[a]	4.1[ab]	5.8[b]

*Means in columns followed by the same letter do not differ significantly according to Duncan's multiple range test (P=0.05).

*Values are means of three sampling dates.

study are within the reported range. The microbial biomass C to total C ratios are also within the range of reported values (Anderson & Domsch, 1980; Jenkinson & Ladd, 1981; Brookes *et al*., 1984). However, the relatively high microbial biomass C to total C ratio of the native site which was nearly twice as high as that of the control and manured plots, indicates higher conversion to biomass and suggests better stability of soil organic C in the native site (Sparling, 1992). The lower microbial biomass C to biomass N ratios of the manured and control plots are further evidence of the greater stability of soil organic C in the native site.

Differences in microbial biomass P contents between treatments were not significant despite the native soil containing three times less biomass P than the control and manured plots (Table 3.2). The microbial biomass P values in the present study were much lower than reported elsewhere (Goladi & Agbenin, 1997). This might be due to adsorption by soil of chloroform-released P that has to be corrected (Brooks *et al*., 1982; Hughs & Reynolds, 1991) but was not included in the present analytical procedure.

The density of bacteria did not differ between treatments (Table 3.2). Numbers of actinomycetes in the control were significantly higher than in the native site. Fungal counts in the native site were more than five-fold higher than in the control and manured plots. The latter two treatments did not differ significantly from each other, though fungal count in the control was higher by more than 38%. The relationship between bacterial counts and microbial biomass N and P was significantly positive with r-values of 0.99 and 0.71, respectively. Microbial biomass C showed a significant correlation (r=0.74) only with fungal counts. Correlations between microbial biomass N and P and fungal counts were insignificant. Microbial biomass C, N and numbers of microflora were generally higher (but mostly not statistically significant) when the soil was under or after field pea than when under maize (Figure 3.3).

Increased C input due to manure addition may result in increased soil microbial populations, as observed in the present study. However, mean counts in the present study were lower than those reported elsewhere (Martyniuk & Wagner, 1978; Bolton *et al*.,

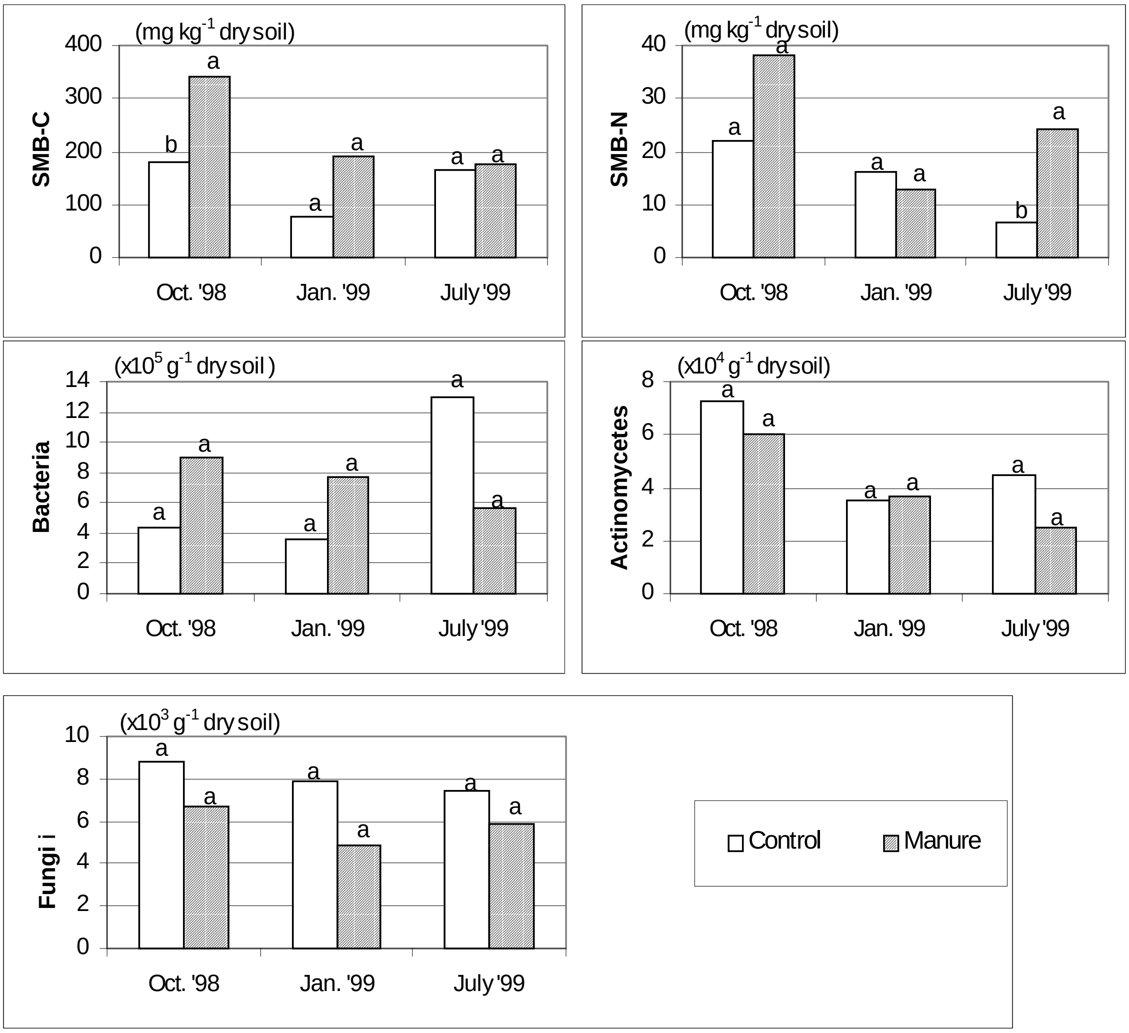

Figure 3.3 Seasonal variations in microbial biomass C (SMB-C), N (SMB-N) and microbial populations in soil under long-term crop rotation as influenced by residual manure. [Means with the same letter at each date within each parameter do not differ significantly according to Student's t-test (P=0.05)].

1985), probably due to differences in organic matter contents and environmental influences. The relatively higher number of actinomycetes in the control plots, compared to the native site, could be attributed to influences other than C inputs that might have resulted from crop rotation. On the other hand, the significantly higher number of fungi in the native site may be due to organic matter as evidenced by the positive correlation between fungal counts and soil microbial biomass C contents. The significant correlation between microbial biomass N and P and numbers of bacteria and actinomycetes suggests higher requirements for N and P by these microorganisms than by fungi.

3.3.3 Maize grain yield

Mean grain yield of maize during the period 1991-99 was more than two-fold and significantly higher in the manured plots than in the control (Figure 3.4). The annual yields of manured plots were also consistently significantly higher with increases of more than 150% over the control. Compared to the base year (1990) when manure application was discontinued, yield increased the next year (1991) but declined thereafter. In 1999, eight years after discontinuation, yield of the manured plot was about 66% of that of the base year. Correlations between the eight-year mean grain yield of maize and total N, microbial biomass C and N were significantly positive (Figure 3.5), whereas relations with the other soil parameters considered were insignificant.

Incorporating manure, in addition to its nutritional value, may improve the physical and biological properties of soil, thereby resulting in crop yield increases. The high maize yields of manured plots are indicative of the positive influences of manure. After discontinuation of manure addition in 1990, annual maize yields of manured plots remained higher than those in control plots confirming previous reports (Ketcheson & Beauchamp, 1978; Dilz *et al*., 1990; Murwira & Kirchmann, 1993) that manure addition can have significant carry-over effects for several years. The positive relationship between crop yield and microbial biomass found here is also in agreement with other reports (McGill *et al*., 1986; Insam *et al*., 1991; Goyal *et al*., 1992).

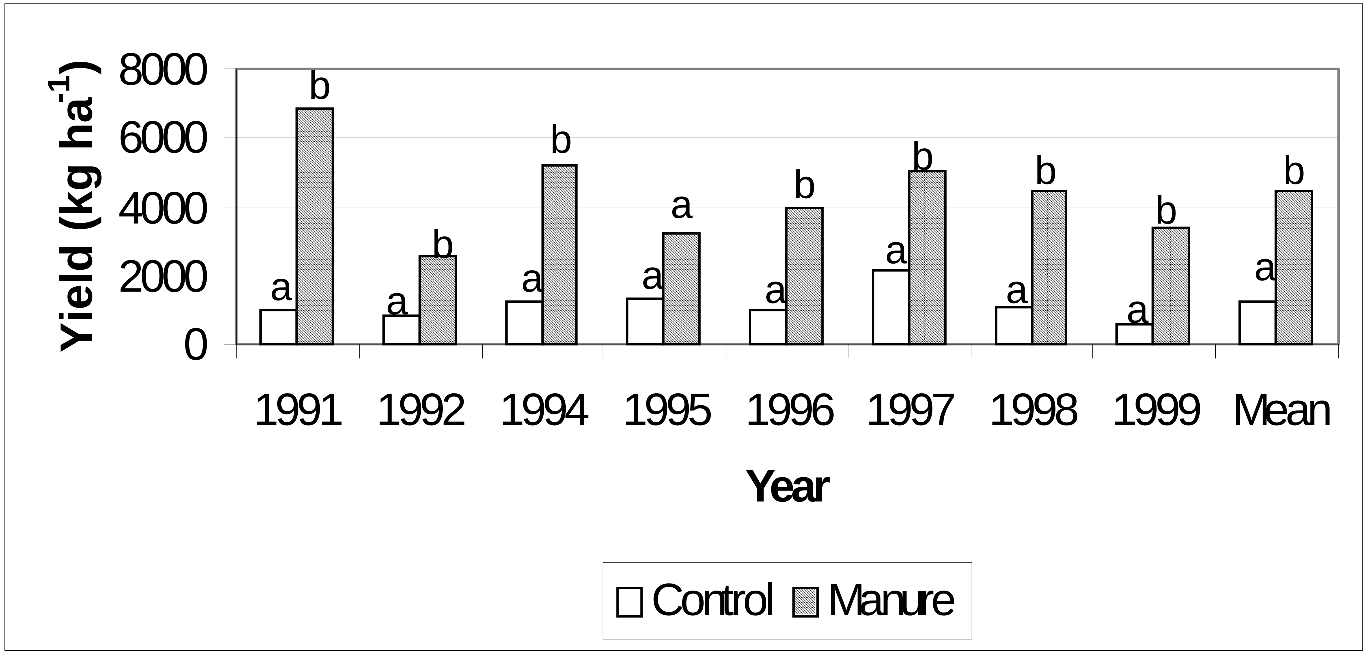

Figure 3.4 Influence of residual manure on annual and mean yield of maize under long-term crop rotation. [Means with the same letter within years do not differ significantly according to Student's t-test (P=0.05)].

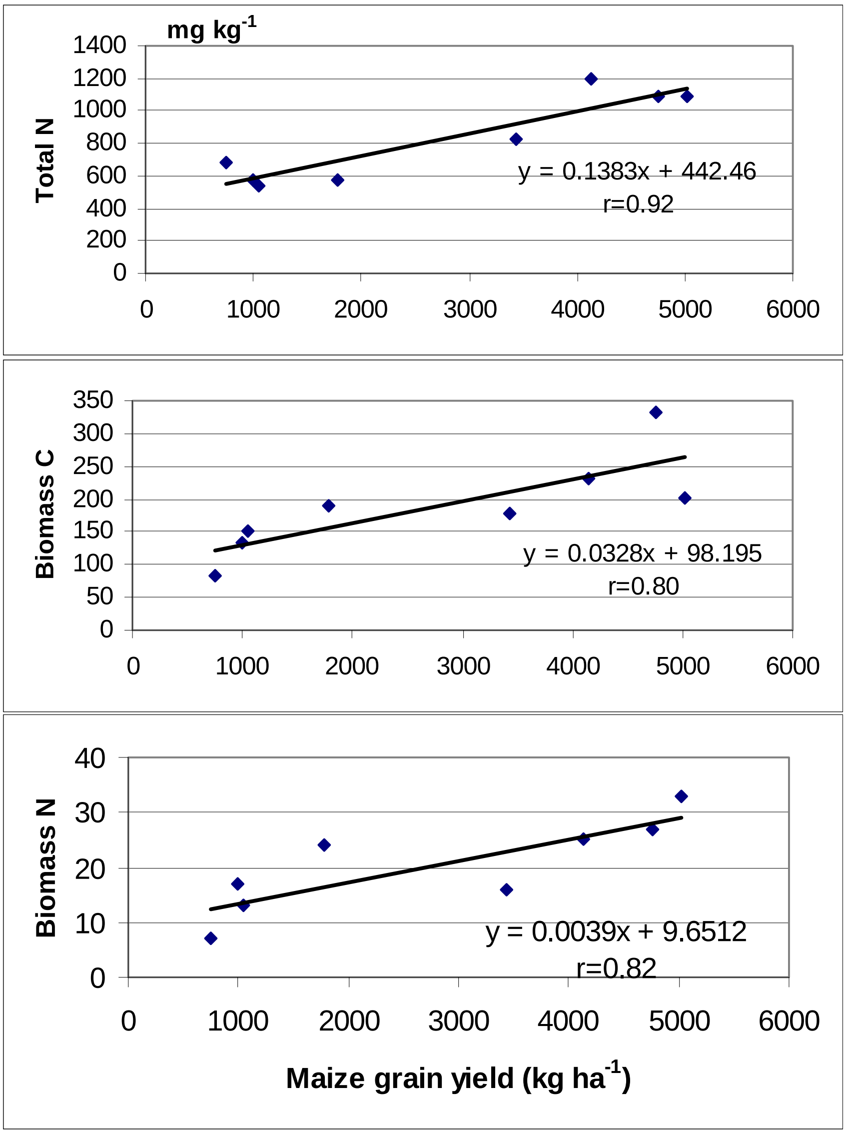

Figure 3.5 Correlations between total N, microbial biomass C and N and mean (1991-99) grain yield of maize under long-term crop rotation as influenced by residual manure.

3.4 Conclusion

Long-term application of manure may result in the build-up of nutrients and their slow release over long periods, thus improving or maintaining the fertility level of the soil. Legume-based crop rotation is also essential in sustaining the N content of the soil. These improvements can have favourable influences on soil microbial properties and crop yield, as demonstrated in the present study. As far as could be established, the present study is the only one besides that of Ketcheson & Beauchamp (1978), and the first in the African continent, to show residual manure effects of eight years or more. This is quite considerable for an area with a warm climate like Pretoria where organic matter decomposition and loss are expected to be high. The significant correlation between maize yield on one hand and microbial biomass C and N on the other supports the suggestion that these parameters may be useful indicators of the sustainability of a particular production system.

3.5. References

Adams, T. McM. & Laughlin, R.J. 1981. The effects of agronomy on the carbon and nitrogen contained in the soil biomass. *J. Agric. Sci. (Camb.*) 97:319-327.

Anderson, J.P.E & Domsch, K.H. 1980. Quantities of plant nutrients in the microbial biomass of selected soils. *Soil Sci*. 130:211-216

Aref, S. & Wander, M.M. 1998. Long-term trends of corn yield and soil organic matter in different crop sequences and soil fertility treatments on the Morrow Plots. *Adv. Agron*. 62:153-197

Bolton, H. jr., Elliott, L.F., Papendick, R.I. & Bezdicek, D.F. 1985. Soil microbial biomass and selected soil enzyme activities: Effect of fertilization and cropping practices. *Soil Biol. Biochem*. 17:297-302.

Brookes, P.C., Powlson, D.S. & Jenkinson, D.S. 1982. Measurement of microbial biomass P in soil. *Soil Biol. Biochem*. 14:318-329.

Brookes, P.C., Powlson, D.S. & Jenkinson, D.S. 1984. The microbial biomass in soil. In: A.H. Fitter (ed.), Ecological interactions in soil, plants, microbes and animals, pp.123-125. Publication No. 4, British Ecological Society.

Brookes, P.C., Londman, A., Pruden, G. & Jenkinson, D.S. 1985. Chloroform fumigation and the release of soil nitrogen: A rapid direct extraction method to measure microbial biomass nitrogen in soil. *Soil Biol. Biochem*. 17:837-842.

Bullock, D.G. 1992. Crop rotation. *Crit. Rev. Plant Sci*. 11:309-326.

Canadian Society of Soil Science. 1993. Soil Sampling and methods of analysis. Lewis Publ., Boca Raton, Florida.

Crawford, D.L., Lynch, J.M., Whipps, J.M. & Ousley, M.A. 1993. Isolation and characterization of actinomycete antagonists of a fungal root pathogen. *Appl. Enviro. Microbiol*. 59:3899-3905.

Dilz, K., Postmus, K. & Prins, W.H. 1990. Residual effects of long-term applications of farmyard manure to silage maize. *Fertilizer Res*. 26:249-252.

Fernandes, E.C.M, Motavallic, P.P., Castilla, C. & Mukurimbira, L. 1997. Management control of soil organic matter dynamics in tropical landuse systems. *Geoderma* 79:49-67.

Fyson, A. & Oaks, A. 1990. Growth promotion of maize by legume oils. *Plant & Soil* 122:259-266.

Goladi, J.T. & Agbenin, J.O. 1997. The cation exchange properties and microbial carbon, nitrogen and phosphorus in Savanna Alfisol under continuous cultivation. *J. Sci. Food Agric*. 75:412-418.

Goyal, S., Mishra, M.M., Hooda, I.S. & Singh, R. 1992. Organic matter-microbial biomass relationships in field experiments under tropical conditions: Effects of inorganic fertilization and organic amendments. *Soil Biol. Biochem*. 24:1081-1084.

Gregorich, E.G., Carter, M.R, Doran, J.W., Pankhurst, C.E. & Dwyer, L.M. 1997. Biological attributes of soil quality. In: E.G. Gregorich & M.R. Carter (eds.), Soil quality and ecosystem health, pp. 81-114. Dev. Soil Sci. 25. Elsevier, Amsterdam.

Hughs, S. & Reynolds, B. 1991. Effects of clearfelling on microbial biomass P in the Oh horizon of an afforested podzol in mid-Wales. *Soil Use Mngmt*. 4:183-188.

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

Jenkinson, D.S. & Ladd, J.N. 1981. Microbial biomass in soil: Measurement and turnover. In: E.A. Paul & J.N. Ladd (eds.), Soil Biochemistry, Vol. 5, pp. 415-471. Dekker, NY.

Karlen, D.L., Varvel, G.E., Bullock, D.G. & Cruse, R.M. 1994. Crop rotations for 21st century. *Adv. Agron*. 53:1-45.

Kennedy, A.C. & Papendick, R.I. 1995. Microbial characteristics of soil quality. *J. Soil Water Cons.* 50:243-248

Ketcheson, J.W. & Beauchamp, E.G. 1978. Effects of corn stover, manure, and nitrogen on soil properties and crop yield. *Agron. J*. 70:792-797.

Lawley, R.A., Campbell, R. & Newman, E.I. 1983. Composition of the bacterial flora of the rhizosphere of three grassland plants grown separately and in mixtures. *Soil Biol. Biochem*. 15:605-607.

Lund, Z.F. & Doss, B.D. 1980. Residual effects of dairy cattle manure on plant growth and soil properties. *Agron. J*. 72:123-130.

Marais, M.J. 1948. Die invloed van bemesting op gewasse wat onder besproeiing verbou is. B.Sc. (Agric.) diss., Univ. Pretoria, Pretoria.

Martyniuk, S. & Wagner, G.H. 1978. Quantitative and qualitative examination of soil microflora associated with different management systems. *Soil Sci*.125:343-350.

McGill, W.B., Cannon, K.R., Robertson, T.A. & Cook, F.D. 1986. Dynamics of soil microbial biomass and water soluble organic carbon in Breton L. after 50 years of cropping to two rotations. *Can. J. Soil Sci*. 66:1-19.

Meek, B., Graham, L. & Donovan, T. 1982. Long-term effects of manure on soil nitrogen, phosphorus, potassium, sodium, organic matter and water infiltration rate. *Soil Sci. Soc. Am. J*. 46:1014-1019.

Mitchel, C.C., Westerman, R.L., Brown, J.R. & Peck, T.R. 1991. Overview of long-term agronomic research. *Agron. J*. 83:24-29.

Murwira, H.K. & Kirchmann, H. 1993. Nitrogen dynamics and maize growth in a Zimbabwean sandy soil under manure fertilization. *Commun. Soil Sci. Plant Anal*. 24:2343-2359.

Nel, P.C. 1972. Sekere neigings in mielie-graan opbrengste in 'n langtermyn bemestingsproef. *Gewasproduksie J. S.A.V.G*. 1:25-34

Nel, P.C., Barnard, R.O., Steynberg, R.E., De Beer, J.M. & Groeneveld, H.T. 1996. Trends in maize grain yields in a long-term fertilizer trial. *Field Crops Res*. 47:53-64.

Paul, J.W. & Beauchamp, E.G. 1993. Nitrogen availability for corn in soils amended with urea, cattle slurry and solid and composted manures. *Can. J. Soil Sci*. 73:253-266.

Russell, E.W. 1961. Soil conditions and plant growth, 9th ed., Jarrold and Sons, Norwich.

Sharpley, A.N., Smith, S.J. & Bain, W.R. 1993. Nitrogen and P fate from long-term poultry litter applications to Oklahoman soils. *Soil Sci. Soc. Am. J*. 57:1131-1137.

Sharpley, A.N. & Smith, S.J. 1995. Nitrogen and phosphorus forms in soils receiving manure. *Soil Sci*. 159:253-258.

Soil Classification Working Group. 1991. Soil classification: A taxonomic system for South Africa. Department of Agric. Dev., Pretoria.

Soil Science Society of South Africa. 1990. Handbook of standard soil testing methods for advisory purposes. SSSSA, Pretoria.

Soil Survey Staff. 1990. Keys to soil taxonomy (4th ed.). SMSS Techn. Monograph 19. Virginia Polytechnic Institute and State Univ., Blacksburg, VA.

Sommerfeldt, T.G., Chang, C. & Entz, T. 1988. Long-term annual manure applications increase soil organic matter and nitrogen, and decrease carbon to nitrogen ratio. *Soil Sci. Soc. Am. J*. 52:1668-1672.

Sparling, G.P. 1992. Ratio of microbial biomass carbon to soil organic carbon as a sensitive indicator of changes in soil organic matter. *Aust. J. Soil Res*. 30:195-207.

Stevenson, F.C. & Van Kessel, C. 1996. The nitrogen and non-nitrogen benefits of peas to succeeding crops. *Can. J. Plant Sci*. 76:735-745.

Steynberg, R.E. 1986. Groei, ontwikkeling en waterverbruiks-doeltreffendheid van mielies (*Zea mays* L.) by verskillende grondvrugbaarheidspeile. M.Sc. (Agric.) diss., Univ. Pretoria, Pretoria.

TSBF (Tropical Soil Biology and Fertility). 1993. A handbook of methods, 2nd ed. CAB international, Wallingford.

Chapter 4

Effect of direct N and K and residual P fertilizers on soil chemical properties, microbial components and maize yield under long-term crop rotation

4.1 Introduction

Inorganic fertilizers, especially nitrogen (N), phosphorus (P) and potassium (K), not only serve to maintain or improve crop yields, but their application directly or indirectly induce changes in chemical, physical and biological properties of the soil. These changes, in the long-term, are believed to have significant influences on the quality and productive capacity of the soil (Acton & Gregorich, 1995). However, available information is conflicting and uncertainties still remain about the long-term influences of inorganic fertilizers on soil quality and productive capacity. Some studies have shown that continued use of inorganic fertilizers may result in diminishing soil quality and productive capacity (Gliessman, 1984; Doran & Werner, 1990; Cassman & Pingali, 1995; Doran *et al*., 1996). Others indicated both positive and negative effects (Hera & Mihaila, 1981; Johnston, 1994) or no noticeable changes (Aref & Wander, 1998). These conflicting reports emphasize the need for research on long-term effects of inorganic fertilizer application on soil quality and productivity (Dobbs & Smolik, 1996).

The aim of this study was to investigate the effects of long-term N, P and K applications on chemical and microbial properties of soil and grain yield of maize (*Zea mays* L.) in rotation with field pea (*Pisum arvense* Poir.) and to assess their impacts on quality and productive capacity of the soil. Conclusions are based on measurements of total organic C (TOC), total N (TN), available P (AP), pH, basic cations, microbial biomass and numbers, and crop yield, all considered to be determinants and good indicators of soil quality and productivity (Subbian *et al*., 2000)

4.2 Materials and methods

The study was conducted in the long-term field experiment of the University of Pretoria described in the previous chapter. Only the control, N, P, K and NPK treatments were considered in the present investigation. The amounts of fertilizers applied are given in Table 4.1. Initially, N was applied as ammonium sulphate and, from 1966 onwards, in the form of ammonium nitrate. P was applied as super phosphate until discontinuation in 1984. K was in the form of KCl. All fertilizers were broadcast before seedbed preparation, and for the NPK treatment, additional N has been top-dressed since 1985. Fertilizers have been applied only to the maize crop which, as described previously, has been grown in summer and rotated with field pea in winter. In this paper, the N, P and K treatments are referred to as single fertilizer treatments and the NPK as balanced fertilizer treatment.

Table 4.1 Rates of N, P and K fertilizers (kg ha^{-1}) applied per season during the course of the experiment.

Year	N	P	K
1939-66	42.5	34	31.5
1967-72	85	68	63
1973-83	205	100	100
1984	205	0	100
1985-1999	125+125[a]	0	80+100[b]

[a] Additional N top-dressed on NPK treatment
[b] Additional K applied to NPK treatment.

Soil sample collection, preparation and analysis of soil chemical and microbial properties were done according procedures described in the previous chapter. Data were subjected to statistical analysis and variances between treatments were compared using Duncan's multiple range test or Student's t-test. The relationship between some selected soil properties and crop yield was determined by linear regression. Variations in chemical and microbial properties of the soil under maize (January, 1999) and under field pea (July, 1999) were compared to assess crop rotation effects. Long-term changes in some selected nutrient contents were computed on the basis of data from Steynberg (1986).

4.3 Results and discussion

4.3.1 Total organic C, total N and available P

Total organic C content of the control was significantly higher than that of the single fertilizer treatments, but did not differ from the NPK plots (Table 4.2). These results are in agreement with the reports that long-term fertilizer applications result in loss of organic matter (Jenkinson, 1991; Nel *et al*., 1996; Aref & Wander, 1998). The greater losses in the single than in the balanced fertilizer treatments are consistent with higher yields and hence greater organic matter inputs in the balanced treatment.

Total N content in the NPK plots was significantly higher than in the N and K plots, but did not differ from the P and control plots. Nel *et al*. (1996) previously also found greater N levels in the balanced than in the single fertilizer treatments in this experiment. The relatively high N levels in the P and control plots could probably be due to N being provided by the legume crop in rotation.

Available P levels in plots that received P fertilizer were significantly higher than in the non-P plots. This confirms the report by McCullum (1991) that long-term P application in excess of that removed by harvested crops can result in a large build-up of P reserves which may persist for many years.

Table 4.2 Effect of direct N and K and residual P fertilizers on chemical properties of soil under long-term crop rotation*.

Treatment	pH(KCl) (1:2.5)	TOC	TN	AP	K^+	Ca^{2+}	Mg^{2+}	Na^+	Ca/Mg	Ca/K	Mg/K
Control	6.35^a	5841^a	591^{ab}	1.71^b	74^c	870^a	392^a	19^{ab}	2.2	11.8	5.3
N	5.79^c	4519^{bc}	581^b	2.08^b	67^c	674^{bc}	295^b	16^{ab}	2.3	10.1	4.4
P	6.13^b	3777^c	659^{ab}	76.8^a	34^d	648^c	261^c	19^{ab}	2.5	19.1	7.7
K	6.24^{ab}	4115^c	567^b	2.31^b	279^a	758^b	315^b	21^a	2.4	2.7	1.1
NPK	4.45^d	5549^{ab}	701^a	73.5^a	158^b	337^d	110^d	13^b	3.1	2.1	0.7

*Means in columns followed by the same letter do not differ significantly according to Duncan's multiple range test (P=0.05)

*All values except pH and ratios are in mg kg^{-1}.

*pH, TOC, TN and AP are means of three determinations; basic cation contents are means of two determinations.

Total organic C, total N and available P levels showed differences according to season (Figure 4.1). Total organic C levels in all fertilizer treatments were significantly higher when the soil was under maize than when under field pea, whereas total N showed an opposite trend. Available P levels in the P and NPK plots were also higher under field pea than under maize. The differences in total organic C levels can be attributed to higher organic matter inputs from maize than from field pea, whereas the variations in total N and available P contents appear to be related to effects of the legume crop in rotation. The increase in total N levels in the non-N and control plots between 1984 and 1999 (Figure 4.2) provides further evidence of the beneficial effect of crop rotation. The long-term increase in N levels of non-N plots ranged from 239 kg ha^{-1} in the K to 689 kg ha^{-1} in the control treatment. The N plots showed an increase of 77 kg ha^{-1}, while levels in the NPK plots declined by about 200 kg ha^{-1}. The relatively slighter increase in the N and decline in the NPK treatment could have been due to either depressed N_2-fixation or higher removal in harvested produce, especially in the balanced fertilizer treatment. Decline in available P levels was also greater in the balanced than in the single fertilizer treatments.

4.3.2 pH and basic cations

pH ranged from 4.45 in the NPK plots, which was significantly the lowest of all treatments, to 6.35 in the control plots (Table 4.2). The pH of the N plots was significantly lower than that of the P, K and control plots. Long-term fertilizer applications, especially of N, therefore had acidifying effects resulting in low pH soils. This is in conformity with the findings of Aref & Wander (1998) who observed lowering of soil pH due to long-term fertilizer applications on the Morrow Plots in Illinois.

Soil K^+ contents in the K and NPK plots were significantly higher than in other treatments. K^+ levels in the P plots were about half of that in the N and control plots. Differences in K^+ levels in the latter two treatments were not significant.

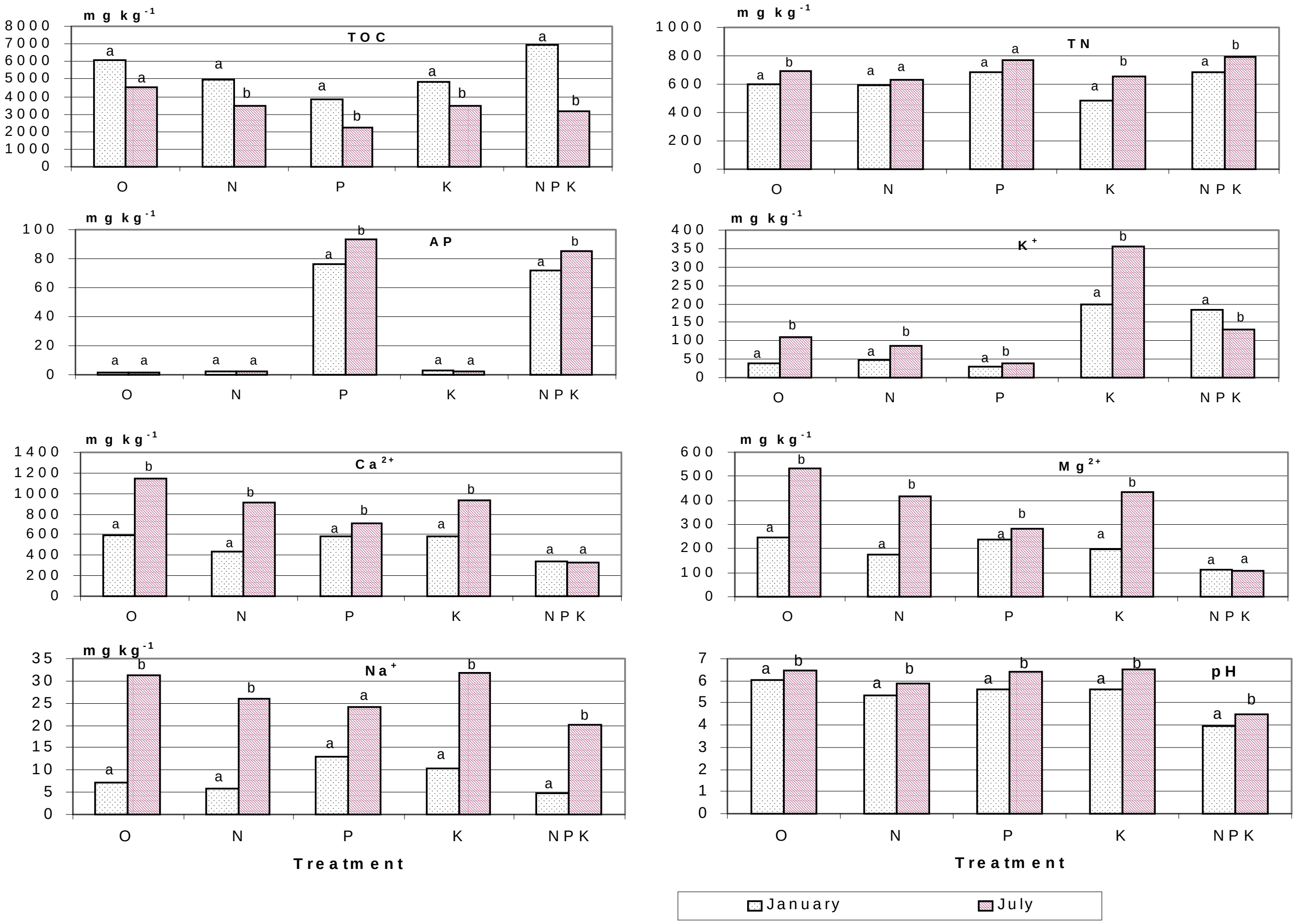

Figure 4.1 Seasonal variations in chemical properties of soil under long-term crop rotation as influenced by direct N and K and residual P fertilizers. [Means with the same letter within treatments do not differ significantly according to Student's t-test (P=0.05)].

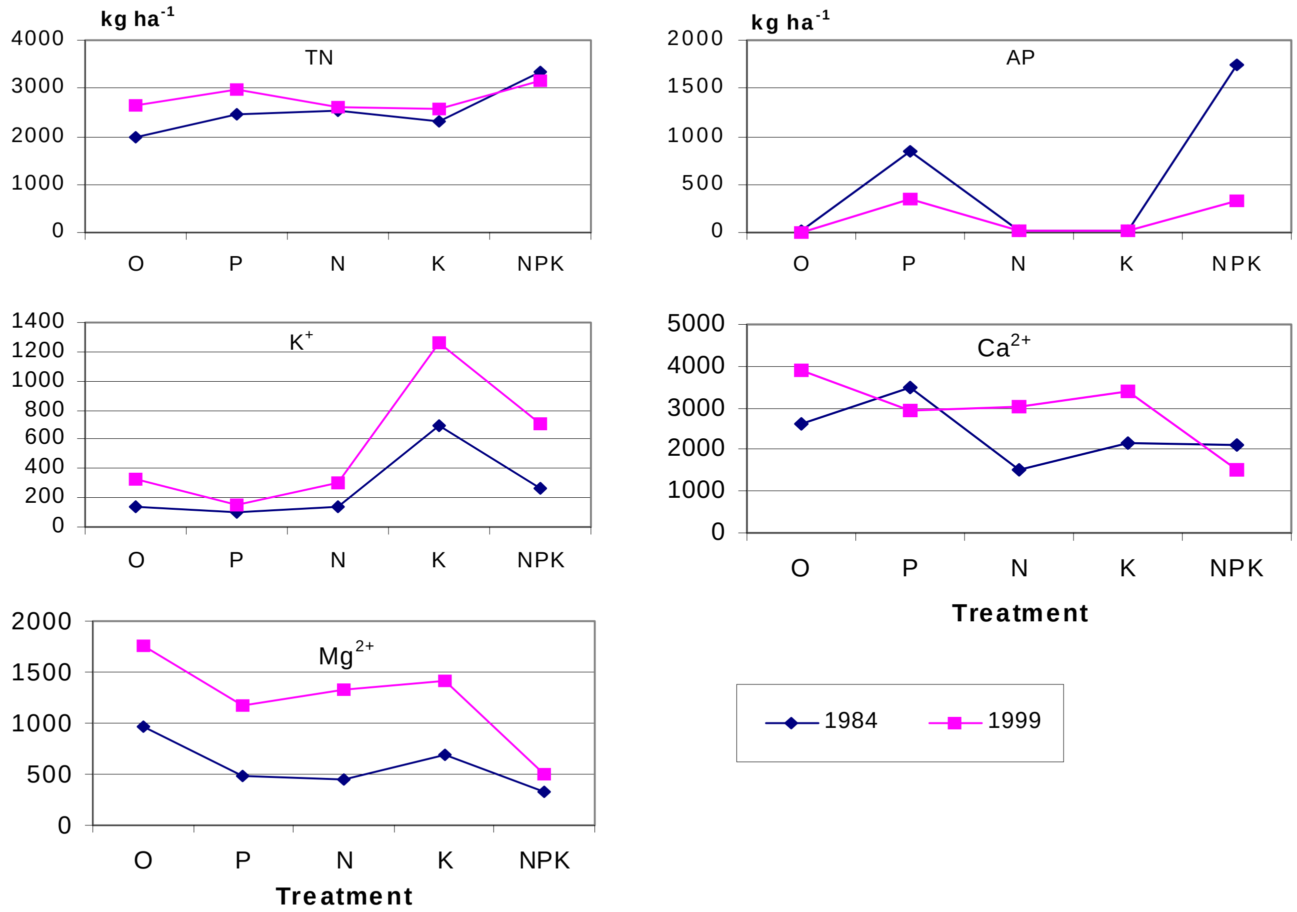

Figure 4.2 Long-term changes in contents of selected elements in soil under long-term crop rotation as influenced by direct N and K and residual P fertilizers. [Data for 1984 from Steynberg (1986)].

The higher levels of K^+ in the K plots obviously resulted from direct K application. Losses from balanced fertilizer treatments were about 77% greater than from the single fertilizer treatments, as previously reported by Nel *et al*. (1996). On the Morrow plots in Illinois, a rather high level of about 240 kg ha^{-1} K^+ was found in unamended control plots after over a century of continuous cropping (Aref & Wander, 1998). Levels in control plots in the present study were comparatively high whereas levels in the P plots were slightly lower than the threshold values reported by Nel *et al*. (1996).

Soil Ca^{2+} levels in fertilized plots were significantly lower than in the control, the lowest being that of the NPK plots. Soil Mg^{2+} and Na^+ contents showed similar trends. Hence, long-term fertilization resulted in a decline in these basic cations, which in the balanced treatment were below the acceptable levels reported by Nel *et al*. (1996). This is attributable to higher removals in harvested crops as well as lowering of the soil pH, as evidenced by the significant correlations between basic cations and pH (r =0.92, 0.90 and 0.59 for Ca^{2+}, Mg^{2+} and Na^+, respectively).

The cationic distribution in the plots generally showed a dominance of Ca^{2+}, followed by Mg^{2+} and Na^+. Except in the K plots, sums of basic cations were lower than in the control, the lowest being in the NPK plots. The latter had the highest Ca/Mg but lowest Ca/K and Mg/K ratio, and was closely followed by the K plots. The Ca/K ratio differed considerably between K-receiving and non-K-receiving plots. The dominance of the cationic distribution by Ca^{2+}, followed by Mg^{2+}, is consistent with observations for Alfisols elsewhere (Kowal & Kassam, 1978; Goladi & Agbenin, 1997) while the disruption of cationic distribution due to fertilizer K inputs is in agreement with the report by Goladi & Agbenin (1997). Basic cationic ratios are important indicators of nutritional imbalances. A Mg/K ratio of about 2, Ca/Mg ratio of 3.2 and Ca/K ratio of 15-30 have been reported to be acceptable (Lombin & Fayemi, 1978; Lombin, 1979). Ratios in the present study mostly were below these levels thus indicating that Ca and Mg are inadequate in the soil.

The pH and basic cation contents generally were lower in soil under maize than under field pea (Figure 4.1). However, levels of K^+, Ca^{2+} and Mg^{2+} in the NPK plots exhibited the opposite trend. Relatively higher seasonal differences were observed in the control plots. These seasonal variations, especially those in the control plots, are related to positive influences of crop rotation on basic cation contents. The higher pH levels in soil under field pea were not expected and can probably be ascribed to fertilizer inputs to the maize crop.

In the period between 1984 and 1999, soil K^+ levels increased in all plots, the highest increase occurring in the K plots (Figure 4.2). Levels of Ca^{2+} were also relatively higher in 1999 than in 1984, except in the P and NPK plots which showed an opposite trend. Mg^{2+} levels increased in all but the NPK plots. These long-term trends are most likely related to differences in fertilizer inputs as well as to removals in harvested produce. The long-term decrease in Ca^{2+} levels in the P and NPK plots is a clear indication of reaction with P and enhanced conversion to Ca-phosphate precipitates (Akinremi & Cho, 1993; Hao *et al*., 2000).

4.3.3 Soil microbial biomass and numbers

Soil microbial biomass C ranged from 140 mg kg^{-1} in the control to 353 mg kg^{-1} in the N plots (Table 4.3). Except for the K treatment, microbial biomass C contents in all fertilized plots were significantly higher than in the control. Soil microbial biomass C was thus increased as a result of fertilizer applications, corroborating previous observations (Bolton *et al*., 1985; Kanazawa *et al*., 1988; Goyal *et al*., 1992). Soil microbial biomass C in the fertilized plots represented between 4.5 and 8.8% of the total organic C content of the soil, which corresponds with the 4-6.5% reported by Franzluebbers *et al*.(1995).

Table 4.3 Effect of direct N and K and residual P fertilizers on microbial biomass C (SMB-C), N (SMB-N) and P (SMB-P) and microbial numbers in soil under long-term crop rotation*.

Treatment	SMB-C	SMB-N	SMB-P	Bacteria ($x10^5$)	Actinomycetes ($x10^4$)	Fungi ($x10^3$)
	I-------------mg kg^{-1}-----------I			I----------------- g^{-1} dry soil----------------I		
Control	140^{d}	15.0^{bc}	0.08^{b}	6.98^{a}	5.05^{a}	8.05^{b}
N	353^{a}	10.9^{c}	0.08^{b}	8.83^{a}	4.08^{a}	7.88^{b}
P	333^{ab}	10.2^{c}	0.06^{b}	7.75^{a}	3.50^{a}	6.18^{b}
K	208^{cd}	19.7^{b}	0.06^{b}	6.33^{a}	6.90^{a}	5.80^{b}
NPK	248^{bc}	32.5^{a}	0.49^{a}	10.93^{a}	4.75^{a}	27.5^{a}

*Means in columns followed by the same letter do not differ significantly according to Duncan's multiple range test (P=0.05).

*All values except SMB-P are means of three determinations; SMB-P is the mean of one determination.

Soil microbial biomass N of NPK plots was significantly the highest. The K plots contained the next highest biomass N, significantly higher than that of the N and P plots but not of the control. Soil microbial biomass P similarly was the highest in the NPK plots. These results show the necessity for fully balanced fertilizer inputs in order to enhance microbial activity and increase biomass. Goyal *et al*. (1992) also found higher soil microbial biomass N and P in balanced than in single fertilizer applications. Soil microbial biomass C to N ratios in the N and P plots were 32 and 33, compared to 11, 8 and 9 in the K, NPK and control plots, respectively. The high ratio in the N and P plots might have impacted negatively on mineralization-immobilization processes and microbial activity, hence the low soil microbial biomass N.

Numbers of bacteria and actinomycetes did not differ significantly between treatments although the bacterial number in NPK plots exceeded that in the control by 87% (Table 4.3). The number of fungi in NPK plots was significantly higher than in the other treatments. These results are in agreement with previous reports (Martyniuk & Wagner, 1977; Biederbeck *et al*., 1984; Kanazawa *et al*., 1988; Goyal *et al*., 1992) and indicate that microbes, particularly fungi, may not thrive in soils with imbalanced nutrient inputs.

Like soil chemical properties, microbial biomass and numbers varied seasonally (Figure 4.3). Soil microbial biomass C of the P, K and NPK treatments was higher under maize than under field pea whereas biomass N was higher under maize in the control soil. Numbers of bacteria were lower under maize than under field pea in the control soil, but higher under maize in the N treatment. Actinomycete and fungal numbers were higher under maize than under field pea in the P and NPK plots. These variations also reflect differences in substrate inputs as well as crop rotation effects, and are consistent with the explanations advanced above regarding variations in soil chemical properties.

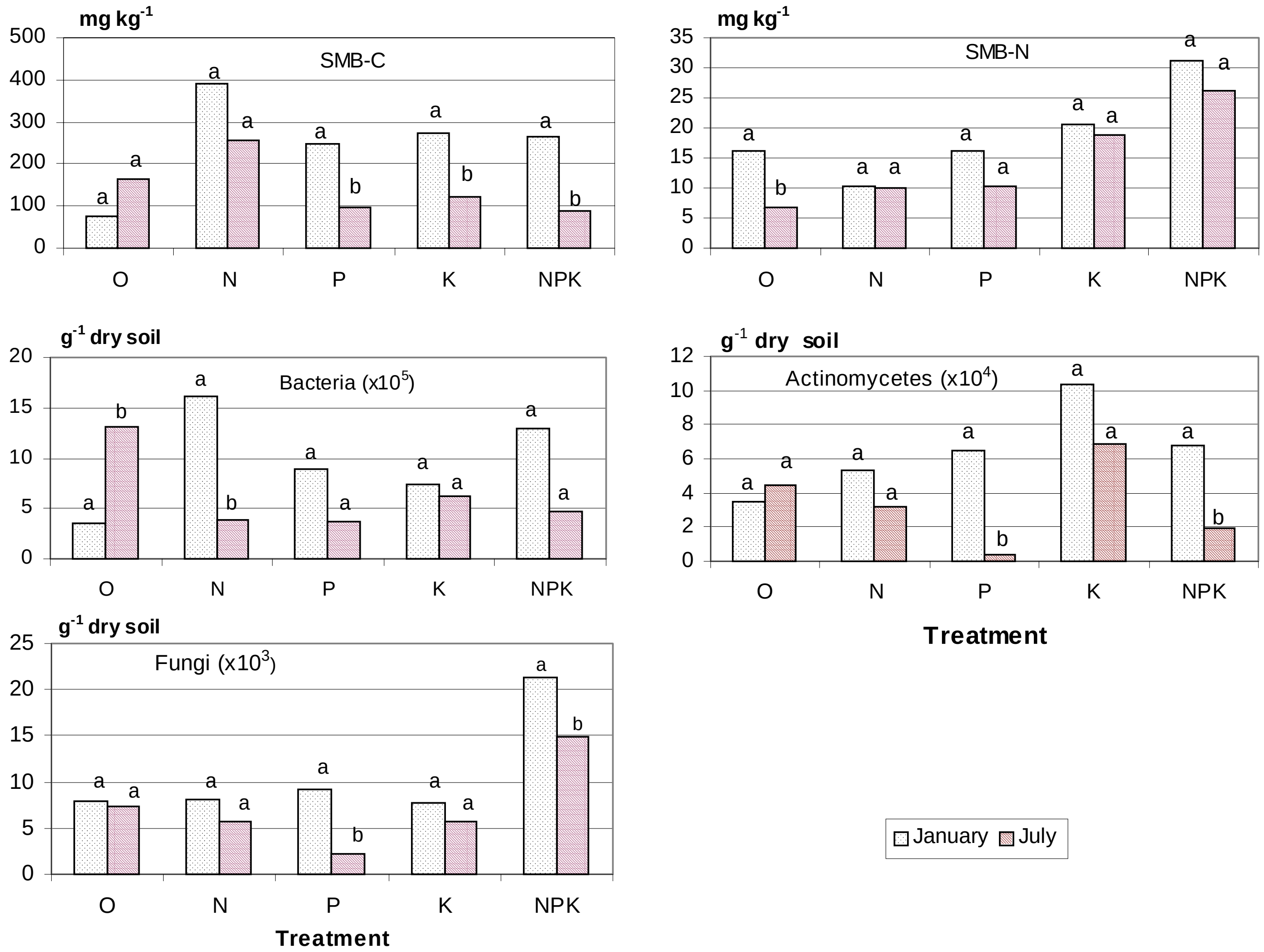

Figure 4.3 Seasonal variations in soil microbial biomass and numbers under long-term crop rotation as influenced by direct N and K and residual P fertilizers. [Means with the same letter within treatments do not differ significantly according to Student's t-test (P=0.05)].

4.3.4 Maize grain yield

Mean (1991-99) grain yield of maize was the highest in the NPK plots with increases of nearly five-fold over the P treatment and control, and more than double that of the N and K plots (Figure 4.4). Yields in the single fertilizer treatments did not differ significantly from the control. This trend is in agreement with the 50-yr averages (Nel *et al.*, 1996) and confirms that single fertilizer treatments in this experiment provided no economic benefits in terms of grain yield returns. The relatively good yields of the control plots after 60 years of cropping without any fertilizer inputs can be attributed to the beneficial effects of crop rotation.

Grain yield in the P plots was about 5% lower than that of the control. This could be ascribed to the depressive effect of P which was still in excess 15 years after P application had been discontinued. Available P content in these plots was 76.8 mg kg^{-1}, a level considered to be excessive (Sims, 1998) and detrimental to crop growth. The high yield in the NPK plots, despite the high P levels, could have been due to K mitigating the adverse effect of excess P (Dibb & Thomson, 1985).

Grain yield correlated positively with soil microbial biomass N (r=0.82) and biomass P (r=0.70), while correlations with other soil properties were non-significant. This is in agreement with the previous observation (see Chapter 3) as well as other studies (McGill *et al*. 1986; Insam *et al*., 1991; Goyal *et al*., 1992) and corroborates the suggestion that soil microbial biomass can serve as an indicator of production sustainability.

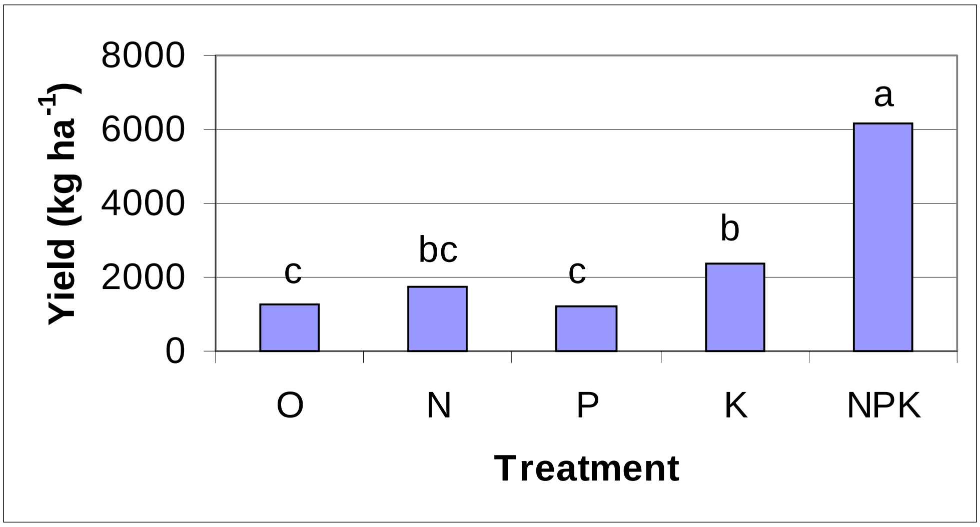

Figure 4.4 Mean (1991-1999) grain yield of maize as influenced by direct N and K and residual P fertilizers under long-term crop rotation. [Means with the same letter do not differ significantly according to Duncan's multiple range test (P=0.05)].

4.4 Conclusion

Prolonged unbalanced fertilizer applications impacted unfavourably on the chemical and microbial properties of soil, and were not beneficial in terms of yield returns. Overall responses were positive in balanced fertilizer treatments, suggesting that judicious use of inorganic fertilizers may, in the long-term, maintain soil quality and productive capacity. It might, however, be necessary to consider supplemental liming to counteract the resulting acidifying effect and decline in Ca^{2+} and Mg^{2+} levels.

4.5 References

Acton, D.F. & Gregorich, L.J. 1995. The health of our soils: Toward sustainable agriculture in Canada. Agric. Agri-food Canada, CDR Unit, Ottawa.

Akinremi, O.O. & Cho, C.M. 1993. Phosphorus diffusion retardation in a calcareous system by co-application of potassium chloride. *Soil Sci. Soc. Am. J*. 57:845-850.

Aref, S. & Wander, M.M. 1998. Long-term trends of corn yield and soil organic matter in different crop sequences and soil fertility treatments on the Morrow Plots. *Adv. Agron.* 62:153-161.

Biederbeck, V.O., Campbell, C.A. & Zentner, R.P. 1984. Effect of crop rotation and fertilization on some biological properties of a loam in southwestern Saskatchewan. *Can. J. Soil Sci*. 64:355-367.

Bolton, H. Jr., Elliott, L.F., Papendick, R.I. & Bezdicek, D.F. 1985. Soil microbial biomass and selected soil enzyme activities: Effect of fertilization and cropping practices. *Soil Biol. Biochem*. 17:297-302.

Cassman, K.G. & Pingali, P.L. 1995. Extrapolating trends from long-term experiments to farmer's fields: The case of irrigated rice systems in Asia. In: V. Barnett, R. Payne, & R. Steiner (eds.), Agricultural sustainability, economic, environmental and statistical considerations, pp. 63-84. Wiley & Sons, London.

Dibb, D.W. & Thompson, W.R. Jr. 1985. Interaction of potassium with other nutrients. In: R.D. Munson (ed.), Potassium in agriculture, pp. 515-533. ASA, CSSA, and SSSA, Madison, WI.

Dobbs, T.L. & Smolik, J.D. 1996. Productivity and profitability of conventional and alternative farming systems: A long-term on farm paired comparison. *J. Sust. Agric*. 9: 63-79.

Doran, J.W. & Werner, M.R. 1990. Management and soil biology. In: C.A. Francis, C.B. Flora, & L.D. King (eds.), Sustainable agriculture in temperate zones, pp. 205-230. Wiley and sons, New York.

Doran, J.W., Sarrantonio, M. & Liebig, M.A. 1996. Soil health and sustainability. *Adv. Agron*. 56: 1-54.

Franzluebbers, A.J., Hons F.M. & Zuberer, D.A. 1995. Soil organic carbon, microbial biomass and mineralizable carbon and nitrogen in sorghum. *Soil Sci. Soc. Am. J*. 59:460-466.

Gliessman, S.R. 1984. An agroecological approach to sustainable agriculture. In: W. Jackson, W. Berry, & B. Colman (eds.), Meeting the expectations of the land, pp. 47-56. North Point Press, San Francisco, CA.

Goladi, J.T. & Agbenin, J.O. 1997. The cation exchange properties and microbial carbon, nitrogen and phosphorus in savanna Alfisol under continuous cultivation. *J. Sci. Food Agric*. 75:412-418.

Goyal, S., Mishra, M.M., Hooda, I.S. & Singh, R. 1992. Organic matter-microbial biomass relationships in field experiments under tropical conditions: Effects of inorganic fertilization and organic amendments. *Soil Biol. Biochem*. 24:1081-1084.

Hera, C. & Mihaila, V. 1981. The changing of some agrochemical indices of the soil by the application of the fertilizers. *Analele ICCPT* 47:319-327.

Hao, X., Cho, C.M. & Racz, G.J. 2000. Chemical retardation of phosphate diffusion in simulated acid soil amended with lignosulfonate. *Can. J. Soil Sci*. 80: 289-299.

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

Jenkinson, D.S. 1991. The Rothamsted long-term experiments: Are they still of use? *Agron. J*. 83:2-10.

Johnston, A.E. 1994. The Rothamsted classical experiments. In: R.A. Leigh & A.E. Johnston (eds.), Long-term experiments in agricultural and ecological sciences, pp. 9-37. CAB International, Wallingford.

Kanazawa, S., Asakawa, S. & Takai, Y. 1988. Effect of fertilizer and manure application on microbial numbers, biomass and enzyme activities in volcanic ash soils. I. Microbial numbers and biomass carbon. *Soil Sci. Plant Nutr*. 34:429-439.

Kowal, J.M. & Kassam, A.H. 1978. Agricultural ecology of savanna: A study of West Africa. Clarendon Press, Oxford.

Lombin, L.G. 1979. Evaluation of the magnesium supplying powers of the Nigerian savanna soils. *Soil Sci. Plant Nutr*. 25:477-492.

Lombin, G. & Fayemi, A.A. 1978. Prospects of magnesium deficiency in soils of Western Nigeria as assessed under field conditions. *Tropical Agric. (Trinidad*) 55: 157-166.

Martyniuk, S. & Wagner, G.H. 1978. Quantitative and qualitative examination of soil microflora associated with different management systems. *Soil Sci*. 25:343-350

McCullum, R.E. 1991. Buildup and decline in soil phosphorus: 30-yr trends on a Typic Umbraquult. *Agron. J*. 83:77-85.

McGill, W.B., Cannon, K.R., Robertson, T.A. & Cook, F.D. 1986. Dynamics of soil microbial biomass and water soluble organic carbon in Breton L. after 50 years of cropping to two rotations. *Can J. Soil Sci*. 66:1-19.

Nel, P.C., Barnard, R.O., Steynberg, R.E., De Beer, J.M. & Groeneveld, H.T. 1996. Trends in maize grain yields in a long-term fertilizer trial. *Field Crops Res*. 47:53-64.

Sims, J.T. 1998. Phosphorus soil testing: Innovations for water quality protection. *Commun. Soil Sci. Plant Anal*. 29:1471-1489.

Steynberg, R.E. 1986. Groei, ontwikkeling en waterverbruiks-doeltreffendheid van mielies (*Zea mays* L.) by verskillende grondvrugbaarheidspeile. M.Sc. (Agric.) diss., University of Pretoria, Pretoria.

Subian, P., Lal, R. & Subramanian, K.S. 2000. Cropping systems effects on soil quality in semi-arid Tropics. *J. Sust. Agric*. 16:7-38.

Chapter 5

Soil nutrient contents, microbial properties and maize yield under long-term crop rotation and fertilization: a comparison of residual manure and NPK fertilizers

5.1 Introduction

Manure is well known for its value as a slow-release source of nutrients (Warman, 1986a,b; Sullivan *et al*., 1998). Upon addition to the soil, manure is initially mineralized at a faster rate until the labile components are exhausted. This is followed by a slow mineralization process and formation of more stable organic forms (N'Dayegamiye *et al*., 1997). The conversion to more stable forms, which may be more pronounced in residual than in freshly added manure, is advantageous in preserving nutrients and their slow release in subsequent years. However, little information is available on whether the released nutrients are as effective to plants and soil microbes as those in inorganic fertilizers, and only a few studies have compared the effects of residual manure and inorganic fertilizers on soil microbial properties and crop yield.

Earlier, a persistent long-term favourable effect of residual manure on selected nutrient contents, microbial properties and maize yield was demonstrated (see Chapter 3). A similar positive response to balanced inorganic fertilizers was found in a subsequent study (Chapter 4). The present investigation compares the effect of residual manure and NPK fertilizers on selected soil nutrient contents, microbial properties, C and N inputs, tissue nutrient concentration and maize yield under long-term crop rotation.

5.2 Materials and methods

The control (O), manure (M), NPK and MNPK treatments of the previously described long-term experiment were considered in the present study. Soil sampling and analyses of total organic C (TOC), total N (TN), available P (AP), soil microbial biomass C (SMB-C), N (SMB-N) and P (SMB-P) were done according to procedures described in the previous chapters. Additionally, turnover rates in TOC, TN, SMB-C and SMB-N were estimated following procedures used by McGill *et al*. (1986). Below-ground C input from the maize crop was quantified based on above-ground biomass yield excluding grain of the crop. A root/straw ratio of 0.59 and tissue C concentration of 45% were assumed in calculating the C input in each treatment (Biederbeck *et al*., 1994).

A separate pot experiment with soils from the selected treatments was also conducted to estimate the amount of symbiotically fixed N by field pea. This was done according to the extended difference method (Hauser, 1992) with maize as the reference crop. Difference in TN levels between the initial soil sample and after harvesting the crop (assuming leaching loss to be negligible or fairly similar) was considered to be the amount of soil N withdrawn by the crops and was used as an extension to the method (see equation below). Pots were each filled with 1 kg freshly-sampled (sieved <2mm) soil and arranged in a randomized complete block design with four replicates in a greenhouse. Seeds of maize (*Zea mays* L. cv Pioneer 6431) and field pea (*Pisum arvense* Poir. cv Swartbekkie) were surface-sterilized in 3.5% (w/v) calcium hypochlorite for 45 min and rinsed several times in sterile distilled water. Four uniform seeds of either maize or field pea were planted to a depth of 25 mm in each pot and the pots were watered regularly with tap water. After 10 days, plants were thinned to three per pot. At the end of the experiment (60 days after planting) plants in each pot were harvested at soil level, oven-dried, ground, sieved and analyzed for tissue N and P concentration. Analysis of N and P was done according to standard procedures described in the Handbook of Standard Soil Testing Methods for Advisory Purposes (Soil Science Society of South Africa, 1990).

The amount of symbiotically fixed N was calculated as:

$$N_{fixed} = (N_{leg} + \Delta N_{leg}) - (N_{ref} + \Delta N_{ref}),$$

where:

N_{fixed} = amount of symbiotically fixed N,
N_{leg} = tissue N concentration in field pea,

ΔN_{leg} = difference in TN levels between initial soil sample and after harvesting of field pea,

N_{ref} = tissue N concentration in maize,

ΔN_{ref} = difference in TN levels between initial soil sample and after harvesting of maize

Data were subjected to statistical analysis and variances between treatments were compared using Duncan's multiple range test. The relationship between some selected soil properties and crop yield was determined by linear regression.

5.3 Results and discussion

5.3.1 Total organic C, total N and available P

Total organic C and total N contents in the M and MNPK plots were significantly higher than in the NPK and control plots (Table 5.1), indicating that residual manure persisted and sustained the C and N levels of the soil for many years. Available P contents in fertilized plots were significantly higher than in the control, the highest being in the MNPK plots followed by the NPK plots. These high P levels are attributed to both residual manure and fertilizer P effects. Several researchers have reported increases in soil C, N and P levels as a result of residual manure (Meek *et al*., 1982; Sommerfeldt *et al*., 1988; Sharpley *et al*., 1993; Sharpley & Smith, 1995; Warman & Cooper, 2000). The persistence for prolonged periods of residual P is also documented (McCullum, 1991).

Differences in total organic C and total N contents between the NPK plots and the control were not significant, suggesting that long-term inorganic fertilizers may not result in a substantial build-up of C and N levels in soils. The comparatively high total N levels in the control plots could have been due to N contribution from the legume crop in rotation.

Table 5.1 Effect of residual manure and NPK fertilizers on total organic C (TOC), total N (TN) and available P (AP) contents, and on C and N input and turnover under long-term crop rotation*.

				Turnover rate		C input		
Treatment	TOC	TN	AP	C	N	mean	total (1991-99)	Fixed N
	I----------- mg kg^{-1}	------------I		I----- yr^{-1}	------I	I---------- kg ha^{-1}	------------I	
O	5841[b]	591[b]	1.7[d]	0.89	0.79	1116[d]	8926[d] (51)**	164
M	8885[a]	1051[a]	58.8[c]	0.83	0.87	1538[c]	12299[c] (46)	102
NPK	5549[b]	701[b]	73.5[b]	1.51	0.55	2262[b]	18098[b] (109)	52
MNPK	9497[a]	1166[a]	161[a]	0.92	0.42	2870[a]	22965[a] (81)	78

*Means in columns followed by the same letter do not differ significantly according to Duncan's multiple range test (P=0.05)

**Values in parenthesis are 8-yr C inputs as percentages of currently available TOC

Rate of C turnover ranged from 0.83 yr^{-1} in the M treatment to 1.51 yr^{-1} in the NPK treatment. The turnover rate in the NPK plots was more than 40% higher than in any other treatment, thus suggesting that mineralization of organic matter was highest in the NPK treatment. Nitrogen turnover showed an opposite trend and was lower in the NPK and MNPK treatments than in the M and control treatments, indicating a low N supply in the latter treatments.

5.3.2 Carbon and N inputs

Mean (1991-99) estimated C input in the MNPK plots was significantly the highest followed by the NPK and M plots (Table 5.1). C input in the NPK plots exceeded that of the M plots by 47% and was twice as high as in the control plots. However, unlike in the plots that received manure, the relatively higher C input in the NPK plots did not result in a proportional increase in total organic C content of the soil, as evidenced by the insignificant correlation between C input and total organic C (Table 5.2). This is consistent with the high turnover rate in this plot (Table 5.1) and implies that organic inputs in the NPK plots were mineralized at a higher rate than in other plots, probably due either to differences in quality of returned materials or to fertilizer N inputs that could have enhanced the decomposition process. Plant residues derived from manured and NPK-fertilized soil have been found to differ in quality and decomposability (Christensen, 1988; Schjonning *et al*., 1994; Jarvis *et al*., 1996; Warman & Cooper 2000). Although the total N content in the manured plots was higher than in the NPK plots, the nutrient may not have been as readily available in the residual manure as in the NPK fertilizer. Smith & Peterson (1982) have shown that N in organic matter has little effect on the rate of decomposition of returned plant materials.

Comparison of the 8-yr total C input with the currently available total organic C showed that C input from maize root biomass accounted for roughly 51, 46 and 81% of the currently available total organic C in the control, M and MNPK plots, respectively (Table

Table 5.2 Correlation coefficient (r) between soil microbial properties, C input from below-ground biomass and grain yield of maize under long-term crop rotation.

Soil properties	C input	Grain yield
TOC	0.01 (NS)	0.39 (NS)
TN	0.25 (NS)	0.48 (NS)
SMB-C	0.61*	0.66*
SMB-N	0.60*	0.62*
SMB-P	0.39 (NS)	0.26 (NS)
Bacteria	0.11 (NS)	0.23 (NS)
Actinomycetes	-0.46 (NS)	-0.41 (NS)
Fungi	0.55*	0.39 (NS)

*Significant at P=0.05

NS = not significant at P=0.05

5.1). The remaining portion is presumed to have been derived from pea residue returns, litter fall and mineralization of native soil organic matter. It appears therefore that the contribution of maize to the soil's organic matter content is higher than that of field pea, which is to be expected given the higher above- and below-ground biomass of maize. In the NPK plots, total C input from maize root biomass in the last 8 years exceeded the currently available total organic C, thus confirming the high turnover rate and supporting the earlier suggestion that mineralization has been fairly rapid in this treatment.

The estimated fixed N ranged from 52 kg ha^{-1} in the NPK plots to 164 kg ha^{-1} in the control plots. Schroder (1992), based on data from several studies, reported that the average amount of N fixed by field pea is about 75 kg ha^{-1}. Values in the present study are far higher and indicate that the method used has exaggerated the estimate. They nevertheless show that N_2 fixation by the legume crop was depressed due to manure and/or NPK applications, which is to be expected since these fertilizer sources contained high N levels.

N input from maize residue (assuming an average C:N ratio of 67) was ca. 17, 23, 34 and 43 kg ha^{-1} $season^{-1}$ in the control, M, NPK and MNPK plots, respectively. A comparison of these figures and the currently available TN indicates that much of the N is derived from fixation by the legume crop as well as from mineralization of soil organic matter.

5.3.3 Soil microbial biomass and numbers

Soil microbial biomass C was significantly increased by fertilization, with increases of more than 75% over the control (Table 5.3). It accounted for 4.5, 2.7, 2.6, and 2.4% of the total organic C in NPK, M, MNPK and control plots, respectively. Soil microbial biomass N was higher in the fertilized plots than in the control, but significantly so only in the NPK plots, where it represented 4.6% of the total N. Soil microbial biomass P was also significantly increased by NPK application. The soil microbial biomass to microbial biomass N ratio in the NPK plots was 7.6, while the MNPK, M and control plots had ratios of 10.5, 9.4 and 9.2, respectively.

Table 5.3 Effect of residual manure and NPK fertilizers on soil microbial biomass, turnover and numbers under long-term crop rotation*.

Treatment	SMB-C	SMB-N	SMB-P	Turnover rate SMB-C	Turnover rate SMB-N	Bacteria ($x10^5$)	Actinomycetes ($x10^4$)	Fungi ($x10^3$)
	I------ mg kg^{-1}		------I	I--- yr^{-1}	---I	I------ g^{-1} dry soil		------I
O	140^b	15.2^b	0.08^b	1.49	2.56	6.98^a	5.05^a	8.05^b
M	236^a	25.2^{ab}	0.09^b	1.91	2.10	7.46^a	4.06^a	5.81^b
NPK	248^a	32.5^a	0.49^a	2.35	1.78	10.9^a	4.75^a	27.5^a
MNPK	246^a	23.5^{ab}	0.07^b	1.97	1.34	8.14^a	2.89^a	11.7^b

*Means in columns followed by the same letter do not differ significantly according to Duncan's multiple range test (P=0.05)

From these results it is evident that, although soil microbial biomass was increased by the fertilizers applied either singly or in combination, a relatively greater response occurred in the NPK treatment. Several previous studies (McGill *et al*., 1986; Kanazawa *et al*., 1988; Goyal *et al*., 1992; Goladi & Agbenin, 1997), have shown that soil microbial biomass is increased to a greater extent by freshly added manure than by inorganic amendments. Results in the present study indicate that residual manure may not be as effective in this regard as NPK fertilizers. The greater effectiveness of the NPK fertilizers may be attributed to higher rates of decomposability and mineralization of organic matter as evidenced by the relatively high microbial biomass turnover rate in the NPK plots than in other treatments. In a manner similar to total organic C and total N, turnover rate of the soil microbial biomass was increased whereas that of soil microbial biomass N was decreased as a result of NPK applications. The relatively high C turnover in the NPK treatment is an indication of enhanced microbial activity and greater microbial biomass.

Total organic C and total N levels in the manured plots were relatively high, but did not result in proportional biomass increases, consistent with the earlier reasoning that the organic matter in these plots was not as readily hydrolyzable as that in the NPK plots. Correlations between C input and biomass C and N were significant whereas those with total organic C and total N were not (Table 5.2), thus showing that the high C and N levels in manured plots were not reflected in the microbial biomass. The comparatively low biomass C to biomass N ratio in the NPK plots further indicates the presence of a relatively higher mineralizable fraction of soil organic matter in the NPK than in manured plots. A close relationship between biomass C to biomass N ratio and the mineralizable fraction of soil organic matter has been demonstrated by Paul & Voroney (1984).

Densities of bacteria and actinomycetes were not affected significantly by fertilization, but fungal populations were significantly the highest in the NPK plots. These results reflect differences in quality and decomposability of organic matter in the different plots. The significantly higher fungal population in the NPK plots and relatively higher correlation between C input and numbers of fungi imply a greater requirement for C by the fungi occupying the experimental site than by the other microbes.

5.3.4. Plant N and P concentration

Nitrogen content of both maize and field pea did not differ significantly between treatments (Figure 5.1) which is in conflict with the significant effects of organic and inorganic fertilizers on N concentration of plants that have previously been reported (Maskina *et al*., 1993; Murwira & Kirchman, 1993; Eghball & Power, 1999). However, significant differences were evident in P concentration. For both maize and field pea, P concentration was highest in the MNPK plots, and differed significantly from the M and control plots. P concentration in field pea, but not in maize, was significantly higher in the M and NPK plots than in the control. Fertilization with manure and NPK has been shown to result in higher P concentrations in crops (Eghball & Power, 1999; Warman & Cooper 2000). Compared to the maize crop, P concentrations in field pea in fertilized plots generally showed greater increases suggesting better utilization and response to soil P reserves by the pea crop. Leguminous crops are known for utilizing soil P reserves more effectively than non-leguminous crops (Salih *et al*., 1989; Matar *et al*., 1992).

5.3.5. Maize grain yield

Maize grain yield ranged from 1249 kg ha^{-1} in the control to 6735 kg ha^{-1} in the MNPK plots (Figure 5.2). Grain yield in the MNPK and NPK plots did not differ, but was significantly higher than in the M and control plots. Compared to the control, yield increases in the NPK and MNPK plots were 4934 kg ha^{-1} (395%) and 5486 kg ha^{-1} (439%), respectively. Yield in the M plots was 247% higher than in the control. These results show that maize yield was substantially increased by residual manure and NPK fertilizers. The response to NPK was, however, greater than to residual manure, suggesting that the nutrient requirement of maize may not have been fully satisfied by residual manure alone. Correlations between grain yield, soil microbial biomass C and N were significant (Table 5.2), consistent with previous observations and indicating that these biological parameters can be used as indicators of production sustainability.

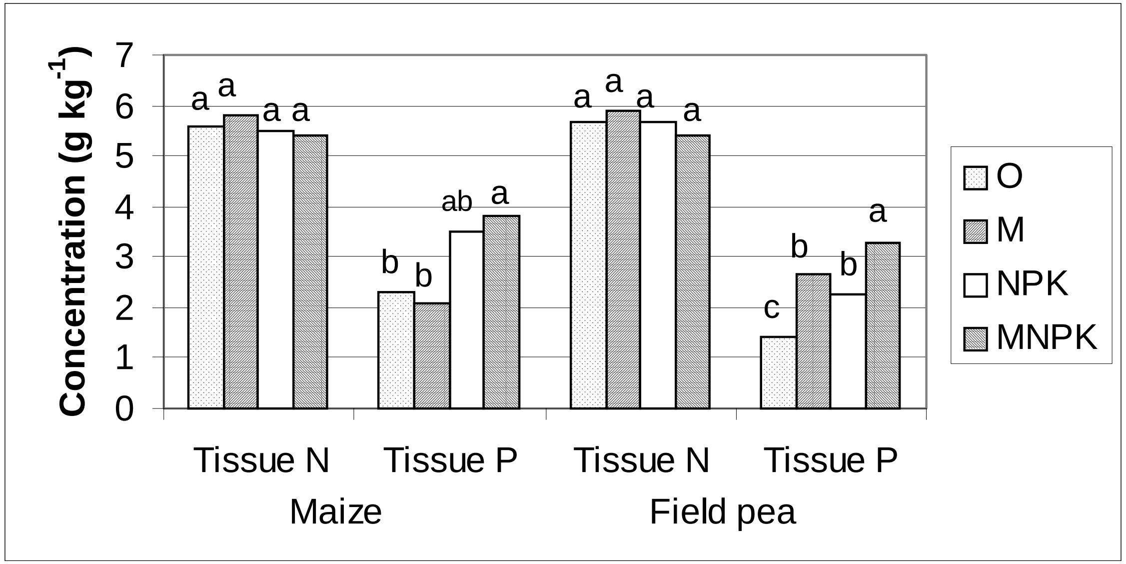

Figure 5.1 Tissue N and P concentrations of maize and field pea as influenced by residual manure and NPK fertilization under long-term crop rotation. [Means with the same letter within parameters do not differ significantly according to Duncan's multiple range test (P=0.05)].

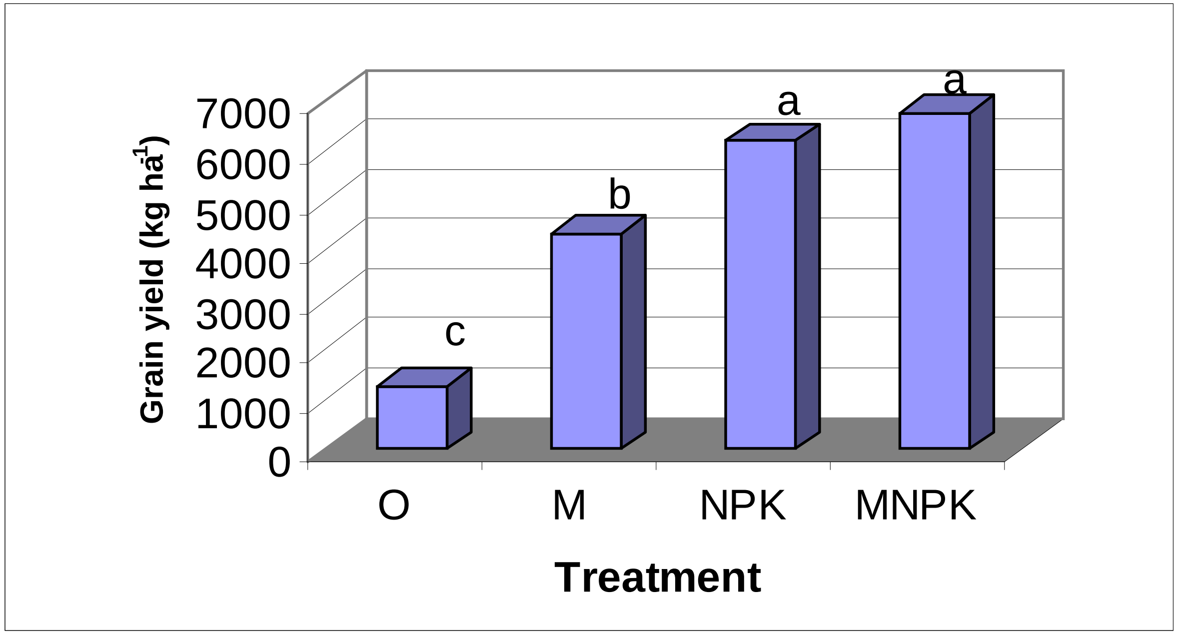

Figure 5.2 Effect of residual manure and NPK fertilizers on mean (1991-99) grain yield of maize under long-term crop rotation. [Means with the same letter do not differ significantly according to Duncan's multiple range test (P=0.05)].

5.4 Conclusion

The selected nutrients and microbial component of the soil and grain yield of maize were increased by residual manure alone or in combination with NPK fertilizers. However, increases in the soil microbial component were not proportional to the relatively high C, N and P levels in these treatments. Responses were generally greater in the NPK treatment. This suggests that increases in nutrient levels by a particular management system such as manure addition may not necessarily imply effective phyto-availability of the nutrients.

Compared to the NPK treatment, maize grain yield and many of the soil microbial properties in the MNPK treatment were either lower or insignificant. Possibly, the nutrients added to soil by the mineral fertilizer might have been incorporated into the organic reservoir, suggesting that the effectiveness of inorganic fertilizers may be lowered when used together with organic amendments.

The relatively greater increase in soil microbial component in the NPK treatment was closely related to influences of freshly added organic material. The decomposition and turnover rate of the organic material in the NPK treatment appeared to be higher than in other treatments. This illustrates that the efficacy of soil organic matter is a function of its quality and decomposability, not its quantity. It also supports the suggestion by Insam *et al.* (1996) that in soils with limited C but good nutrient supply, the lack of C may be compensated for by a higher turnover rate of the organic material.

5.5. References

Biederbeck, V.O., Janzen, H.H., Campbell, C.A. & Zenter, R.P. 1994. Labile soil organic matter as influenced by cropping practices in an arid environment. *Soil Biol. Biochem*. 26:1647-1656.

Christensen, B.T. 1988. Effects of animal manure and mineral fertilizers on the total carbon and nitrogen contents of soil size fractions. *Biol. Fertil. Soils* 5:304-307.

Eghball, B. & Power, J.F. 1999. Phosphorus- and nitrogen-based manure and compost applications: Crop production and soil phosphorus. *Soil Sci. Soc. Am. J*. 63:895-901.

Goladi, J.T. & Agbenin, J.O. 1997. The cation exchange properties and microbial carbon, nitrogen and phosphorus in savanna Alfisol under continuous cultivation. *J. Sci. Food Agric*. 75:412-418.

Goyal, S., Mishra, M.M., Hooda, I.S. & Singh, R. 1992. Organic matter-microbial biomass relationships in field experiments under tropical conditions: Effects of inorganic fertilization and organic amendments. *Soil Biol. Biochem*. 24:1081-1084.

Hauser, S. 1992. Estimation of symbiotically fixed nitrogen using extended difference methods. In: K. Mulongy, M. Gueye & D.S.C. Spencer (eds.), Biological nitrogen fixation and sustainability of tropical agriculture, pp. 309-321. John Wiley and Sons, Chichester.

Insam, H., Hutchinson, T.C. & Reber, H.H. 1996. Effects of heavy metal stress on the metabolic quotient of the soil microflora. *Soil Biol. Biochem*. 28:691-694.

Jarvis, S.C., Stockdale, E.A., Shepherd, M.A. & Powlson, D.S. 1996. Nitrogen mineralization in temperate agricultural soils: Processes and measurement. *Adv. Agron*. 57:187-235

Kanazawa, S., Asakawa, S. & Takai, Y. 1988. Effect of fertilizer and manure application on microbial numbers, biomass and enzyme activities in volcanic ash soils. I. Microbial numbers and biomass carbon. *Soil Sci. Plant Nutr*. 34:429-439.

Maskina, M.S., Power, J.F., Doran, J.W. & Wilhelm, W.W. 1993. Residual effects of no-till crop residues on corn yield and nitrogen uptake. *Soil Sci. Soc. Am. J*. 57:1555-1560.

Matar, A., Torrent, J. & Ryan, J. 1992. Soil and fertilizer phosphorus and crop responses in the dryland Mediterranean zone. *Adv. Soil Sci*. 18:82-146.

McCullum, R.E. 1991. Buildup and decline in soil phosphorus: 30-yr trends on a Typic Umbraquult. *Agron. J*. 83:77-85.

McGill, W.B., Cannon, K.R., Robertson, T.A. & Cook, F.D. 1986. Dynamics of soil microbial biomass and water soluble organic carbon in Breton L. after 50 years of cropping to two rotations. *Can J. Soil Sci*. 66:1-19.

Meek, B., Graham, L. & Donovan, T. 1982. Long-term effects of manure on soil nitrogen, phosphorus, potassium, sodium, organic matter and water infiltration rate. *Soil Sci. Soc. Am. J*. 46:1014-1019.

Murwira, H.K. & Kirchmann, H. 1993. Nitrogen dynamics and maize growth in a Zimbabwean sandy soil under manure fertilization. *Commun. Soil Sci. Plant Anal*. 24:2343-2359.

N'Dayegamiye, A., Royer, R. & Audesse, P. 1997. Nitrogen mineralization and availability in manure composts from Quebec biological farms. *Can J. Soil Sci*. 77:345-350.

Paul, E.A. & Voroney, R.P. 1984. Field interpretation of microbial biomass activity measurements. In: M.J. King & C.A. Reddy (eds.), Current perspectives in microbial ecology, pp. 509-514. Am. Soc. Microbiol., Washington D.C.

Salih, H.M., Yahya, A.I., Abdul-Rahem, A.M. & Munam, B.H. 1989. Availability of phosphorus in a calcareous soil treated with rock phosphate or super-phosphate as affected by phosphate-dissolving fungi. *Plant Soil* 120:181-185.

Schjonning, P., Christensen, B.T. & Carstensen, B. 1994. Physical and chemical properties of a sandy loam receiving animal manure, mineral fertilizer or no fertilizer for 90 years. *Euro. J. Soil Sci*. 45:257-268.

Schroder, E.C. 1992. Improvement of the phaseolus/*Rhizobium* symbiosis, with particular reference to the Caribbean region. In: K. Mulongy, M. Gueye & D.S.C. Spencer (eds.), Biological nitrogen fixation and sustainability of tropical agriculture, pp. 79-95. John Wiley and Sons, Chichester.

Sharpley, A.N., Smith, S.J. & Bain, W.R. 1993. Nitrogen and phosphorus fate from long-term poultry litter applications to Oklahoman soils. *Soil Sci. Soc. Am. J*. 57:1131-1137.

Sharpley, A.N. & Smith, S.J. 1995. Nitrogen and phosphorus forms in soils receiving manure. *Soil Sci*. 159:253-258.

Smith, J.H. & Peterson, J.R. 1982. Recycling of nitrogen through land application of agricultural, food processing and municipal wastes. Agronomy 22, ASA-CSSA-SSSA, Madison, WI.

Soil Science Society of South Africa. 1990. Handbook of standard soil testing methods for advisory purposes. SSSSA, Pretoria.

Sommerfeldt, T.G., Chang, C. & Entz, T. 1988. Long-term annual manure applications increase soil organic matter and nitrogen, and decrease carbon to nitrogen ratio. *Soil Sci. Soc. Am. J*. 52:1668-1672.

Sullivan, D.M., Fransen, S.C., Bray, A.I. & Cogger, C.G. 1998. Fertilizer nitrogen replacement value of food residues composted with yard trimmings, paper or wood wastes. *Compost Sci. Util*. 6:6-18.

Warman, P.R. 1986a. The effect of fertilizer, chicken manure and dairy manure on timothy yield, tissue composition and soil fertility. *Agric. Wastes* 18:289-298.

Warman, P.R. 1986b. Effects of fertilizer, pig manure and sewage sludge on timothy and soils. *J. Environ. Qual*. 15:95-100.

Warman, P.R. & Cooper, J.M. 2000. Fertilization of a mixed forage crop with fresh and composted chicken manure and NPK fertilizer: Effects on dry matter yield and soil and tissue N, P and K. *Can. J. Soil Sci*. 80:337-344.

Chapter 6

Effect of supplemental N and K on the residual value of manure and P to soil chemical properties, microbial components and maize yield under long-term crop rotation

6.1 Introduction

The enhancing effect of residual manure on microbial activity and crop growth is known to decline gradually since most of the nutrients contained in the manure diminish over time (Bosatta & Agren, 1985). Because of the high requirement for N by both microorganisms and crop plants, the decrease in N content, in particular, may take place at a relatively fast rate. This, in turn, causes the C:N ratio of the manure to increase, thereby further slowing down its mineralization. Though to a lesser extent, K contents of the manure may also decline and influence the mineralization process. Supplemental application of N and K fertilizers could, therefore, be essential in enhancing the mineralization of residual manure and improving its effectiveness to microorganisms and crop plants.

In many intensive agricultural systems, prolonged P fertilizer additions have resulted in a widespread build-up of soil P levels that are considered excessive from a microbiological and agronomic perspective (Stewart & Sharpley, 1987; Maroko *et al*., 1999). Most soils along the Atlantic seaboard, for example, are highly saturated with P as a result of decades of P fertilization in excess of removal (McCullum, 1991). High soil P levels exceeding 200 mg kg^{-1} due to continued superphosphate application were also observed in a long-term experimental field at Pretoria, South Africa (Nel *et al*., 1996). Such excessive P levels not only are detrimental to crops and microorganisms, but may also be of environmental concern (Sims *et al*., 1998; Schoumans & Groendijk, 1999) and require greater management efforts (Paulter & Sims, 2000).

One means of mitigating the adverse effect of excessive P levels on soil microorganisms and crop plants is through application of supplemental N, K and/or manure. These fertilizers can increase yield, thereby resulting in greater removal of P in harvested produce or enhanced P fixation in the soil, thus causing chemical decline of the excess P levels (McCullum, 1991; Xie *et al*., 1995; Iyamuremye & Dick, 1996; Hao *et al*., 2000). However, information in this regard is very limited and mostly based on either short-term studies or laboratory investigations. The aim of this study was to investigate the effect of supplemental N and K fertilizer application on the residual value of manure and P to soil chemical properties, microbial components and maize yield under long-term crop rotation.

6.2 Materials and methods

From the long-term field experiment described previously, the following two sets of treatments were selected: 1) Manure (M), manure + nitrogen (MN), manure + potassium (MK), manure + nitrogen + potassium (MNK), and 2) Control (O), phosphorus (P), nitrogen + phosphorus (NP), phosphorus + potassium (PK), manure + phosphorus (MP). Soil and plant sampling and analysis were done as in the previous studies. Data from the two sets of treatments were separately subjected to statistical analysis and variances between treatments were compared using Duncan’s multiple range test.

6.3 Results and discussion

6.3.1 Effect of supplemental N and K on residual manure

6.3.1.1 Soil chemical properties

Supplemental N applied to residual manure caused lowering of the soil pH (Table 6.1). pH in the MN and MNK treatments was significantly lower than in the M treatment by 1.59 and 1.53 units, respectively. Several researchers (Warren & Fontenno, 1993; Iyamuremye & Dick, 1996; Cooper & Warman, 1997; Eghball, 1999) have found manure to be effective in increasing the pH of acid soils. Results of the present study suggest that soil acidity caused by fertilizer N may not be counteracted by residual manure.

Table 6.1 Soil chemical properties as influenced by residual manure supplemented with N and K fertilizers under long-term crop rotation*.

Treatment	pH	TOC	TN	AP	K^+	Ca^{2+}	Mg^{2+}	Na^+
		I----------	----------	----------	mg kg^{-1}	----------	----------	----------I
M	6.25[a]	8885[a]	1051[ab]	58.8[a]	42.3[c]	873.8[a]	272.3[a]	14.75[c]
MN	4.66[b]	9075[a]	1000[bc]	63.9[a]	29.8[c]	769.3[a]	285.0[a]	17.93[b]
MK	6.07[a]	7380[a]	1195[a]	59.8[a]	304.8[a]	811.0[a]	224.0[b]	17.53[b]
MNK	4.72[b]	7658[a]	878[c]	53.5[a]	231.5[b]	786.0[a]	219.0[b]	26.93[a]

*Means in columns followed by the same letter do not differ significantly according to Duncan's multiple range range test (P=0.05).

Total organic C did not differ significantly between treatments. Total N in the MNK treatment was significantly lower than in the MK and control treatments, but did not differ from the MN treatment. The increase in total N in the MK treatment could be due to relatively high organic matter mineralization while the decrease in the MNK treatment is largely attributable to crop removal. The C:N ratio in the MK treatment was on average 2.57 lower than in other treatments, thus showing the relatively high organic matter decomposition in the MK treatment. Available P in the residual manure remained high and unaffected by supplemental N and K applications or by crop removal, suggesting high reserves and replenishment of P from residual manure.

Soil K^+ levels in the MK and MNK treatments were significantly higher than in the MN and M treatments, the levels in the MK treatment being significantly the highest. Supplemental K applied to residual manure has therefore resulted in increased soil K^+ levels. Concomitant removal of K^+, possibly in harvested produce, were relatively high in the MNK treatment. Despite reports that K^+ levels may be increased as a result of the use of ammoniacal fertilizers and lowering of the soil pH (Sparks, 1987; Rahmatullah & Mengel, 2000), K^+ levels in the MN treatment were about 30%, albeit not significantly, lower than in the M treatment. This could be due to relatively low microbial activity in the MN treatment and emphasizes the importance of microbial decomposition in the release of K^+ from organic materials such as manure.

Ca^{2+} levels were unaffected by supplemental N applications. However, Mg^{2+} levels decreased as a result of supplemental K applied to residual manure. The decrease might have been due either to crop uptake or preferential adsorption of Mg^{2+} on organic matter exchange sites. The affinity of divalent over monovalent cations by organic colloids has been documented (Jardine & Sparks, 1984b). Levels of Na^+ in the MNK treatment were the highest followed by the MN and MK treatments, and lowest in the M treatment. This indicates enhanced release of Na^+ from soil reserves as a result of supplemental N and K applications to residual manure.

6.3.1.2 Soil microbial biomass and numbers

Soil microbial biomass C content in the MNK and MK treatments was significantly higher than in the MN treatment but did not differ from the M treatment (Table 6.2). Soil microbial biomass C represented 2.1-3.7% of the total organic C, the highest being in the MNK and the lowest in the MN treatment. Soil microbial biomass C was thus decreased by supplemental N and increased by supplemental K applied to residual manure. Soil microbial biomass N showed the same trend as soil microbial biomass C. The decrease in biomass C and N in the MN treatment is most likely due to low soil pH. Soil microbial biomass P was not influenced by supplemental N and K applications.

Microbial density in treatments supplemented with fertilizer K generally was higher than in non-K treatments which is consistent with differences in soil microbial biomass. The high fungal than bacterial density in the MN treatment could be ascribed to the relatively higher tolerance to soil acidity of fungi.

6.3.1.3 Maize grain yield

Maize grain yield in the MNK treatment was the highest with an increase of more than 45% over the M treatment (Figure 6.1). Yield in the MN treatment was the lowest. Hence, the residual effect of manure on maize grain yield was decreased by supplemental N applications, probably due to lowering of the soil pH.

Table 6.2 Soil microbial biomass and numbers as influenced by residual manure supplemented with N and K fertilizers under long-term crop rotation*.

Treatment	SMB-C	SMB-N	SMB-P	Bacteria ($x10^5$)	Actinomycetes ($x10^4$)	Fungi ($x10^3$)
	I-------------- mg kg^{-1}-----------I			I--------------- g^{-1} dry soil ------------I		
M	236.0^{ab}	25.2^{a}	0.09^{a}	7.46^{b}	4.06^{a}	5.81^{b}
MN	186.8^{b}	11.1^{b}	0.06^{a}	7.49^{b}	4.21^{a}	15.34^{a}
MK	274.0^{a}	19.9^{a}	0.07^{a}	17.4^{a}	9.21^{a}	16.09^{a}
MNK	270.8^{a}	26.4^{a}	0.09^{a}	15.72^{a}	9.36^{a}	19.38^{a}

*Means in columns followed by the same letter do not differ significantly according to Duncan's multiple range test (P=0.05).

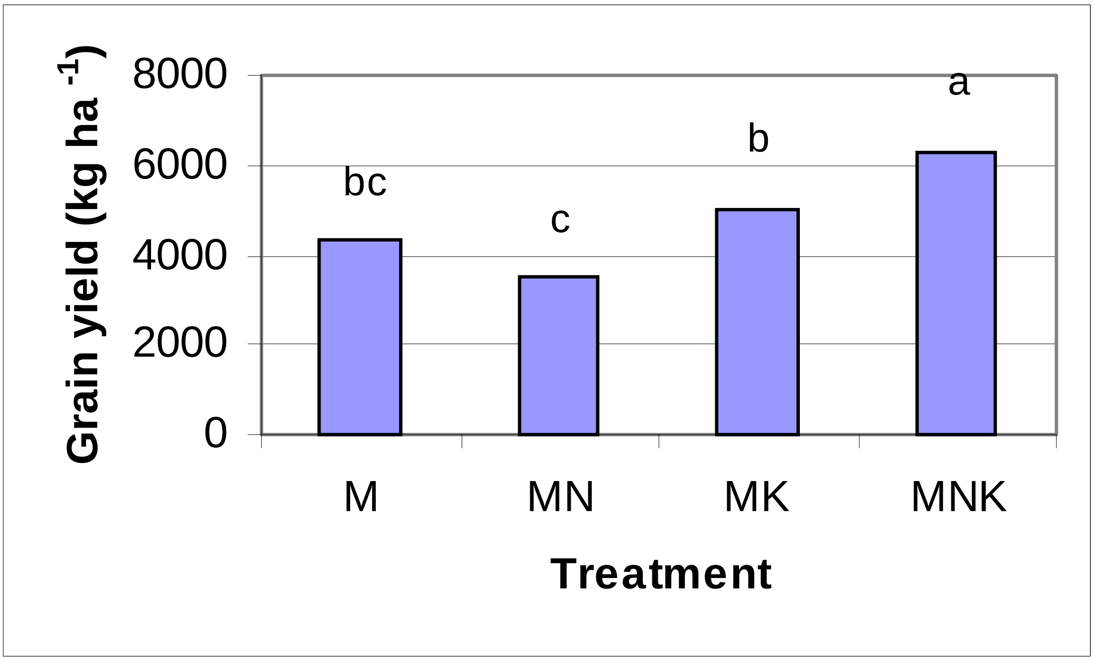

Figure 6.1 Mean (1991-99) grain yield of maize under long-term crop rotation as influenced by residual manure supplemented with N and K fertilizers. [Means with the same letter do not differ significantly according to Duncan's multiple range test (P=0.05)].

6.3.2 Effect of supplemental N, K and manure on residual P fertilizer

6.3.2.1 Soil chemical properties

pH of the residual P treatment and P treatment supplemented with manure did not differ significantly from the control (Table 6.3). As would be expected, supplementing the residual P treatment with N fertilizer decreased the pH to the lowest level of all treatments.

Total organic C in the MP treatment was more than twice as high as in the P treatment and 42, 49 and 69% higher than in the control, KP and NP treatments, respectively. The low total organic C contents in the P treatment might be due to depressed plant growth and thus low organic matter input in these plots. Despite fertilizer N application, total N level in the NP treatment was low, indicating a relatively high leaching loss. Compared to the residual P treatment, supplemental K application resulted in a significant decrease in available P levels. Apparently this resulted in better plant growth and high organic matter inputs, hence the higher total organic C level in the KP treatment. The relatively high levels of total organic C, total N and available P in the MP treatment are attributable to effects of residual manure.

K^+ level in the KP treatment was significantly the highest, obviously as a result of fertilizer K application. Levels in the P, NP and MP treatments were about half that of the KP treatment and significantly lower than in the control. Application of N and P fertilizers over the years has therefore resulted in K-deficient soils, in agreement with the findings of Nel *et al*. (1996).

Ca^{2+} and Mg^{2+} levels in the MP treatment were significantly the highest, followed by the KP treatment. Na^+ levels in the MP and KP treatments were also relatively higher than in other treatments. Compared to the P and NP treatments, cation contents in the control were generally higher, probably as a result of less removal in harvested produce. The increase in Ca^{2+}, Mg^{2+} and Na^+ levels in the MP treatment is due to addition of these cations with manure, whereas the increase in the KP treatment may be attributed to dis-

Table 6.3 Soil chemical property as influenced by residual P supplemented with N, K or manure under long-term crop rotation*.

Treatment	pH	TOC	TN	AP	K^+	Ca^{2+}	Mg^{2+}	Na^+
		I----------	----------	---------- mg kg^{-1}	----------	----------	----------	----------I
O	6.35[a]	5841[b]	591[c]	1.71[d]	73.8[b]	795[c]	392[b]	19.3[ab]
P	6.13[ab]	3777[c]	659[bc]	76.8[b]	34.0[d]	648[d]	261[c]	18.5[ab]
NP	5.59[c]	4927[bc]	624[c]	80.5[b]	31.3[d]	544[d]	210[d]	15.0[b]
KP	6.09[b]	5570[b]	772[b]	54.6[c]	218.8[a]	958[b]	396[b]	22.8[a]
MP	6.18[ab]	8310[a]	969[a]	104.2[a]	42.8[c]	1247[a]	489[a]	22.0[a]

*Means in columns followed by the same letter do not differ significantly according to Duncan's multiple range test (P=0.05).

placement by fertilizer K^+ and release from clay minerals of Ca^{2+}, Mg^{2+} and Na^+. The preference by the exchange complex for K^+ over Ca^{2+}, Mg^{2+} and Na^+ has been demonstrated by a number of researchers (Jensen, 1973; Udo, 1978; Jardine & Sparks, 1984a,b). The released Ca^{2+} and Mg^{2+} ions could possibly have complexed with P and resulted in its precipitation, thus partly explaining the significant decrease in available P levels in the KP treatment.

6.3.2.2 Soil microbial biomass and numbers

Soil microbial biomass C, N and P were the highest in the KP and MP treatments, although not always significantly higher than in the other treatments. (Table 6.4). Microbial density, particularly fungal numbers, was similarly increased by manure and K applications. Supplemental manure and K applied to residual P have thus resulted in increased microbial biomass due, most likely, to relatively high organic C and nutrient levels.

6.3.2.3 Tissue P concentration and maize grain yield

Tissue P concentration in maize did not differ significantly between treatments (Figure 6.2). In the pea crop, tissue P concentration in fertilized treatments was significantly higher than in the control. Supplemental manure and N applied to the residual P treatment resulted in tissue P concentrations significantly higher than in the P treatment. Tissue P concentration in the KP treatment did not differ significantly from the P treatment. These results confirm that the effect of supplemental K in reducing the excess P levels was not due to enhanced uptake of P by plants but rather to K increasing the complexation and precipitation of available P in the soil.

Grain yield of maize in the control, P and NP treatments did not differ, but was substantially increased by supplemental K and manure (Figure 6.3), suggesting that the adverse effect of excess P was decreased as a result of the supplemental fertilizer applications.

Table 6.4 Soil microbial biomass and numbers as influenced by residual P supplemented with N, K or manure under long-term crop rotation*.

Treatment	SMB-C	SMB-N	SMB-P	Bacteria ($x10^5$)	Actinomycetes ($x10^4$)	Fungi ($x10^3$)
	I------------- mg kg^{-1}	------------I		I----------------- g^{-1} dry soil	-----------	I
O	140[c]	15.2[ab]	0.08[b]	6.98[a]	5.05[a]	8.05[b]
P	333[ab]	10.2[bc]	0.06[b]	7.75[a]	3.50[a]	6.18[b]
NP	208[bc]	8.75[c]	0.12[b]	6.10[a]	4.15[a]	8.7[b]
KP	389[a]	17.4[a]	0.38[a]	8.55[a]	6.23[a]	14.4[a]
MP	371[a]	21.1[a]	0.39[a]	7.89[a]	6.35[a]	12.6[a]

*Means in columns followed by the same letter do not differ significantly according to Duncan's multiple range test (P=0.05).

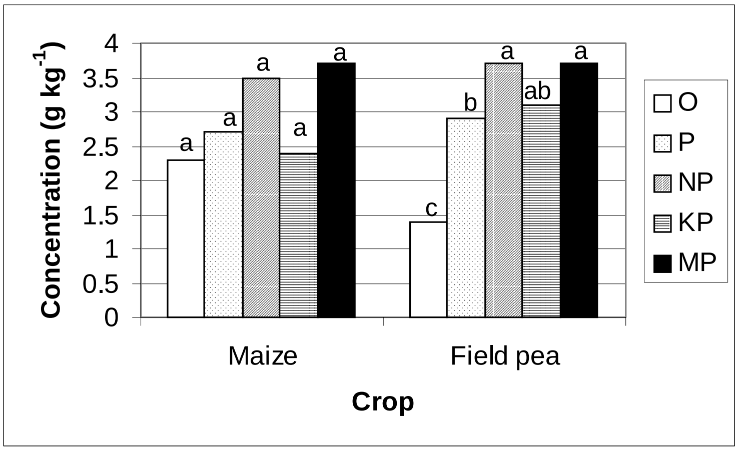

Figure 6.2 Tissue P concentration of maize and field pea under long-term crop rotation as influenced by residual P supplemented with N, K or manure. [Means with the same letter within crops do not differ significantly according to Duncan's multiple rang test (P=0.05)].

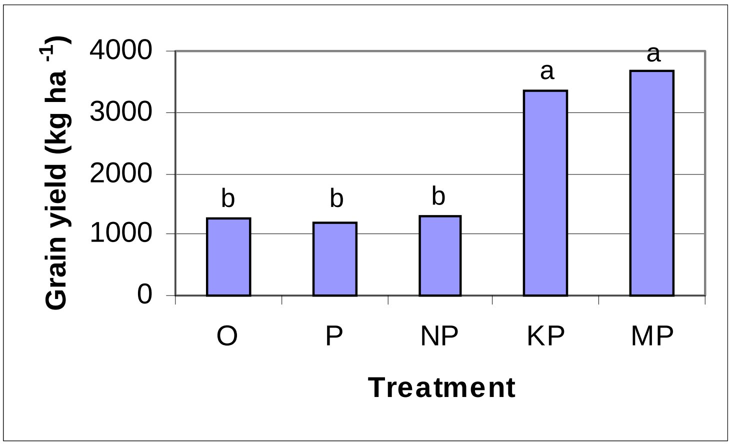

Figure 6.3 Mean (1991-99) grain yield of maize under long-term crop rotation as influenced by residual P supplemented with N, K and manure. [Means with the same letter do not differ significantly according to Duncan's multiple range test (P=0.05)].

6.4 Conclusion

The benefit of residual manure to microbial properties and crop yield was reduced by application of supplemental N fertilizer and remained unaffected by application of supplemental K fertilizer. The decrease by supplemental N was largely due to the resultant soil acidity caused by the N fertilizer. Supplementing residual manure with N fertilizer may therefore not be advisable unless coupled with measures that increase soil pH. The lack of response to supplemental K suggests that K^+ levels in the residual manure were still high and sufficient for microbial and crop requirements.

The depressive effect of excess soil P on soil microbial properties and crop yield was exacerbated by supplemental N fertilizer and mitigated by supplemental manure and K fertilizer applied to residual P. Supplemental manure resulted in higher yields and greater P removal by plants, hence lowering the excess soil P levels. The role of supplemental K, on the other hand, appeared to be rather indirect, involving exchange reactions with, and accelerated release from clay minerals of, Ca^{2+} and Mg^{2+} that subsequently resulted in complexation and loss through precipitation of the excess P from soil solution. The significant decrease in available P levels by supplemental K fertilizer indicates that K-fertilization may serve as a viable alternative to ameliorate soils with excess P levels.

6.5 References

Bosatta, E. & Agren, G.I. 1985. Theoretical analysis of decomposition of heterogeneous substrates. *Soil Biol. Biochem*. 17:601-610.

Cooper, J.M. & Warman, P.R. 1997. Effects of three fertility amendments on soil dehydrogenase activity, organic carbon and pH. *Can. J. Soil Sci*. 77:281-283.

Eghball, B. 1999. Liming effects of beef cattle feedlot manure and compost. *Commun. Soil Sci. Plant Anal*. 30:2563-2570.

Hao, X., Cho, C.M. & Racz, G.J. 2000. Chemical retardation of phosphate diffusion in simulated acid soil amended with lignosulfonate. *Can. J. Soil Sci*. 80:289-299.

Iyamuremye, F. & Dick, R.P. 1996. Organic amendments and phosphorus sorption by soils. *Adv. Agron*. 56:139-185.

Jardine, P.M. & Sparks, D.L. 1984a. Potassium-calcium exchange in a multi-reactive soil system. I. Kinetics. *Soil Sci. Soc. Am. J*. 47:39-45.

Jardine, P.M. & Sparks, D.L. 1984b. Potassium-calcium exchange in a multi-reactive soil system. II. Thermodynamics. *Soil Sci. Soc. Am. J*. 47:45-50.

Jensen, H.E. 1973. Potassium-calcium exchange equilibria on a montmorillonite and a kaolinite clay. I. A test on the Argersinger thermodynamic approach. *Agrochemica*, 17:181-190.

Maroko, J.B., Buresh, R.J. & Smithson, P.C. 1999. Soil phosphorus fractions in unfertilized fallow-maize systems on two tropical soils. *Soil Sci. Soc. Am. J*. 63:320-326.

McCullum, R.E. 1991. Buildup and decline in soil phosphorus: 30-year trends on a Typic Umprabuult. *Agron. J*. 83:77-85.

Nel, P.C., Barnard, R.O., Steynberg, R.E., De Beer, J.M. & Groeneveld, H.T. 1996. Trends in maize grain yields in a long-term fertilizer trial. *Field Crops Res*. 47:53-64.

Pautler, M.C. & Sims, J.T. 2000. Relationship between soil test phosphorus, soluble phosphorus and phosphorus saturation in Delaware soils. *Soil Sci. Soc. Am. J*. 64:765-773.

Rahmatullah & Mengel, K. 2000. Potassium release from mineral structures by H^+ ion resin. *Geoderma* 96:291-305.

Schoumans, O.F., & Groendijk, P. 1999. Modeling soil phosphorus levels and phosphorus leaching from agricultural land in the Netherlands. *J. Environ. Qual.* 29: 111-116.

Sims, J.T., Simard, R.R. & Joern, B.C. 1998. Phosphorus losses in agricultural drainage: Historical perspective and current research. *J. Environ. Qual.* 27:277-293.

Sparks, D.L. 1987. Potassium dynamics in soils. *Adv. Soil Sci.* 6:1-63.

Stewart, J.W.B. & Sharpley, A.N. 1987. Controls on dynamics of soil and fertilizer phosphorus and sulfur. pp. 101-121. Soil Sci. Soc. Am., Spec. Publ. No. 19. Madison, WI.

Udo, E.J. 1978. Thermodynamics of potassium-calcium and magnesium-calcium exchange reactions on a kaolinitic soil clay. *Soil Sci. Soc. Am. J.* 42:556-560.

Warren, S.L. & Fonteno, W.C. 1993. Changes in physical and chemical properties of a loamy sand soil when amended with composted poultry litter. *J. Environ. Hortic.* 11: 186-190.

Xie, X.H., Mackenzie, A.F., Xie, R.J., Fyles, J.W. & O'Halloran, I.P. 1995. Effects of ammonium lignosulphonate and diammonium phosphate on soil organic carbon, soil phosphorus fractions and phosphorus uptake by corn. *Can. J. Soil Sci.* 75:233-238.

Chapter 7
Summary and general conclusion

Management-induced degradation of productive agricultural land is one of the most pressing concerns threatening the sustainability of agroecosystems. Consequently, there is a need to develop management systems that balance the demands and priorities for greater food production with those that maintain ecological stability and preserve the natural resource base. This in turn necessitates a better understanding of the impact of land management on quality and productive capacity of soils. Since soil quality is largely a function of chemical and microbial properties such as pH, soil organic matter, nutrient supplying capacity, microbial activity and soil fauna and flora, assessment of these parameters is essential in determining the sustainability and effect on soil quality of land management systems.

In the present study, impacts and changes in quality and productive capacity of the soil in response to different management systems could be correlated with various chemical and microbial parameters. Long-term manure addition under legume-based crop rotation improved the fertility level and microbial component of soil and yield of maize, thus demonstrating the positive impact of the practice on quality and productive capacity of the soil. The most striking observation in this regard was the persistent effect of the manure nearly eight years after application had been discontinued. In a warm climate like Pretoria, the decomposition and loss of soil organic matter is expected to be high. The substantial residual effect observed in the present study therefore illustrates the recalcitrance and stability of manure-derived organic matter and its potential benefit to soil quality and productive capacity in the long-term.

It was also demonstrated that application of NPK fertilizers in a balanced manner and at recommended rates enhanced productivity and did not impact unfavourably on quality of the soil. This implies that the current deterioration in quality and productive capacity of soils may be reversed even with conventional management practices such as the use of inorganic fertilizers. Compared to residual manure, balanced NPK fertilizer treatments contained lower C and nutrient levels but resulted in relatively high increases in soil microbial content and crop yield. These disproportionate increases were largely due to differences in quality and decomposability of organic materials. From the comparatively higher turnover rate of organic C and microbial biomass in the NPK than in the residual manure treatment, it was evident that the former contained a greater labile organic fraction. These results indicate that management systems not only determine C input and persistence but also the quality of soil organic matter. The results also emphasize the importance of the composition of soil organic matter rather than the total amount, in the maintenance of soil quality and productive capacity. In other words, a soil with high soil organic matter and nutrients, most of which are inert as in the residual manure treatment in the present study, may be less productive than a soil with comparatively low but labile levels, as in the NPK-fertilized soil. Lower soil organic matter and nutrient levels that may be noticed in continuously NPK-fertilized soils therefore do not necessarily imply loss of quality and productive capacity of the soils.

The residual value of manure to soil microbial components and crop yield was not affected by application of supplemental inorganic fertilizers. On the contrary, residual manure lowered the efficiency of the inorganic fertilizers, probably due to incorporation of the nutrients into the organic reservoir. This stresses the need for synchronizing nutrient release and availability in the soil with demand for, and uptake by, crop plants when inorganic fertilizers are used together with organic amendments.

Prolonged P fertilizer additions can result in a considerable build-up of soil P that may be detrimental to plant growth and microbial activity. In the present study, the depressive effect could be mitigated by supplemental manure application which enhanced removal of the excess P level by crops, or by supplemental K application which facilitated the conversion of P to unavailable forms. The decline in available P level by supplemental K application was much greater than by supplemental manure, suggesting that the former may serve as a viable alternative for ameliorating the widespread problem of excess P levels in many soils.

Finally, the persistence for many years of residual manure and P effects observed in the present study warrants further studies aimed at identifying and fractionating the different components and pools as well as their distribution in relation to soil depth. Such an investigation, for which the Pretoria long-term field experiment is particularly suited, would provide a greater insight into the fate of the applied nutrients and the impact of prolonged application of the fertilizers on soil and water resources. Concomitantly, it could direct the more agronomic-oriented scope of the experiment towards a broader approach of addressing environmental concerns as well. Because of the absence of a continuously monocropped control, future studies on the contribution of the long-term crop rotation practice to the quality and productive capacity of the soil may necessitate use of tracer techniques. To maintain the overall value and significance of the Pretoria long-term experiment, archiving of plant and soil samples, which unfortunately had so far been neglected, should also be given due consideration.