INFLUENCE OF LONG-TERM WHEAT RESIDUE MANAGEMENT ON SOME FERTILITY INDICATORS OF AN AVALON SOIL AT BETHLEHEM

by

ELMARIE KOTZÉ

A dissertation submitted in accordance
with the requirements for the
Magister Scientiae degree
in the
Department of Soil, Crop and Climate Sciences
Faculty of Natural and Agricultural Sciences
University of the Free State
Bloemfontein

November 2004

Supervisor: Prof C C Du Preez

TABLE OF CONTENTS

DECLARATION

I declare that the dissertation hereby submitted by me for the Master of Science degree at the University of the Free State is my own independent work and has not previously been submitted by me at another university / faculty. I furthermore cede copyright of the dissertation in favour of the University of the Free State.

Signature: ……………………………………………….. Date: ………………….

ABSTRACT

Influence of long-term wheat residue management on some fertility indicators of an Avalon soil at Bethlehem

Awareness of the environmental aspects of soil quality and crop production has been increasing in recent years, which has led to renewed interest in crop residues as a source of soil organic matter and nutrients for crops. Crop residue management is known to both directly or indirectly affect soil quality and therefore soil fertility. Some residue management practices have been tested since 1979 in a long-term wheat trial at the ARC-Small Grain Institute near Bethlehem in the Eastern Free State on an Avalon soil.

This trial offered an opportunity to study the influences of wheat residue management practices on some soil fertility indicators and to establish whether differences in wheat grain yield could be attributed to changes in the soil fertility indicators. The treatments that were applied are two methods of straw disposal (burned and unburned) x three methods of tillage (ploughing, stubble mulch and no tillage) x two methods of weed control (mechanical and chemical). Soil samples were collected in 1999 at depth intervals of 0-50, 50-100, 100-150, 150-250, 250-350 and 350-450 mm and analyzed for various soil fertility indicators, *viz.* organic C and total N as indices of organic matter. In addition the pH, P, K, Ca, Mg, Na, Cu, Fe, Mn and Zn were also determined.

The different tillage practices had a larger effect on organic matter than either straw burning or weeding method, especially in the upper 100 mm soil. No tillage and to a lesser extent mulch tillage, especially when combined with chemical weeding were more beneficial to soil organic matter than when ploughing was combined with mechanical weeding. Soil acidification seems to be retarded by mulch or no tillage when combined with chemical weeding. The burning of wheat residues increased pH significantly compared to no burning. It was found that the content of P, K, Cu, Fe, Mn and Zn were increased with straw burning when compared to no burning. No tillage and to a lesser extent also mulch tillage resulted in an accumulation of P, K, Ca, Mg, Cu, Fe, Mn and Zn in the upper 150 mm soil compared to mouldboard ploughing.

Grain yield does not coincide with the higher organic matter and lower acidity resulting from mulch and no tillage. A reason for this may be that the nutrients accumulated in the upper 150 mm soil with these two tillage practices, are not always available for plant uptake. This aspect warrants further investigation.

Keywords: Organic matter, plant nutrients, soil acidity, straw disposal, tillage practices, weed control methods.

UITTREKSEL

Invloed van langtermyn koringrestebestuur op sekere vrugbaarheidsindikatore van 'n Avalongrond by Bethlehem

Bewustheid van die omgewingsaspekte van grondkwaliteit en gewasproduksie het toegeneem in afgelope jare, wat gelei het tot hernude belangstelling in gewasreste as 'n bron van grondorganiese materiaal en voedingstowwe vir gewasse. Gewasrestebestuur is bekend om direk of indirek grondkwaliteit te beïnvloed en dus ook grondvrugbaarheid. Sekere restebestuurspraktyke is getoets vanaf 1979 op 'n langtermyn koringproef by die LNR-Kleingraan Instituut naby Bethlehem in die Oos-Vrystaat op 'n Avalongrond.

Hierdie proef het 'n geleentheid gebied om die invloed van koringrestebestuurspraktyke op sekere grondvrugbaarheidsindikatore te ondersoek en om vas te stel of verskille in koringgraanopbrengs wel toegeskryf kan word aan veranderinge in grondvrugbaarheidsindikatore. Die behandelings wat toegepas is, is twee metodes van strooiverwydering (brand en nie-brand) x drie metodes van bewerking (ploeg-, deklaag- en geenbewerking) x twee metodes van onkruidbeheer (meganies en chemies). Grondmonsters is in 1999 geneem op diepte-intevalle van 0-50, 50-100, 100-150, 150-250, 250-350 en 350-450 mm en ontleed vir verskeie grondvrugbaarheidsindikatore, nl. organiese C en totale N as indekse van organiese materiaal. Addisioneel is pH, P, K, Ca, Mg, Na, Cu, Fe, Mn en Zn ook bepaal.

Die verskillende bewerkingspraktyke het ‘n groter effek op organiese materiaal gehad as wat strooiverwydering of onkruidbeheermetodes gehad het, spesifiek in die boonste 100 mm grond. Geenbewerking en in ‘n mindere mate deklaagbewerking, spesifiek wanneer dit gekombineer is met chemiese onkruidbeheer was meer voordelig vir grondorganiese materiaal as wanneer konvensionele bewerking gekombineer is met meganiese onkruidbeheer. Dit wil voorkom asof grondversuring vertraag word deur deklaag- en geenbewerking wanneer gekombineer word met chemiese onkruidbeheer. Die brand van koringreste het pH betekenisvol verhoog in vergelyking met nie-brand. Dit is gevind dat die inhoud van P, K, Cu, Fe, Mn en Zn toegeneem het wanneer die strooi gebrand is in vergelyking met wanneer dit nie gebrand is nie. Geenbewerking en tot ‘n mindere mate ook deklaagbewerking het tot gevolg dat ‘n akkumulasie van P, K, Ca, Mg, Cu, Fe, Mn en Zn in die boonste 150 mm grond plaasvind in vergelyking met deklaagbewerking.

Graanopbrengs stem nie altyd ooreen met die hoër organiese materiaal en laer suurheid as gevolg van deklaag- en geenbewerking nie. ‘n Rede hiervoor mag wees dat die voedingstowwe wat in die boonste 150 mm grond geakkumuleer het met die twee bewerkingspraktyke, nie altyd beksikbaar is vir plantopname nie. Hierdie aspek regverdig verdere ondersoek.

Sleutelwoorde: Bewerkingspraktyke, grondsuurheid, onkruidbeheer metodes, organiese materiaal, plantvoedingstowwe, strooi brand,.

ACKNOWLEDGEMENTS

I sincerely want to thank the following persons for their contribution to this dissertation. Without their help and support this would have been a blank document:

Prof CC Du Preez whose insight and wisdom helped me through the process of researching and writing this document.

The ARC-Small Grain Institute at Bethlehem in the Eastern Free State, where the trial is situated, for the use of the site for soil sampling as well as the use of the grain yield data: particularly Mr W H Kilian and J T Steyn.

The Department of Soil, Crop and Climate Sciences at the University of the Free State for the use of laboratories and Me Y Dessels and R van Heerden who always helped so willingly.

My family, who always stood by me and supported me.

CHAPTER 1

Motivation and objectives

1.1 Motivation

Humans have been increasingly exploiting soils to meet their food and fibre needs and to support the increasing population. Increased monoculture production of cash grain crops and greater reliance on the use of chemical fertilizers and pesticides to maintain crop growth, have resulted in greatly increased grain yields and labour efficiency. These conventional management practices have however led to a decline in soil organic matter, increased soil erosion and surface and groundwater contamination. Awareness of the environmental aspects of soil quality and crop production has been increasing in recent years, which has led to renewed interest in crop residues as a source of soil organic matter and nutrients for crops (Kumar & Goh, 2000).

The main goal of conservation tillage systems is threefold: to leave enough plant residue on the soil surface for water and wind erosion control, to reduce energy use, and to conserve soil and water (Unger & McCalla, 1980). Proper management of residues in a cropping system is essential for sustainable production, especially in semi-arid regions where conservation of soil and water is of the utmost importance (Smith & Elliot, 1990; Rasmussen & Collins, 1991).

Crop residues left on the soil surface often increase crop yields. There are also some cases where the yields are reduced where crop residues are maintained on the soil surface. This may be due to factors such as: 1) lack of proper equipment and knowledge of how to manage the residues with the equipment; 2) colder, wetter, and less aerated soil; 3) weed, insect, and disease problems; 4) lower nutrient availability; and 5) changes in the microbial status of the soil and the possible production of phytotoxic substances (Unger & McCalla, 1980).

Consequently worldwide research has been done on various crop residue management practices. Each of these practices has definite results associated with it, and some of these effects can overlap (Smith & Elliot, 1990). Options available to farmers in the management of crop residues include (Kumar & Goh, 2000):

- Residue burning, baling or removing of straw from the soil surface for stock feed, fuel, building material and other uses.
- Direct drilling in surface mulched and unmulched residues or undersowing crops.
- Incorporation of residues into the soil by using conventional tillage methods.

Crop residue management is known to either directly or indirectly affect soil quality, and therefore soil fertility (Kumar & Goh, 2000). In general, leaving crop residues on the soil surface has resulted in an increase in organic C, total N, extractable P, exchangeable K, and other plant nutrients in the 0-50 mm soil layer, and a decrease in soil pH. Leaving crop residues on the soil surface also results in higher storage and retention of soil water and lower temperatures. This is advantageous for germination and early seedling growth of crops under drier conditions, but harmful under cooler and wetter climates (Prasad & Power, 1991).

Leaving a residue cover on the soil surface can have a positive, negative or no effect on grain yield, depending on soil-climate conditions. Because of this variability Prasad & Power (1991) and Kumar & Goh (2000) emphasize that no one residue management system is superior under all conditions. It is therefore important to determine the consequences associated with residue management practices under local conditions, before it is propogated to farmers for implementation (Unger & McCalla, 1980).

In the last two or three decades, several researchers have examined the effect of residue management practices on soil biological, chemical and physical properties. In spite of these attempts, Prasad & Power (1991) are of the opinion that more information is needed on the distribution of plant nutrients in soil where different residue management practices are applied for a substantial period. Kumar & Goh (2000) are also of the opinion that multidisciplinary and integrated efforts by soil scientists, agronomists, ecologists, environmentalists, and economists are needed to design a system approach for the best choice of crop residue management practices for enhancing agricultural productivity and sustainability.

Some of the residue management practices mentioned earlier have been tested since 1979 in a long-term wheat trial at the ARC-Small Grain Institute near Bethlehem in the Eastern Free State, on an Avalon soil. Until now only grain yield was determined on a regular basis but not yet interpreted properly with regard to the treatments. However, Hoffman (1990) studied the soil water balance on selected treatments in 1986 and 1987. He found that although more water was stored in the no-tilled than in the stubble-mulched or conventionally ploughed plots, grain yields increased from mulched to uncultivated to ploughed treatments. Hoffman (1990) partially explained these unexpected results by the incidence of the root pathogen *Gaeumannomyces graminis* var. *tritici* ("Take-all" disease) that infected 65% of the plants in the mulched, 14% in the uncultivated and only 9% in the conventionally ploughed plots.

In the first 10 years there has also been no consistent response of grain yield to N application in the different residue management practices. A comparison in 1989 and 1990 by Wiltshire & Du Preez (1993) indicated that mouldboard ploughing depleted organic matter and available N more than stubble mulch, compared with no tillage. Mechanical weeding control, compared with chemical weeding reduced available N in the surface layer of plots that had received no primary cultivation. Straw burning compared with no burning, increased residual inorganic N at the surface in one of the two years.

In 1989 and 1990 Du Preez, Steyn & Kotzé (2001) also investigated the influence of the different residue management practices on some other soil fertility indicators, *viz*. pH, Ca, Mg, K, Na, P and Zn. They established that only pH, K, P and Zn were significantly influenced. Straw burning and conservation tillage increased the levels of those four indicators when compared with no burning and conventional tillage, especially nearer to the soil surface. Against this background it was decided in 1999 to study the influence of the different residue management practices on some soil fertility indicators again.

1.2 Objectives

The primary objective with this study on the mentioned long-term trial was therefore to determine the temporal and spatial influence of wheat residue management practices on some soil fertility indicators. A secondary objective was to establish whether differences in wheat grain yield could be attributed to temporal and spatial changes in soil fertility indicators.

CHAPTER 2

Materials and methods

2.1 Experimental site and soil

As mentioned in Chapter 1 the effects of some residue management practices were examined in a field trial from 1979 at the ARC-Small Grain Institute near Bethlehem in the Eastern Free State. The approximate location of the trial is 28º13'S and 28º18'E, about 1680 m above sea level.

Some long-term climate data on the experimental site are presented in Table 2.1. The mean annual rainfall is 695 mm and the mean annual class-A pan evaporation 1883 mm, resulting in a mean annual aridity index of 0.37. Most of the rain, *viz.* 79% falls from October to March, with mean daily temperatures ranging from 6.7 °C in June to 20.1 °C in January.

The trial is located in land type Ca6n which covers an area of about 420 000 ha (Land Type Survey Staff, 2001). This land type is described as a plinthic catena where upland duplex and/or margalitic soils are common. Parent material of these soils comprises Beaufort mudstone, shale, sandstone and grit, with dolerite sills in places.

Table 2.1 Long-term climate data as retrieved from weather station 19833 at the ARC-Small Grain Institute near Bethlehem (ARC-ISCW, 2002)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Rain (mm)	115.8	91.1	74.2	49.6	24.2	9.8	9.8	17.4	32.2	77.5	94.0	99.6	695.2
E_0 (mm)	214.1	179.4	164.9	122.0	103.4	82.5	93.7	129.1	172.7	195.7	201.2	223.9	1882.8
AI	0.54	0.51	0.45	0.41	0.23	0.12	0.11	0.13	0.19	0.40	0.47	0.45	0.37
Tmax (°C)	26.7	25.9	24.5	21.4	18.7	15.7	16.1	18.7	22.3	23.5	24.6	26.1	22.0
Tmin (°C)	13.4	13.0	11.2	6.7	1.8	-2.4	-2.5	0.0	4.6	8.1	10.5	12.3	6.4
Tm (°C)	20.1	19.5	17.9	14.1	10.2	6.7	6.8	9.4	13.5	15.8	17.6	19.2	14.2

E_0 = Class A pan evaporation (mm)

AI = Aridity index which is the ratio of rainfall to class-A pan evaporation

Tmax = Mean daily maximum temperature

Tmin = Mean daily minimum temperature

Tm = Mean daily temperature, *viz*. (Tmax + Tmin) / 2

The soil within the trial is of the Mafikeng family (Soil Classification Working Group, 1991) previously described as Soetmelk series (MacVicar, De Villiers, Loxton, Verster, Lambrechts, Merryweather, Le Roux, Van Rooyen & Harmse, 1977) of the Avalon form and covers about 17% of land type Ca6n. The equivalent classification according to the USDA system would be the great group Plinthustalfs (Soil Survey Staff, 1987). This Plinthosol (FAO, 1998) has three distinct horizons as described in detail by Hoffman (1990), *viz*. an orthic Ap (0-300 mm), yellow-brown apedal B1 (300-650 mm) and soft plinthic B2 (>650 mm) that contain 18, 23 and 36% clay, respectively. The soil occurs on terrain unit 3 with a northern slope of 2 to 3% and the parent material is either aeolian or colluvial deposits on shales.

The history of the site before laying down the experiment is not documented nor is any baseline analyses on the soil available, but it is known to have been cropped conventionally for at least 20 years before 1979. However, some soil samples were collected from the headlands with perennial grass outside the trial and analyzed for the same fertility indicators as the soil samples collected from the treatment plots inside the trial (See Section 2.3). These data is presented in Table 2.2 and thorough inspection of especially the extractable P and Zn values indicated that the headlands were probably cultivated before the trial commenced. In soils never cultivated the extractable P and Zn values are usually very low which is not the case here. Thus the data in Table 2.2 are not at all representative of an Avalon soil with native vegetation in the Ca6n land type. However, those values may give an indication of the soil's fertility status before the experiment was laid out.

Table 2.2 Mean values of soil fertility indicators in the headlands with perennial grass outside the trial.

Depths (mm)	**Org C** (%)	**Tot N** (%)	**C:N** ratio	**pH** (H_2O)	**P** (mg kg^{-1})	**K** (mg kg^{-1})	**Ca** (mg kg^{-1})	**Mg** (mg kg^{-1})	**Na** (mg kg^{-1})	**Cu** (mg kg^{-1})	**Fe** (mg kg^{-1})	**Mn** (mg kg^{-1})	**Zn** (mg kg^{-1})
0-50	0.78	0.08	9.8	6.0	12.1	421	752	165	58	1.6	65.4	59.8	2.9
50-100	0.64	0.05	12.8	6.1	10.2	338	996	158	161	1.6	55.3	55.9	2.1
100-150	0.68	0.05	13.6	5.9	11.4	249	933	148	85	5.2	16.2	25.5	5.8
150-250	0.67	0.06	11.2	5.9	8.6	167	983	139	81	4.6	16.6	18.1	4.8
250-350	0.64	0.06	10.7	6.0	7.2	182	1180	166	144	1.3	20.8	17.4	0.7
350-450	0.59	0.06	9.8	6.2	6.6	134	1167	237	114	1.7	39.9	34.5	1.0

9

2.2 Experimental layout and treatments

The layout is a randomized complete block design in three blocks laid out across a north-facing slope of the Avalon soil. Block 1 being the highest and block 3 the lowest. The highest point of the trial is at the western end of block 1 and the lowest is at the eastern end of block 3.

The trial includes 36 field treatments: two methods of straw disposal (burned and unburned) x three methods of tillage (ploughing, stubble mulch and no tillage) x two methods of weed control (mechanical and chemical) x three levels of nitrogen fertilization (20, 30 and 40 kg N ha^{-1}). The plot size is 6 x 30 m with 10 m borders.

Winter wheat is grown annually on the same plots with no intervening summer crop. In order to accumulate precipitation, a bare fallow is maintained by weed control during the five-month period between harvest and seeding, when most of the annual rainfall is expected. However, in 1990 and 1991 wheat was replaced with oats due to the high incidence of the soil-borne disease “Take-all” in some treatments as mentioned in Chapter 1.

In this trial wheat straw was burned immediately after harvesting in December or left unburned. The standard primary cultivation was disced with a two-way offset disc to 150 mm depth soon after straw burning, followed by mouldboard ploughing to 250 mm in February or March when the soil is sufficiently moist (which is a practice that most farmers follow in the Eastern Free State); stubble mulch was not disced but roots were cut at 100-150 mm with a V-blade and then ripped with a 50 mm width chisel plough at 300 mm spacing to the same depth and at the same time as mouldboard ploughing; the no-tilled treatment was only disturbed when planting with the seeder-fertilizer drill.

Weed control is carried out during the five-month water-storing period from harvest until planting by a mechanical cultivator, either a rod-weeder or V-blade depending on soil moisture condition, or by spraying a chemical. In earlier years the herbicide used was Roundup and more recently Paraquat. All plots were disturbed slightly by the combined seeder-fertilizer drill used for planting *Triticum aestivum* L. cv. Betta and 3:2:0 (25) + 0.75% Zn fertilizer application. This fertilizer mixture was applied at a rate resulting in N, P, K and Zn applications of 20, 13, 0 and 1 kg ha^{-1}, respectively. The deficit for nitrogen levels two and three, *viz*. 10 and 20 kg N ha^{-1} was supplemented by mixing appropriate amounts of limestone ammonium nitrate (28% N) thoroughly with the fertilizer mixture.

2.3 Soil sampling and analyses

As mentioned previously, composite soil samples were collected with a 70 mm diameter auger from the top and bottom headlands outside the trial, respectively. Subsamples were taken at two sites 50 m apart, 100 m from the highest, and at two sites 50 m apart, 100 m from the lowest corner of the trial and thoroughly mixed. Inside the trial only nitrogen level two was sampled, reducing the number of treatments to 12. Three auger cores with a 70 mm diameter were taken from the centerline of each plot and thoroughly mixed. Both outside and inside the trial soil from the 0-50, 50-100, 100-150, 150-250, 250-350 and 350-450 mm layers was sampled on 21 June 1999. Samples were dried at room temperature for one week and passed through a 2 mm sieve and chemical analyses were then done on the samples.

All chemical analyses were done in duplicate according to standard methods (The Non-Affiliated Soil Analyses Work Committee, 1990). The following analyses were done to determine some fertility indicators: organic C (Walkley-Black method), total N (Kjeldahl method), pH (1:2.5 soil to water suspension), exchangeable acidity (1 mol dm^{-3} KCl), exchangeable Ca, Mg, K and Na (1 mol dm^{-3} NH_4OA_c at pH7), extractable P (1 mol dm^{-3} $NaHCO_3$ at pH 8.5) and exchangeable Cu, Fe, Mn and Zn (DTPA-method).

2.4 Grain yield data

The grain yield data was made available kindly by the ARC-Small Grain Institute for use at discretion if needed, to give a better perspective on the outcomes of this study.

2.5 Data processing and analyses

In Section 2.1 it was mentioned that very little is known about the experimental site and soil before the different residue management practices commenced in 1979. This hampered data processing and analyses of the measured soil fertility indicators somewhat. However, because the site, and hence soil, were cropped conventionally for a relatively long period before 1979, this led to the following assumption: any variation in the fertility indicators should have resulted from the different residue management practices which were applied consecutively for 21 years at sampling in 1999.

Based on this assumption, analyses of variance were computed for every soil layer using the measurement means of the mentioned soil fertility indicators. All the analyses of variance were computed at a 95% confidence level using the NCSS software package of Hintze (1997). This software package was also used to compare treatment means with Tukey's procedure at a confidence level of 95%.

CHAPTER 3

Effect of wheat residue management on soil organic matter

3.1 Introduction

Soil organic matter is a heterogeneous mixture of living, dead and decomposing organic and inorganic compounds of which the precise composition is unknown (Rasmussen & Collins, 1991). Organic matter in soil is derived from plant, animal, and microbial tissue and contains various amounts of C, H, O, N, P, S and traces of other elements. In most instances either organic C or N are used as indices of soil organic matter. However, sometimes total N instead of organic N is used. Reference hereafter to any three of these indices therefore implies soil organic matter.

Some of the most important contributions organic matter makes to soil is that it is a major natural source of inorganic nutrients and microbial energy, and serves as an ion exchange material and a chelating agent to hold water and nutrients in available form. It promotes soil aggregation and root development, and it improves the water infiltration and hence water-use efficiency of the soil. It also gives a substantial buffering capacity to the soil due to its large ion exchange capacity (Rasmussen & Collins, 1991).

Soils in semi-arid regions are highly susceptible to organic matter loss when cultivated because of erratic yield, removal of crop residue for feed or fuel, uncontrolled erosion, and frequent fallowing to increase water storage (Rasmussen, Albrecht & Smiley, 1998). Most of the loss of organic C and N is due to biological oxidation and the lack of C input into soils. Cultivation accelerates the oxidation of organic matter at or near the surface and ranges from 20 to 50% in soils dominating semi-arid regions (Smith & Elliott, 1990).

In an effort to reduce organic matter loss in cultivated soils, several conservation tillage management systems have been proposed. These practices include no-tillage, reduced-tillage, stubble-mulching, and shallow conventional ploughing. Each practice has beneficial aspects; however, there have been problems with conservation tillage systems such as high equipment costs and varied reductions in yield. Proper crop residue management can increase water retention, prevent erosion, alter nutrient availability, and possibly reverse the decline in soil organic matter due to cultivation. In a semi-arid wheat-fallow system, Rasmussen, Allmaras, Rohde & Roager (1980) investigated the effect of several crop residue treatments on soil organic matter during a 45-year period. Only the addition of manure with incorporated straw prevented the decline of soil organic matter as indicated by organic C and N.

Soils in their natural or undisturbed state contain large organic C pools. The size of these organic C pools depends on temperature (higher in cool than in warm climates), moisture (higher in wetter climates and poorly drained soils than in drier climates and well-drained soils), soil texture (more in fine-textured than coarse-textured soils), and structure (more in well-aggregated than in poorly aggregated soils). Most soils lose one-third to one-half of their native organic C pool upon conversion from natural to agricultural ecosystems. The loss of organic C from soils is accentuated when inputs of organic C in cultivated systems are lower, and losses due to mineralization, leaching and erosion are higher than in natural systems (Lal, 2001).

Irregular yields, fallow systems, and burning are all contributors to long-term reduction in soil organic matter. Paustian, Elliott & Carter (1998) documented changes in organic C and N in long-term experiments worldwide. Most of the organic C is lost during the fallow year of a crop cycle; the loss is both from continuing biological activity and the absence of C input. In a fallow system, C input occurs every other year, which intensifies the oxidation of organic C by soil organisms. Biological activity is greater in fallow soils because the soil organisms are not competing with plants for soil moisture, hence the soil microorganisms have adequate moisture for growth and activity during the warm summer months. While erosion is minimal in the long-term experiments and less important than biological oxidation in the loss of organic C from soil, it may have a long-term impact on the C and N levels in a soil. Although decreasing tillage intensity reduces organic C and N loss, it is not as effective as eliminating fallow systems.

Paustian *et al.* (1998) found that organic matter could be maintained or increased in most semi-arid soils if they are cropped every year, the residues are returned to the soil, and erosion reduced or eliminated. Fallowing, while improving soil moisture for the crop, is very detrimental to soil organic matter retention and soil quality. Management practices, such as N fertilization, increase residue production and improve organic C and N levels in the soil.

Rasmussen & Collins (1991) investigated some studies and found that most have shown that conservation practices increase organic C and N in the top 50-150 mm of soil compared to conventional tillage methods. In general, the increase averages from 1 to 2% per year for both organic C and N, in the upper 150 mm of soil. Below the upper few mm, the amount of organic C and N was found to be either equal to or less than that in conventional tillage. Thus, the net change in the soil profile is not as positive as it might seem, even though the amount near the surface is much greater. Increased levels of organic C and N near the surface are attributed to delayed residue decomposition, slower oxidation of organic matter, reduced erosion, or any combination of these factors (Parr & Papendick, 1978; Doran, 1980). There is very little evidence that organic C or N moves substantially from the zone where it is placed if it is stabilized into the humus fraction of soil.

Biederbeck, Campbell, Bowren, Schnitzer & McIver (1980) found that after 20 years, residue burning reduced organic C and total N by about 15 to 20% and 4 to 10% respectively, as compared to incorporating residues. Moss & Cotterill (1985) on the other hand found greater organic C in the surface soil after burning. There are several possible reasons for these conflicting results, which include the degree to which crop residues are burned, time of burning, depth of sampling, effects of burning on soil bulk density, and tillage employed.

Prasad & Power (1991) came to the following conclusions regarding tillage effects on soil organic matter: 1) soil tillage of all kinds leads to a decrease in organic matter as compared to uncultivated soil; 2) incorporation of crop residues as compared to their removal usually increases the organic matter content of soil; 3) leaving a crop residue cover on the soil surface leads to accumulation of organic matter in the surface soil; and 4) burning of crop residues often produces a variable effect on organic matter content, depending on soil depth, tillage practices, degree of burning, time, and other factors.

As described in Chapter 2 several residue management practices were applied continuously from 1979 on an Avalon soil, near Bethlehem in the Eastern Free State. In this Chapter the temporal and spatial influence of these residual management practices on soil organic matter are presented and discussed.

3.2 Results and discussion

Organic C and total N were determined as indices of soil organic matter. The effects of the different residue management practices on these two indices and their ratio will be discussed separately.

3.2.1 Organic C

As displayed in the summary of the analyses of variance in Table 3.1 this index of organic matter was significantly influenced by either the tillage or weeding methods which were applied consecutively for 21 years.

Table 3.1 Summary of the analyses of variance indicating the significant effects on organic C at a 95% confidence level

	Layer (mm)					
Treatments[a]	**0-50**	**50-100**	**100-150**	**150-250**	**250-350**	**350-450**
A						
B	*	*				
AB						
C	*	*				
AC						
BC					*	
ABC						

[a]A : burning, B : tillage and C : weeding

Main effects

Surprisingly, the organic C in the burned plots was slightly higher than in the unburned plots (Figure 3.1). However, these differences in organic C between the burned and unburned plots were not significant. As indicated earlier research on straw burning showed either increases (Moss & Cotterill, 1985) or decreases (Biederbeck *et al.*, 1980) of organic C and several reasons are given by these authors for this phenomenon.

Inspection of Figure 3.1 showed that tillage methods had a significant effect on organic C in the two upper soil layers. The organic C in the 0-50 mm layer ranged from 0.60% in the ploughed plots to 0.84% in the no-tilled plots, and in the 50-100 mm layer from 0.59% in the ploughed plots to 0.68% in the no-tilled plots. In the mulched plots organic C was intermediate, *viz*. 0.72% in the 0-50 mm layer and 0.65% in the 50-100 mm layer. However, the tillage methods had no significant

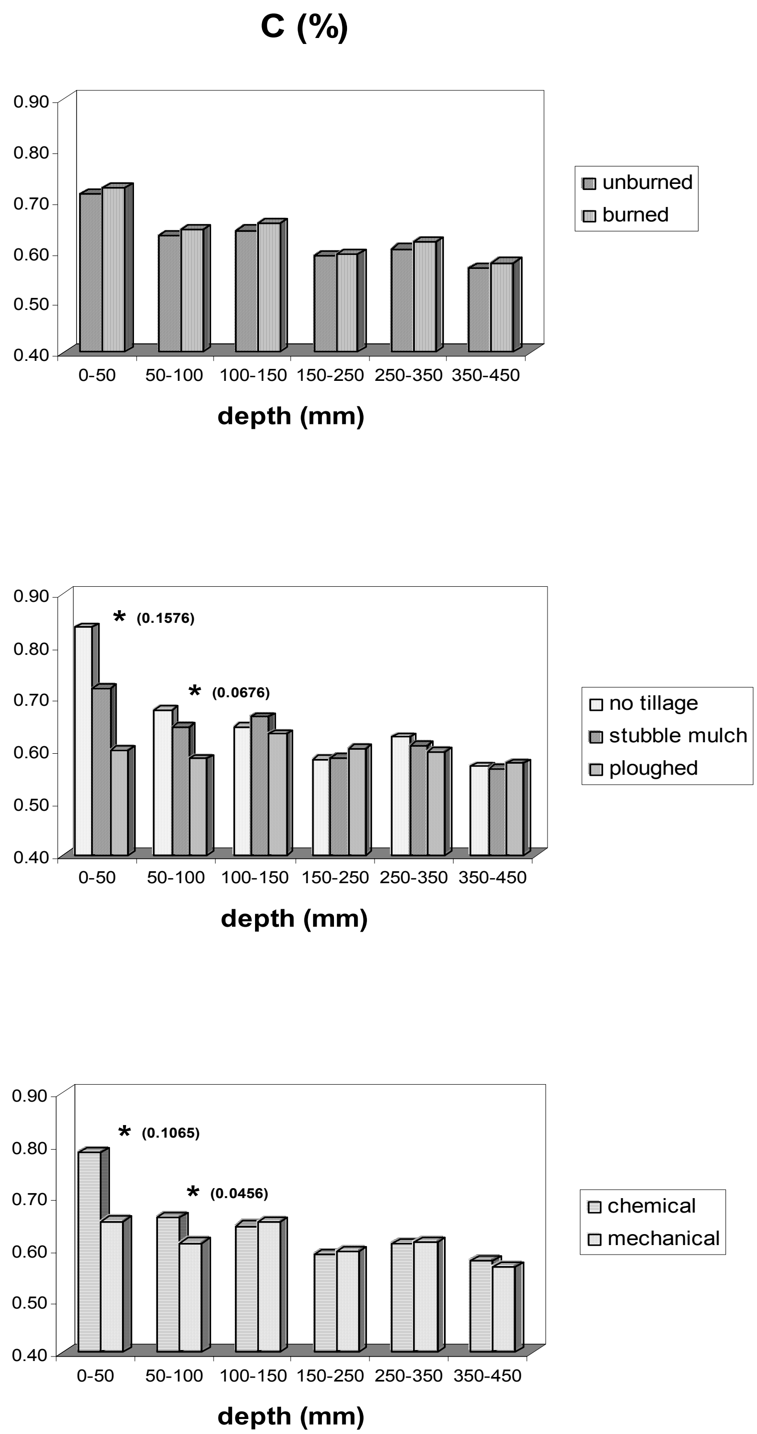

Figure 3.1 Effect of straw burning, tillage and weed control methods on organic C (%). LSD_T-values are shown, where applicable.

effect on organic C in the four deeper layers. These changes in organic C as a result of tillage methods correspond largely with those of researchers from elsewhere in the world (Parr & Papendick, 1978; Rasmussen & Collins, 1991).

Organic C was also affected by the weeding method to 100 mm depth as illustrated in Figure 3.1. In the 0-50 and 50-100 mm layers the chemically-weeded plots contained 0.79 and 0.66% organic C respectively, and the mechanically-weeded plots 0.65 and 0.61% organic C respectively. The organic C in the deeper layers showed no significant differences as a result of the weeding method.

Interactions

Data on the interactions between the different treatments with regard to organic C is presented in Table 3.2. Only in the 250-350 mm layer a significant interaction was recorded, *viz*. between tillage and weeding methods with a LSD_{Tukey} of 0.06% (Table 3.1). In this particular case the mechanically-weeded mulched plots had more organic C than the chemically-weeded mulched plots, while the chemically-weeded ploughed plots had more organic C than the mechanically-weeded ploughed plots (Table 3.2).

However, inspection of Table 3.2 showed some interesting trends. The no-tilled plots (upper three layers) and chemically-weeded plots (upper two layers) tended to have more organic C when burned than unburned, which are not the case with the mulched, ploughed and mechanically-weeded plots. In the upper two layers no tillage combined with chemical weeding showed the highest organic C values and ploughing combined with mechanical weeding the lowest organic C values.

Table 3.2 Effect of the interactions between straw burning, tillage and weed control methods on organic C (%)

		Tillage			Weeding	
		None	Mulched	Ploughed	Chemical	Mechanical
0 – 50 mm layer						
Straw	Unburned	0.80	0.72	0.61	0.77	0.66
	Burned	0.87	0.71	0.59	0.81	0.65
Weeding	Chemical	0.96	0.76	0.64		
	Mechanical	0.71	0.68	0.56		
50 – 100 mm layer						
Straw	Unburned	0.65	0.65	0.59	0.64	0.62
	Burned	0.70	0.64	0.58	0.68	0.61
Weeding	Chemical	0.73	0.65	0.60		
	Mechanical	0.62	0.64	0.57		
100 – 150 mm layer						
Straw	Unburned	0.62	0.66	0.64	0.64	0.64
	Burned	0.67	0.67	0.62	0.64	0.66
Weeding	Chemical	0.63	0.67	0.63		
	Mechanical	0.66	0.66	0.63		
150 – 250 mm layer						
Straw	Unburned	0.59	0.57	0.62	0.59	0.59
	Burned	0.58	0.61	0.59	0.59	0.59
Weeding	Chemical	0.58	0.57	0.61		
	Mechanical	0.59	0.60	0.59		
250 – 350 mm layer						
Straw	Unburned	0.62	0.61	0.58	0.61	0.60
	Burned	0.63	0.61	0.62	0.61	0.62
Weeding	Chemical	0.62	0.59	0.62		
	Mechanical	0.63	0.63	0.58		
350 – 450 mm layer						
Straw	Unburned	0.59	0.54	0.57	0.57	0.56
	Burned	0.55	0.59	0.58	0.58	0.57
Weeding	Chemical	0.57	0.56	0.60		
	Mechanical	0.57	0.58	0.55		

3.2.2 Total N

A summary of the analyses of variance on this index of organic matter is presented in Table 3.3. As with organic C the total N was mainly affected by either the tillage or weeding methods.

Table 3.3 Summary of the analyses of variance indicating the significant effects on total N at a 95% confidence level

	Layer (mm)					
Trestatments[a]	**0-50**	**50-100**	**100-150**	**150-250**	**250-350**	**350-450**
A					*	
B	*	*				
AB						
C		*				
AC						
BC						
ABC						

[a]A : burning, B : tillage and C : weeding

Main effects

In contrast to organic C the total N was slightly higher in the unburned than the burned plots (Figure 3.2). This difference in total N was only significant in the 250-350 mm layer. No obvious explanation could be found in literature why organic C and total N react differently to straw burning.

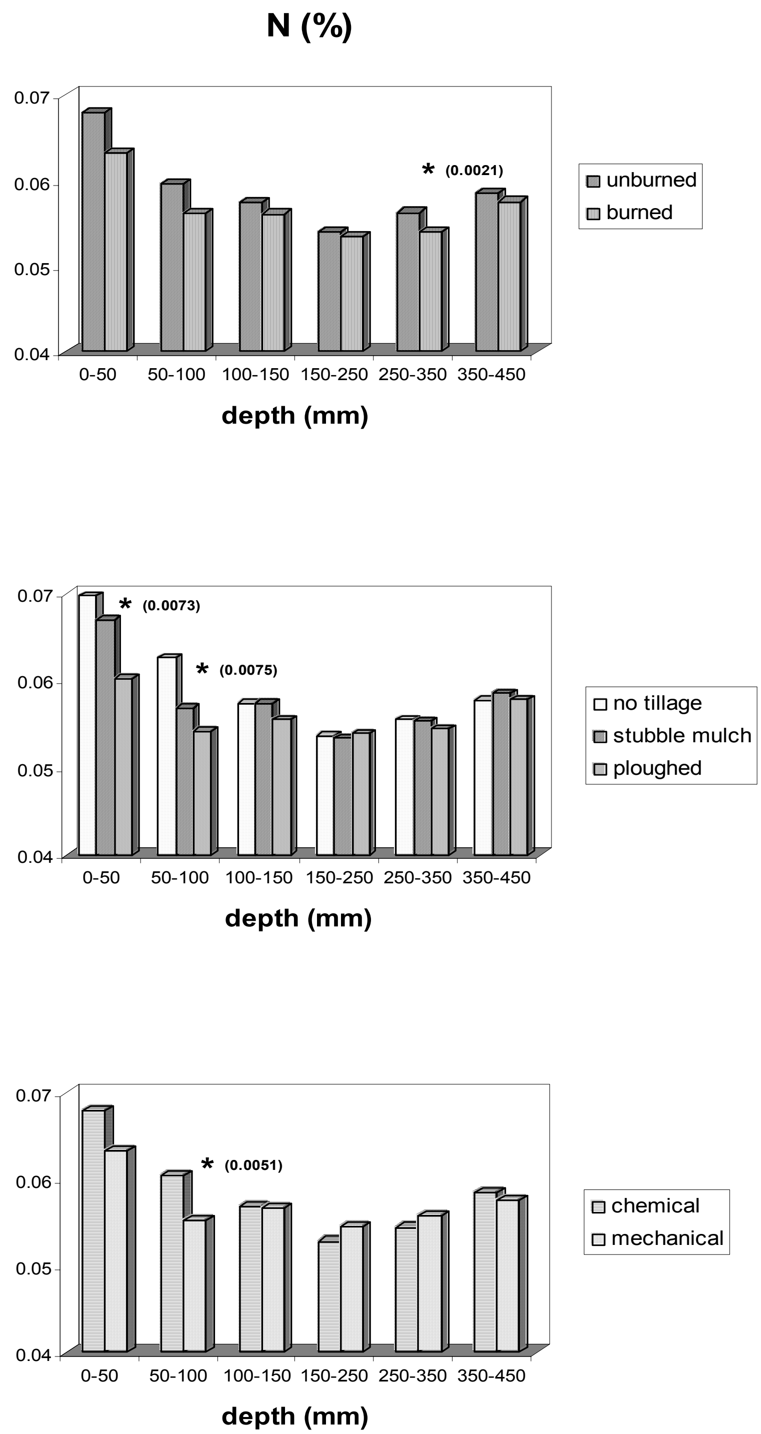

Figure 3.2 Effect of straw burning, tillage and weed control methods on organic N (%). LSD_T-values are shown, where applicable.

The influence of the tillage methods on total N was more or less similar to organic C (Figure 3.2). Total N in the 0-50 mm layer ranged from 0.060% in the ploughed plots to 0.070% in the no-tilled plots, and in the 50-100 mm layer from 0.054% in the ploughed plots to 0.063% in the no-tilled plots. Intermediate values for total N were recorded in the mulched plots, *viz*. 0.067% in the 0-50 mm layer and 0.057% in the 50-100 mm layer. In the deeper layers the tillage methods had no significant effects on total N.

Total N was affected in a similar way to organic C by the weeding methods (Figure 3.2). After 21 years the chemically-weeded plots contained more total N in the upper two soil layers than the mechanically-weeded plots, *viz*. 0.068 versus 0.063% in the 0-50 mm layer and 0.061 versus 0.055% in the 50-100 mm layer.

Interactions

None of the interactions between the different treatments were significant (Table 3.3). However, for the sake of convenience these data are presented in Table 3.4 and some trends can be observed in the upper two layers. Except for the ploughed plots all the other plots tended to contain slightly more total N when unburned than burned. As with organic C no tillage combined with chemical weeding resulted in the highest total N values and ploughing combined with mechanical weeding in the lowest N values.

Table 3.4 Effect of the interactions between straw burning, tillage and weed control methods on total N (%)

		Tillage			Weeding	
		None	Mulched	Ploughed	Chemical	Mechanical
0 – 50 mm layer						
Straw	Unburned	0.073	0.071	0.060	0.071	0.066
	Burned	0.066	0.063	0.060	0.065	0.061
Weeding	Chemical	0.073	0.069	0.062		
	Mechanical	0.067	0.065	0.058		
50 – 100 mm layer						
Straw	Unburned	0.064	0.060	0.054	0.062	0.057
	Burned	0.061	0.053	0.054	0.059	0.054
Weeding	Chemical	0.066	0.059	0.056		
	Mechanical	0.060	0.054	0.052		
100 – 150 mm layer						
Straw	Unburned	0.057	0.058	0.058	0.058	0.057
	Burned	0.058	0.057	0.053	0.056	0.056
Weeding	Chemical	0.055	0.058	0.057		
	Mechanical	0.060	0.057	0.054		
150 – 250 mm layer						
Straw	Unburned	0.055	0.053	0.054	0.053	0.055
	Burned	0.053	0.054	0.054	0.052	0.055
Weeding	Chemical	0.053	0.052	0.054		
	Mechanical	0.055	0.055	0.054		
250 – 350 mm layer						
Straw	Unburned	0.057	0.056	0.056	0.055	0.057
	Burned	0.055	0.055	0.053	0.054	0.055
Weeding	Chemical	0.054	0.055	0.055		
	Mechanical	0.057	0.056	0.054		
350 – 450 mm layer						
Straw	Unburned	0.059	0.059	0.058	0.059	0.058
	Burned	0.057	0.058	0.058	0.058	0.057
Weeding	Chemical	0.058	0.059	0.059		
	Mechanical	0.058	0.058	0.056		

3.2.3 C:N ratio

According to the summary of analyses of variance given in Table 3.5 the C:N ratio differed significantly in the 0-50 mm layer as a result of tillage and weeding methods, and in the 250-350 mm layer on account of wheat straw burning.

Table 3.5 Summary of the analyses of variance indicating the significant effects on the C:N ratio at a 95% confidence level

	Layer (mm)					
Treatments[a]	**0-50**	**50-100**	**100-150**	**150-250**	**250-350**	**350-450**
A					*	
B	*					
AB						
C	*					
AC						
BC						
ABC						

[a]A : burning, B : tillage and C : weeding

Main effect

In all six soil layers the C:N ratio was slightly higher in the burned than unburned plots but only significant in the 250-350 mm layer (Figure 3.3). This phenomenon can be attributed to the fact that organic C increased (See Section 3.2.1) and total N decreased (See Section 3.2.2) as a result of straw burning.

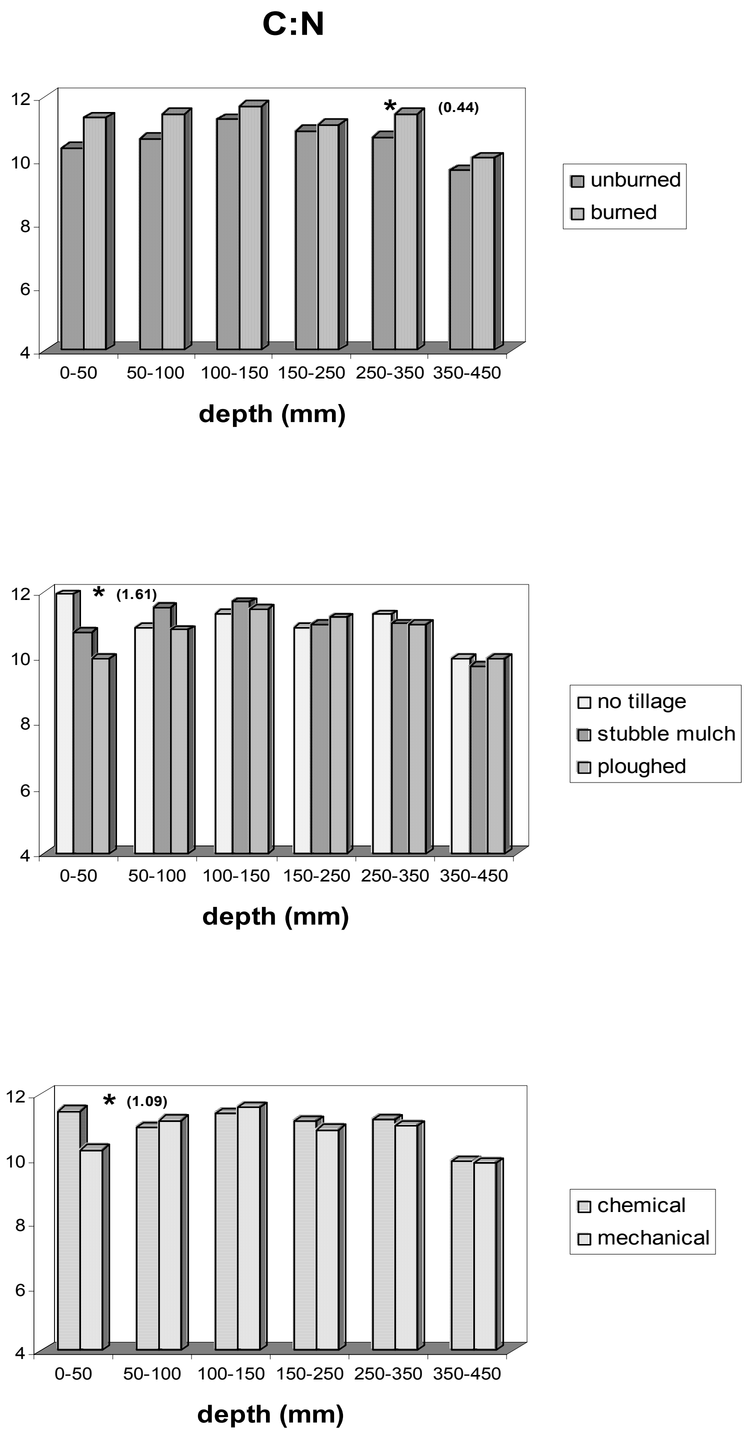

Figure 3.3 Effect of straw burning, tillage and weed control methods on the C:N ratio. LSD_T-values are shown, where applicable.

Only in the 0-50 mm layer the C:N ratio differed significantly on account of the tillage methods (Figure 3.3). The C:N ratio of this layer was 9.96, 10.75 and 11.92 in the ploughed, mulched and no-tilled plots, respectively.

The weeding methods only caused a significant difference in the 0-50 mm layer in the C:N ratio (Figure 3.3). In this layer the C:N ratio of the chemically-weeded plots was 11.47 and that of the mechanically-weeded plots 10.28.

Interactions

The interactions between the treatments had no significant influence on the C:N ratio (Table 3.5). However, some interesting trends can be observed in Table 3.6. The C:N ratio of the 0-50 mm layer ranged from 9.60 for the ploughed plots that were mechanically-weeded, to 13.13 for the no-tilled plots that were chemically-weeded. In this layer and the next one all plots except the ploughed plots had a higher C:N ratio when burned than left unburned.

In Section 2.1 it was pointed out that no baseline analyses of either organic C or total N as indices of organic matter are available for the experimental soil. The organic C and total N values of the headlands given in Table 2.2 are also as explained not representative of the soil before its conversion from grassland to cropland.

However, two studies (Du Toit, Du Preez, Hensley & Bennie, 1994; Lobe, Amelung & Du Preez, 2001) on Avalon soils in the Eastern Free State showed that both indices of organic matter declined as a result of conventional cultivation practices. The rate of organic matter loss was high during the first 10 years of cultivation.

Table 3.6 Effect of the interactions between straw burning, tillage and weed control methods on the C:N ratio

		Tillage		Weeding	
		None	Mulched	Ploughed	Chemical	Mechanical
0 – 50 mm layer						
Straw	Unburned	10.83	10.22	10.13	10.74	10.05
	Burned	13.01	11.28	9.79	12.21	10.51
Weeding	Chemical	13.13	10.97	10.32		
	Mechanical	10.71	10.53	9.60		
50 – 100 mm layer						
Straw	Unburned	10.26	10.92	10.92	10.38	11.01
	Burned	11.55	12.10	10.76	11.59	11.35
Weeding	Chemical	11.17	11.17	10.62		
	Mechanical	10.64	11.85	11.06		
100 – 150 mm layer						
Straw	Unburned	10.94	11.73	11.19	11.24	11.33
	Burned	11.73	11.65	11.76	11.57	11.86
Weeding	Chemical	11.49	11.54	11.18		
	Mechanical	11.18	11.84	11.77		
150 – 250 mm layer						
Straw	Unburned	10.76	10.68	11.37	11.01	10.86
	Burned	11.03	11.29	11.06	11.31	10.95
Weeding	Chemical	10.94	11.07	11.47		
	Mechanical	10.86	10.90	10.96		
250 – 350 mm layer						
Straw	Unburned	11.03	10.89	10.31	10.93	10.56
	Burned	11.59	11.15	11.70	11.50	11.45
Weeding	Chemical	11.47	10.84	11.33		
	Mechanical	11.15	11.20	10.68		
350 – 450 mm layer						
Straw	Unburned	9.96	9.16	9.91	9.71	9.65
	Burned	9.94	10.26	10.04	10.09	10.07
Weeding	Chemical	10.04	9.52	10.15		
	Mechanical	9.87	9.91	9.80		

Thereafter the rate decreased until equilibrium was reached after 35 years. After this very little or no further loss occurred. At this equilibrium stage loss of organic matter from cultivated soils with grassland soils as reference was approximately 60%. Thus, it can be assumed that when the residue management trial started in 1979 on this Avalon soil which was conventionally cultivated for at least 20 years the organic matter therein was already near equilibrium.

Results of this study and the previous one by Wiltshire & Du Preez (1993) indicated that the effects of especially straw burning and to a lesser extent of weeding method on organic matter were small compared to that of tillage method. On a relative basis the mulched and no-tilled plots contained respectively after 10 years 10 and 22%, and after 21 years 20 and 39% more organic C than the ploughed plots in the 0-50 mm layer. However, in the 50-250 mm layer the mulched and no-tilled plots contained on a relative basis after 10 years 1.5 and 4.9%, and after 21 years 2.2 and 4.4% more organic C than the ploughed plots. Total N, although not as large as organic C, showed similar increases in the mulched and no-tilled plots compared to the ploughed plots for those two layers which Wiltshire & Du Preez (1993) investigated.

Birru (2002) also reported that the restoration of organic matter in Avalon soils of the Eastern Free State by conversion of cultivated land to perennial pasture was disappointedly slow. After about 15 years under perennial pasture only 25% of the organic C or total N, which had been lost during 20 or more years of cultivation had been restored. Most of this was stored in the 0-50 mm layer, a little in the 50-100 mm layer, and very little in the 100-200 mm layer.

3.3 Conclusion

The effect of either straw burning or weeding method on organic matter in this Avalon soil were small compared to that of tillage practice. A slightly higher organic C and lower total N content were measured in the unburned than burned plots to a depth of 450 mm. Therefore any conclusive remark on the effect of straw burning on organic matter is impossible. However, the tillage practices affected organic C and total N significantly in a similar manner to a 100 mm depth. In this upper 100 mm the organic matter content of no-tilled plots was the highest, followed in decreasing order by the mulched and ploughed plots. The organic matter content of the chemically-weeded plots was significantly higher than that of the mechanically-weeded plots to a 100 mm depth, as indicated by organic C and total N.

Significant interactions between the treatments on either organic C or total N were almost absent. However, based on these two indices to approximately 150 mm depth ploughing combined with mechanical weeding resulted in the lowest organic matter content, whereas no tillage combined with chemical weeding resulted in the highest organic matter content. The latter combination is therefore recommended to maintain and even increase the organic matter content of this Avalon soil when cropped annually with wheat.

CHAPTER 4

Effect of wheat residue management on soil acidity

4.1 Introduction

Soil acidity, as indicated by pH, is one of the most important factors determining soil fertility for crop production (Havlin, Beaton, Tisdale &,Nelson 1999). However, crop production sometimes alters soil pH. Changes in soil pH are important for determining P and micronutrient availability, root growth, herbicide persistence, and microbial activity. Soil pH in crop production is influenced by factors such as: 1) use of commercial fertilizers, especially ammoniacal sources which produce H^+ during nitrification; 2) crop removal of basic cations, including Ca, Mg, K and Na in exchange for H^+; 3) leaching of these cations being replaced first by H^+ and subsequently by Al^{3+}; and 4) decomposition of organic residues.

On account of above mentioned factors continuous cultivation over the long term usually causes soil pH to decrease (Lal 1997). Recently Kumar & Goh (2000) confirmed that soil pH had decreased as a result of continuous cultivation in many parts of the world. They attributed it *inter alia* to proton release by crop roots, resulting in the accumulation of organic anions such as malate, citrate, and oxalate in plants. However, according to Kumar & Goh (2000), research has shown that if these organic anions are returned to the soil, on decomposition by microorganisms, soil pH can be increased due to the decarboxylation of organic anions, ligand exchange, and addition of basic cations. Thus, one possible way of protecting cultivated soils from acidification is by returning the crop residues to the soil.

The fate of crop residues as a result of tillage practice also influences soil pH (Pekrun, Kaul & Claupein, 2003). Conventional tillage causes rapid microbial decomposition of organic matter due to the incorporation of crop residues during tillage, and hence, rapid utilization and microbial immobilization of soil N. Therefore the greater organic matter concentrations occurring in no tillage soils are due to the absence of such rapid decomposition. Microbial decomposition and mineralization of organic matter in conventional tillage is known to result in the formation of organic acids which lower soil pH. However some research done in Alabama, United States of America, showed that different tillage treatments did not affect soil pH, but that crop rotation rather had an influence on the differences in soil pH that were recorded (Edwards, Wood, Thurlow & Ruf, 1992).

Some surface soils become more acidic under no tillage than under conventional tillage. According to Blevins, Thomas, Smith, Frye & Cornelius (1983) no tillage decreased soil pH and increased exchangeable Al compared to conventional tillage. Such changes in pH associated with tillage systems usually occur only when fertilizer is applied, because acidification occurs primarily due to nitrification of surface-applied ammoniacal fertilizer. The greatest differences in pH between different tillage practices should therefore occur near the soil surface, with no tillage leading to stratification of soil pH in the top layers. Studies done by DeMaria, Mnabude & de Castro (1999) in southern Brazil on the long-term effects of tillage practice and crop rotation on soil chemical properties, found that the different tillage practices caused no significant variation in soil pH below the 50 mm depth.

One of the other possible sources of soil acidity as already mentioned, could be leaching of basic cations from the soil. Under no tillage evaporation is reduced and more water is consequently available for leaching, especially in the early part of the growing season. When water moves downward through the soil it moves soluble anions and attracts cations as accompanying ions. When Ca^{2+} is removed from the exchange sites in a soil by water, it is replaced by H^+ which dissolve the clay releasing Al^{3+} and Mn^{2+} which then become exchangeable cations. The loss of Ca^{2+} and its replacement with Al^{3+} and Mn^{2+} lowers the soil pH, particularly in the soil surface layer where most of the Ca^{2+} loss occurs. However, nitrification is still the primary source of soil acidity through the release of H^+ ions (Blevins *et al*., 1983).

Prasad & Power (1991) found in their review on crop residue management that the burning of crop residues left on the soil surface leads to a higher pH in the upper layer and often even in deeper layers. Increases in pH after burning of crop residues can generally be attributed to the accumulation of ash as it is not only dominated by carbonates of alkali and alkaline earth metals but also contains variable amounts of silica.

From this discussion it is clear that the management of crop residues can affect soil acidity in different ways. The nett result of a particular management practice is often difficult to foresee and proper quantification is therefore essential.

As described in Chapter 2 several residue management practices were applied continuously from 1979 on an Avalon soil, near Bethlehem in the Eastern Free State. In this Chapter the temporal and spatial influence of these residue management practices on soil pH are presented and discussed.

4.2 Results and discussion

Soil pH was determined as an index of soil acidity. As can be seen in the summary of the analyses of variance in Table 4.1, pH was significantly influenced by either the burning or tillage methods, or a combination of these two methods. Weeding methods showed no significant effect on pH.

Table 4.1 Summary of the analyses of variance indicating the significant effects on pH at a 95% confidence level

	Layer (mm)					
Treatments[a]	**0-50**	**50-100**	**100-150**	**150-250**	**250-350**	**350-450**
A	*	*	*			
B	*	*			*	*
AB	*	*				
C						
AC						
BC						
ABC						

[a]A : burning, B : tillage and C : weeding

Main effects

The pH in the burned plots was higher than in the unburned plots, with the three upper soil layers showing significant differences (Figure 4.1). From the 150-250 mm layer and downwards the differences are not significant, although the burned plots were also slightly higher in pH than the unburned plots.

As can be seen in Figure 4.1, the tillage methods had a significant effect on pH in the upper two layers and lower two layers, but not in the middle two layers. However, the pH of the no-tilled plots was higher than that of the mulched or ploughed plots right through the profile. The pH in the 0-50 mm layer ranged from 5.59 in the no-tilled plots to 5.34 in the mulched plots, with the ploughed plots being intermediate with a pH of 5.38. Very much the same trend was recorded in the 50-100 and 100-150 mm layers. This was not the case in the 150-250 mm layer where the pH of the no-tilled and ploughed plots was almost similar, whereas the mulched plots tended to have a lower pH. In the 250-350 mm layer as well as the 350-450 mm layer the no-tilled plots still had the highest pH (5.74 and 6.28 respectively), but the pH of the ploughed plots (5.50 and 6.02 respectively) was now lower than that of the mulched plots (5.54 and 6.17 respectively).

Inspection of Figure 4.1 shows that pH was not affected significantly by the weeding method at all. The chemically-weeded plots however tended to have slightly higher pH values than the mechanically-weeded plots.

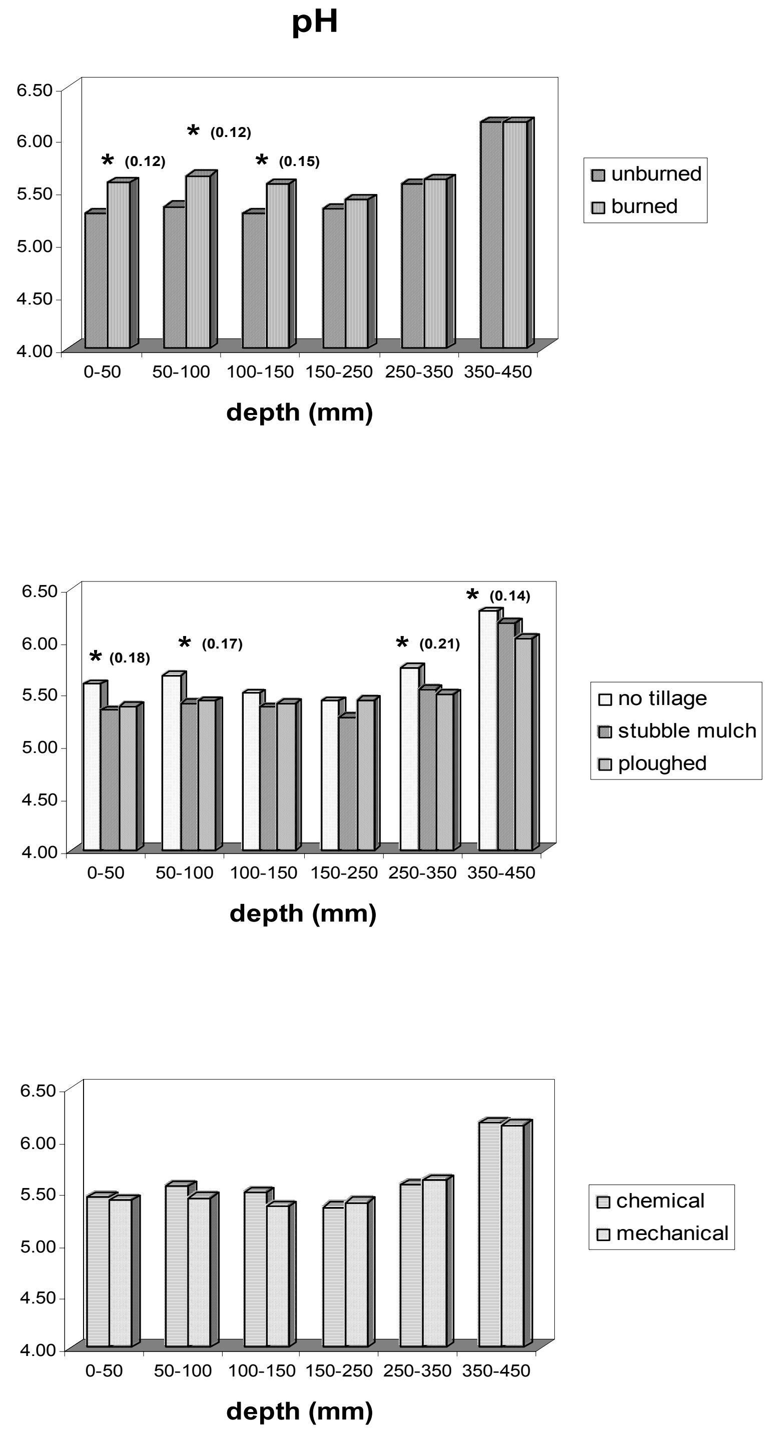

Figure 4.1 Effect of straw burning, tillage and weed control methods on pH. LSD_T-values are shown, where applicable.

Interactions

Data on the interactions between the different treatments with regard to pH is presented in Table 4.2. The only significant interactions were recorded between burning and tillage methods in the 0-50 mm layer (LSD_{Tukey} of 0.31) and 50-100 mm layer (LSD_{Tukey} of 0.30) (Table 4.1). In both layers the same trend is observed, namely the no-tilled plots that were burned had the highest pH values (5.82 in the 0-50 mm layer and 5.91 in the 50-100 mm layer) and the mulched plots that were not burned had the lowest pH values (5.12 in the 0-50 mm layer and 5.21 in the 50-100 mm layer).

A further inspection of Table 4.2 shows the following interesting trends, although not significant. Most of the burned plots have a higher pH than the unburned plots regardless of the tillage or weeding method applied. In addition most of the no-tilled plots tend to have a higher pH than that of the mulched and ploughed plots irrespective of the burning or weeding method applied. In both cases these pH differences diminish with depth as was also found by De Maria *et al.* (1999).

The higher pH recorded in the burned relative to the unburned plots can probably be attributed to the accumulation of ash with its alkaline nature in the soil, as discussed earlier (Prasad & Power, 1991). As already pointed out earlier the higher pH recorded in the no-tilled than mulched and ploughed plots can probably be ascribed to the decarboxylation of organic anions, ligand exchange and addition of basic cations when crop residues are left on the soil surface.

Table 4.2 Effect of the interactions between straw burning, tillage and weed control methods on pH

		Tillage			Weeding	
		None	Mulched	Ploughed	Chemical	Mechanical
0 – 50 mm layer						
Straw	Unburned	5.37	5.12	5.36	5.27	5.29
	Burned	5.82	5.55	5.39	5.63	5.55
Weeding	Chemical	5.61	5.33	5.41		
	Mechanical	5.58	5.34	5.34		
50 – 100 mm layer						
Straw	Unburned	5.44	5.21	5.41	5.36	5.34
	Burned	5.91	5.59	5.45	5.75	5.55
Weeding	Chemical	5.75	5.44	5.49		
	Mechanical	5.60	5.37	5.37		
100 – 150 mm layer						
Straw	Unburned	5.29	5.18	5.40	5.29	5.28
	Burned	5.71	5.56	5.42	5.69	5.43
Weeding	Chemical	5.55	5.44	5.49		
	Mechanical	5.45	5.30	5.33		
150 – 250 mm layer						
Straw	Unburned	5.37	5.18	5.45	5.27	5.40
	Burned	5.48	5.36	5.43	5.44	5.40
Weeding	Chemical	5.35	5.24	5.47		
	Mechanical	5.50	5.29	5.41		
250 – 350 mm layer						
Straw	Unburned	5.71	5.52	5.48	5.53	5.61
	Burned	5.77	5.56	5.51	5.61	5.61
Weeding	Chemical	5.67	5.47	5.57		
	Mechanical	5.81	5.60	5.42		
350 – 450 mm layer						
Straw	Unburned	6.26	6.20	6.02	6.15	6.17
	Burned	6.30	6.14	6.02	6.18	6.12
Weeding	Chemical	6.26	6.16	6.09		
	Mechanical	6.30	6.18	5.96		

The pH differed significantly as a result of burning and tillage methods applied, but only in the 0-50 mm layer. Burning increased the pH irrespective of the tillage method, with this effect being the greatest in the no-tilled plots and the smallest in the ploughed plots, with the mulched plots being intermediate. The pH also decreased as the degree of tillage intensified, especially in the burned plots.

It was mentioned in Section 2.1 that no baseline analyses of pH are available for the experimental soil. However, if the pH values of the headlands given in Table 2.2 are used as reference then it seems that the experimental soil acidified slightly in the upper 350 mm from 1979 to 1999 when the treatment effects are ignored. The weighted mean pH to a 350 mm depth is 6.0 in the headlands (5.9 to 6.1 for the upper five layers) and 5.5 within the trial (5.4 to 5.6 for the upper five layers). This acidification can be attributed to the factors listed earlier in Section 4.1.

4.3 Conclusion

The burning of wheat residues influenced the acidity of this Avalon soil significantly. A higher pH was recorded in the burned plots to 150 mm depth than in the unburned plots. Wheat residues that remained on or near the soil surface seem to result in less acidification than when incorporated into the soil. In comparison with the ploughed and mulched plots the no-tilled plots had a higher pH to 450 mm depth. The chemically-weeded plots also tended to have a higher pH in the upper 150 mm than the mechanically-weeded plots. Therefore no tillage with chemical weeding is the most beneficial combination to restrict acidification.

CHAPTER 5

Effect of wheat residue management on some plant nutrients

5.1 Introduction

A considerable amount of research has been done over time to quantify the temporal and spatial effects of different residue management practices on plant nutrients in soil. This research has been reviewed by Prasad & Power (1991), Kumar & Goh (2000) and Pekrun *et al.* (2003). From these reviews it is clear that the fate of plant nutrients depends very much on the particular residue management practice applied.

In general most research has shown a greater plant availability of both macro- and micronutrients in soils under conservational than conventional tillage (Langdale, Hargrove & Giddens, 1984; Hargrove, 1985; Luna-Orea, Wagner & Gumpertz, 1996; Lal, 1997). However, conservational tillage in comparison with conventional tillage caused, in many instances, a stratification of especially the immobile nutrients within soils (Follett & Peterson, 1988). The rate and extent of this stratification when changing from conventional to conservational tillage depends not only on residue management but also on climatic conditions, soil properties, cropping systems and fertilizer applications (Lal, 1997).

In a comprehensive study Fransluebbers & Hons (1996) found that the most dramatic changes occurred in the surface layer where a soil under no tillage had a lower pH, with less plant available Fe and Cu than under conventional tillage, but more plant available P, K, Zn and Mn. They recorded also below the tilled zone, *viz.* in the 150-300 mm soil layer more plant available P and K with no tillage than with conventional tillage. No tillage generally results in an accumulation of nutrients in the top soil layer, particularly the less mobile elements such as P, K and Mg (Horne, Ross & Hughes, 1992).

As can be expected with regard to nutrient stratification, most research was done on P which is very immobile in soil. In the majority of studies it was found that significantly more P had accumulated near the soil surface with no tillage when stubble mulch tillage (Shear & Moschler, 1969; Unger, 1991) or conventional tillage (Hargrove, Reid, Touchton & Gallaher 1982; Follett & Peterson, 1988; Edwards *et al.*, 1992; Selles, Kochhann, Denardin, Zentner & Faganello, 1997) serves as reference. This stratification of P on account of no tillage can be attributed to: 1) no incorporation of surface-applied fertilizer P into soil; 2) uneven extraction of soil P by crop roots; 3) release of plant P from crop residues that decompose on the soil surface; and 4) little movement of P in soil due to its immobility (Dick, 1983; Unger, 1991; Vyn & Yin, 1999).

The accumulation of P in the surface layer of soil on account of no tillage usually results in improved availability of P to plants. Researchers ascribe this improved plant availability of P in no-tilled soils to the higher organic matter content which not only enhances the storage and cycling of P but also its solubility (Ismail, Blevins & Frye, 1994; Buschiazzo, Panigatti & Unger, 1998)

Juo & Lal (1979) on the other hand found lower P levels in the surface layer of a soil when no tillage instead of conventional tillage was applied. They attributed this phenomenon *inter alia* to loss of surface soil by erosion and hence increased fixation of fertilizer P in the remaining soil. In another study Lal (1997) concluded that almost no P stratification resulted from the application of different conservational tillage practices. These findings can be assumed as the exception to the rule.

The stratification of K on account of tillage practices was also studied by several researchers. In most of these studies significantly more K was measured in the surface layer of soils with either no tillage or stubble mulch tillage than with conventional tillage (Evangelou & Blevins, 1985; Follett & Peterson, 1988; Unger 1991; Ismail *et al.*, 1994). Below this surface layer the soils under conventional tillage usually had more K than the soils under either stubble mulch tillage or no tillage. This stratification of K in soils where conservational tillage practices are applied can be ascribed to the same factors as listed earlier for P.

Hargrove *et al.* (1982) found, with no tillage, significantly less K in the surface layer of soil than with other tillage practices. They are of the opinion that the K could have been lost in surface runoff from the no-tilled soil or that tillage operations may have resulted in more K being released through mineral weathering.

No tillage and stubble mulch tillage in comparison with conventional tillage also resulted in an accumulation of Ca and Mg in the surface layer of soils (Juo & Lal, 1979; Hargrove *et al.*, 1982; Evangelou & Blevins, 1985; Unger, 1991). This accumulation of Ca and Mg in the surface soil layer, coincides with the higher organic matter content therein. It is well known that cation exchange sites on soil organic matter preferentially retain Ca, followed by Mg and then K. Below this surface layer little or no differences in either Ca or Mg were recorded due to different tillage practices, which was not always the case with either P or K (Fransluebbers & Hons, 1996).

The few studies on micronutrients showed that conservational tillage practices, especially no tillage and to a lesser extent stubble mulch tillage in comparison with conventional tillage caused an accumulation of Cu, Fe, Mn and Zn in the surface layer of soils (Hargrove *et al.*, 1982; Shuman & Hargrove, 1985; Follett & Peterson, 1988). This accumulation could be related to crop residues on or near the soil surface releasing significant quantities of those four nutrients upon decomposition. The released Cu, Fe, Mn and Zn may then form stable complexes with the organic matter in the surface soil layer. In such a chelated form the four plant nutrients will be more stable and thus available for uptake. However, tillage practices had, as with Ca and Mg, little or no effect on Cu, Fe, Mn and Zn below this surface soil layer.

Studies with regard to the burning of crop residues and the fate of plant nutrients are limited. However, burning of crop residues usually resulted in higher P, K and Zn contents in the surface soil layer. These higher nutrient contents are often of short-term duration due to convective transfer of the ash from the soil surface (Moss & Cotterill, 1985; Kumar & Goh, 2000).

The uptake of nutrients by crops can be affected if a residue management practice results in severe nutrient accumulation (Matawo, Pierzynski, Whitney & Lamond, 1999). Quantification of nutrient stratification is therefore of importance in the evaluation of a particular residue management practice.

In this Chapter the temporal and spatial influence of the different residue management practices that were applied continuously from 1979 on an Avalon soil near Bethlehem in the Eastern Free State on some nutrients are presented and discussed.

5.2 Results and discussion

The effects of the different residue management practices on each of the nine plant nutrients that were determined, *viz*. P, K, Ca, Mg, Na, Cu, Fe, Mn and Zn will be discussed separately.

5.2.1 Extractable P

As can be seen in the summary of the analyses of variance in Table 5.1, P was significantly influenced by either the tillage or weeding methods, or a combination of them. The burning treatments had no significant influence on P.

Main effects

The P in the burned plots was slightly higher than in the unburned plots although there were no significant differences recorded in any soil layer (Figure 5.1). This trend corresponds with findings of Moss & Cotterill (1985).

Table 5.1 Summary of the analyses of variance indicating the significant effects on P at a 95% confidence level

	Layer (mm)					
Treatments[a]	**0-50**	**50-100**	**100-150**	**150-250**	**250-350**	**350-450**
A						
B	*	*	*			*
AB						
C	*			*		
AC						
BC						*
ABC						

[a]A : burning, B : tillage and C : weeding

As shown in Figure 5.1, the tillage methods had a significant effect on P in the upper three soil layers as well as the deepest soil layer that were sampled for analyses. The no-tilled and mulched plots had higher P contents than the ploughed plots to a depth of 250 mm. Below this depth the trend reversed, with the ploughed plots having higher P contents than the mulched and no-tilled plots. No tillage caused slightly higher P contents than mulch in the 0-50 and 100-150 mm soil layers, but this trend is reversed in the 50-100 and 150-250 mm soil layers.

Inspection of Figure 5.1 shows a higher P content in the 0-50, 150-250 and 250-350 mm soil layers of the chemically-weeded plots than the mechanically-weeded plots, where a significant difference was recorded in the 0-50 mm as well as the 150-250 mm soil layers. The P content in the 50-100, 100-150 and 350-450 mm soil layers was almost similar irrespective of the weeding method.

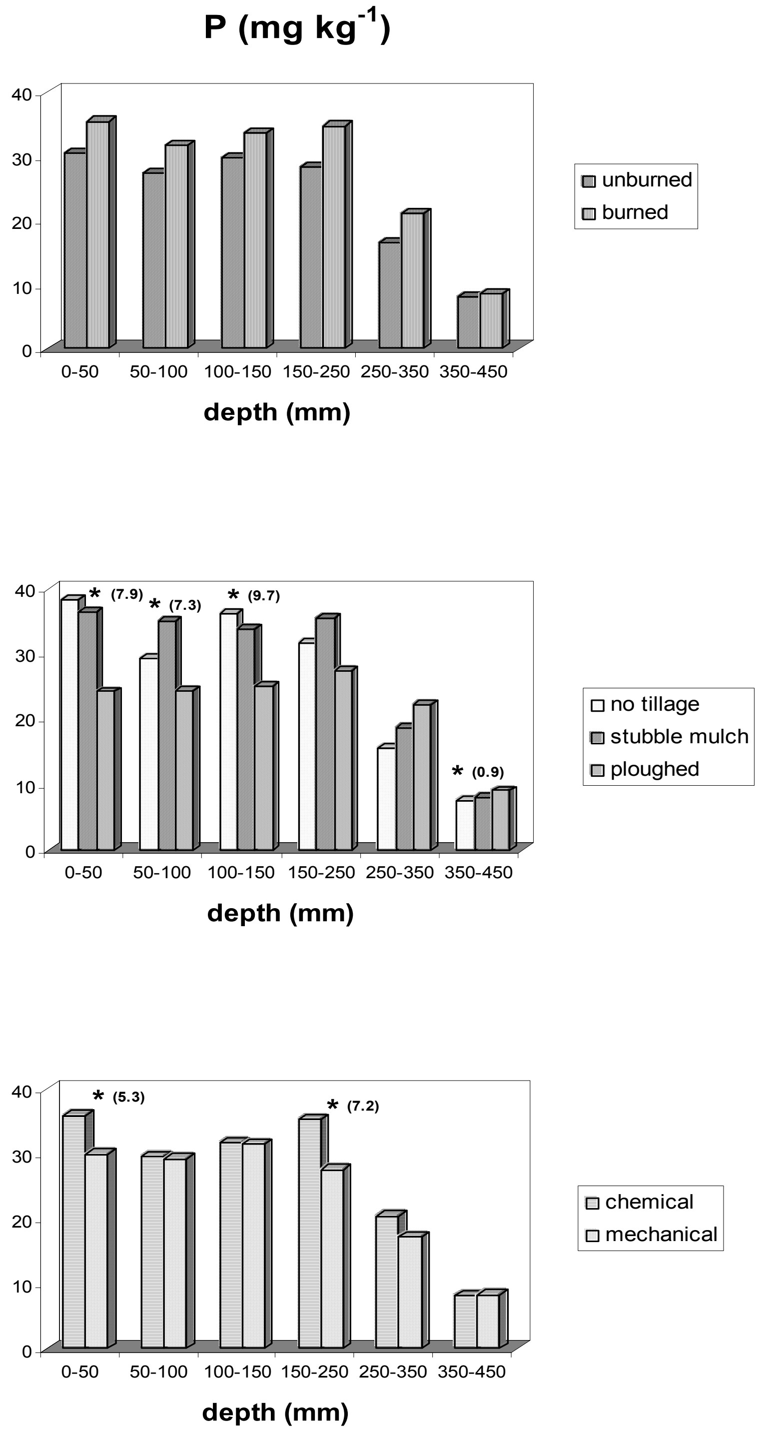

Figure 5.1 Effect of straw burning, tillage and weed control methods on P. LSD_T-values are shown, where applicable.

Interactions

Data on the interactions between the different treatments with regard to P is presented in Table 5.2. The only significant interaction was observed between the burning and tillage treatments in the 350-450 mm layer with an LSD_{Tukey} of 1.6 mg kg^{-1} (Table 5.1). Plots that were burned and ploughed had the highest P content (9.5 mg kg^{-1}) and unburned plots that were not tilled had the lowest P content (7.4 mg kg^{-1}) in this layer.

However, Table 5.2 shows that the burned plots tend to have, in all six soil layers, a higher P content than the unburned plots, despite the tillage and weeding methods applied. The P content in the upper four layers of the ploughed plots was lower than that of the mulched and no-tilled plots irrespective of the burning or weeding treatments. Despite the burning or tillage treatment, the P content in the 0-50 mm soil layer of chemically–weeded plots is higher than that of the mechanically-weeded plots.

Similar trends were reported for P by Du Preez *et al.* (2001) after the trial had been running for only 11-12 years. They found that burning of the wheat straw increased the P content to a 250 mm depth when compared to no burning of the wheat straw, regardless of the tillage or weeding method applied. A lower P content was recorded by them in the 0-50 mm layer of the ploughed than the mulched and no-tilled plots. However in the 150-250 mm layer they found that the mulched plots had the highest P content, followed by the no-tilled and then the ploughed plots.

Table 5.2 Effect of the interactions between straw burning, tillage and weed control methods on P (mg kg^{-1})

		Tillage			Weeding	
		None	Mulched	Ploughed	Chemical	Mechanical
0 – 50 mm layer						
Straw	Unburned	33.3	36.2	22.2	32.1	28.9
	Burned	43.3	36.8	26.4	39.9	31.1
Weeding	Chemical	43.5	39.9	24.6		
	Mechanical	33.0	33.1	23.9		
50 – 100 mm layer						
Straw	Unburned	27.2	32.5	22.4	27.4	27.3
	Burned	31.4	37.4	26.2	32.0	31.3
Weeding	Chemical	28.9	35.9	24.4		
	Mechanical	29.7	34.0	24.2		
100 – 150 mm layer						
Straw	Unburned	34.5	31.7	23.1	31.1	28.6
	Burned	37.9	35.9	27.0	32.6	34.7
Weeding	Chemical	35.8	35.3	24.4		
	Mechanical	36.6	32.4	25.8		
150 – 250 mm layer						
Straw	Unburned	28.6	33.2	23.4	33.3	23.4
	Burned	34.7	37.7	31.6	37.5	31.9
Weeding	Chemical	37.6	40.8	27.8		
	Mechanical	25.7	30.1	27.2		
250 – 350 mm layer						
Straw	Unburned	13.6	16.9	19.1	17.7	15.4
	Burned	17.6	20.4	25.3	23.2	19.0
Weeding	Chemical	16.8	22.6	21.9		
	Mechanical	14.4	14.8	22.4		
350 – 450 mm layer						
Straw	Unburned	7.4	7.8	8.8	7.9	8.2
	Burned	7.6	8.2	9.5	8.4	8.5
Weeding	Chemical	7.6	8.4	8.4		
	Mechanical	7.5	7.6	9.8		

5.2.2 Exchangeable K

The summary of the analyses of variance in Table 5.3 indicates that K was significantly influenced by the burning and tillage treatments to a depth of 450 mm. In comparison with these treatments the weeding treatment influenced K significantly to only 50 mm depth.

Table 5.3 Summary of the analyses of variance indicating the significant effects on K at a 95% confidence level

	Layer (mm)					
Treatments[a]	**0-50**	**50-100**	**100-150**	**150-250**	**250-350**	**350-450**
A	*	*	*	*	*	*
B	*	*	*	*	*	*
AB		*				
C	*					
AC		*	*			
BC						
ABC						

[a]A : burning, B : tillage and C : weeding

Main effects

The burning treatment had, as shown in Figure 5.2, a significant influence on the K content in all the soil layers, with K being higher in the burned plots than in the unburned plots.

As illustrated in Figure 5.2, the tillage methods also had a significant effect on the K content in every soil layer. The K in the no-tilled and mulched plots was higher than in the ploughed plots to a depth of 150 mm. Below this depth the trend is reversed, with higher K in the ploughed plots than in the mulched and no-tilled plots. Except in the 100-150 mm layer the no-tilled plots had slightly higher K contents than the mulched plots.

Inspection of Figure 5.2 shows that in the upper four layers chemical weeding increased K slightly compared to mechanical weeding, with a significant difference only in the 0-50 mm soil layer.

Interactions

The data on the interactions between the different treatments with regard to K is given in Table 5.4. It is interesting to note that although not always significant for all six layers, a higher K content was measured in the burned than unburned plots irrespective of the tillage or weeding methods.

There was a significant interaction between the burning and tillage treatments in the 50-100 mm layer with an LSD_{Tukey} of 84 mg kg^{-1} (Table 5.3). The highest K was measured in the burned plots where no tillage was applied (489 mg kg^{-1}), and the lowest K was measured in the unburned plots where ploughing was applied (271 mg kg^{-1}).

Significant interactions were also recorded on account of the burning and weeding treatments in the 50-100 and 100-150 mm soil layers, with an LSD_{Tukey} of 61 and 57 mg kg^{-1} respectively (Table 5.3). In the 50-100 mm layer, the burned plots subject to chemical weeding had the highest K content of 443 mg kg^{-1} and the unburned plots

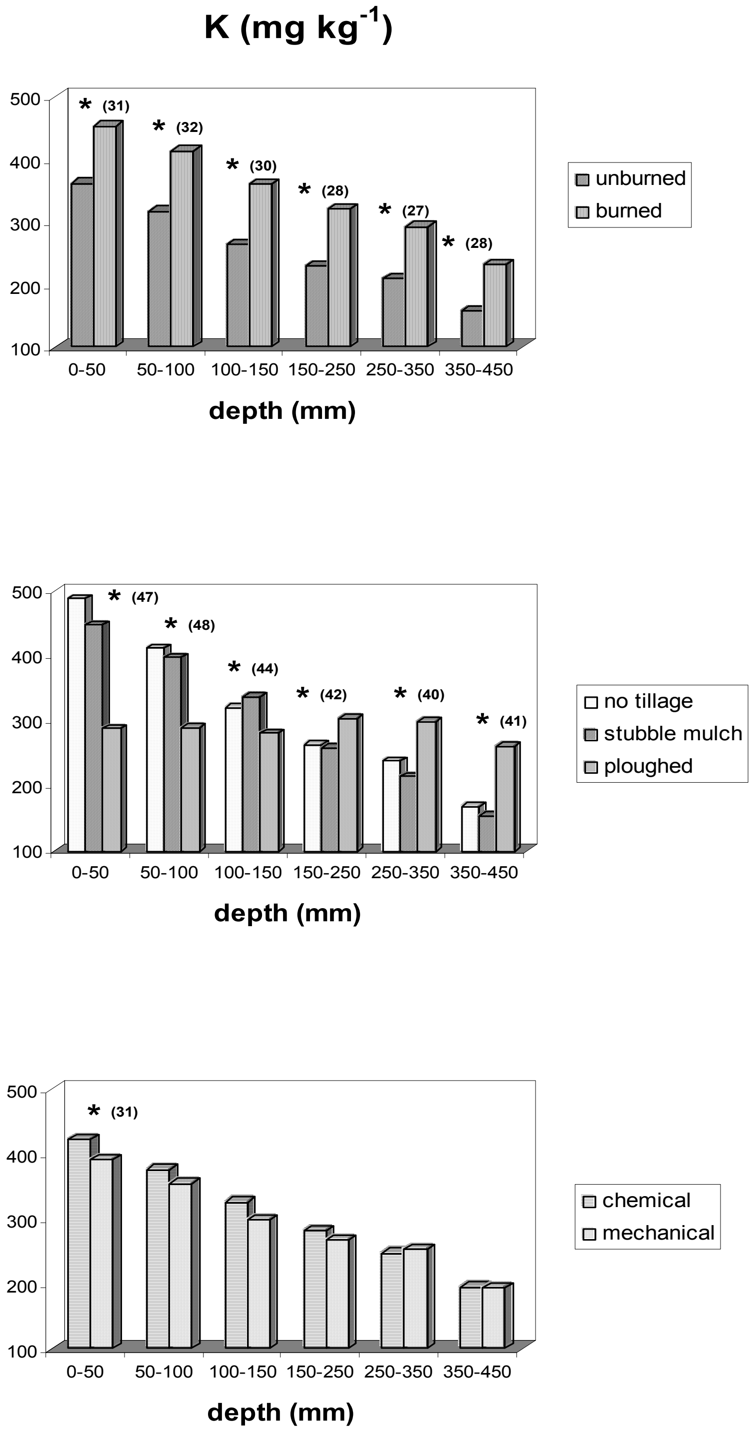

Figure 5.2 Effect of straw burning, tillage and weed control methods on K.

LSD_T-values are shown, where applicable.

subject to chemical weeding had the lowest K content of 310 mg kg^{-1}. The same trend is also observed in the 100-150 mm layer, where the K content ranged from 262 mg kg^{-1} in the unburned plots that were chemically-weeded to 390 mg kg^{-1} in the burned plots that were mechanically-weeded.

The ploughed plots had, regardless of the burning or weeding treatments, lower K contents in the upper three soil layers than either the mulched or no-tilled plots. However, this trend was reversed in the lower three layers. Despite the tillage practice applied, a higher K content was measured in the chemically-weeded than mechanically-weeded plots. This trend is observed to a depth of 250 mm.

In a study conducted by Du Preez *et al.* (2001) on this trial after it had been running for 11-12 years it was found that burning had already increased the K content to a depth of 250 mm, irrespective of tillage or weeding method. They also reported that, regardless of the burning or weeding methods, to a depth of 150 mm the no-tilled plots contained the most K, followed by mulched and then ploughed plots. However, below 150 mm this trend reversed. Chemical weeding compared with mechanical weeding also increased K to 50 mm depth, especially in the no-tilled and mulched plots that were burned.

Table 5.4 Effect of the interactions between straw burning, tillage and weed control methods on K (mg kg^{-1})

		Tillage			Weeding	
		None	Mulched	Ploughed	Chemical	Mechanical
0 – 50 mm layer						
Straw	Unburned	419	400	267	364	360
	Burned	556	495	310	483	424
Weeding	Chemical	513	466	291		
	Mechanical	462	429	285		
50 – 100 mm layer						
Straw	Unburned	334	348	271	310	325
	Burned	489	448	306	443	386
Weeding	Chemical	423	412	295		
	Mechanical	400	383	283		
100 – 150 mm layer						
Straw	Unburned	257	281	254	262	266
	Burned	383	393	308	390	333
Weeding	Chemical	335	359	284		
	Mechanical	304	315	279		
150 – 250 mm layer						
Straw	Unburned	208	208	274	231	228
	Burned	319	309	334	333	308
Weeding	Chemical	276	267	304		
	Mechanical	251	250	303		
250 – 350 mm layer						
Straw	Unburned	186	172	269	203	214
	Burned	291	258	328	291	294
Weeding	Chemical	224	229	289		
	Mechanical	253	201	309		
350 – 450 mm layer						
Straw	Unburned	121	124	228	151	164
	Burned	215	184	295	239	223
Weeding	Chemical	167	149	269		
	Mechanical	168	159	254		

5.2.3 Exchangeable Ca

Inspection of the summary of the analyses of variance in Table 5.5 displays that the different treatments had almost no significant influence on Ca.

Table 5.5 Summary of the analyses of variance indicating the significant effects on Ca at a 95% confidence level

	Layer (mm)					
Treatments[a]	**0-50**	**50-100**	**100-150**	**150-250**	**250-350**	**350-450**
A						
B					*	
AB						
C	*					
AC						
BC						
ABC						

[a]A : burning, B : tillage and C : weeding

Main effects

As shown in Figure 5.3, no significant difference in Ca content was recorded for any soil layer as a result of the burning treatment. Neither could any trend in Ca content between the burned and unburned plots be observed.

The influence of tillage methods on Ca is displayed in Figure 5.3. In the upper three layers the ploughed plots tended to have the highest Ca content, followed by the no-tilled plots and then the mulched plots. This trend changed in the 150-250 mm layer where the no-tilled plots tended to have the highest Ca content, followed by the

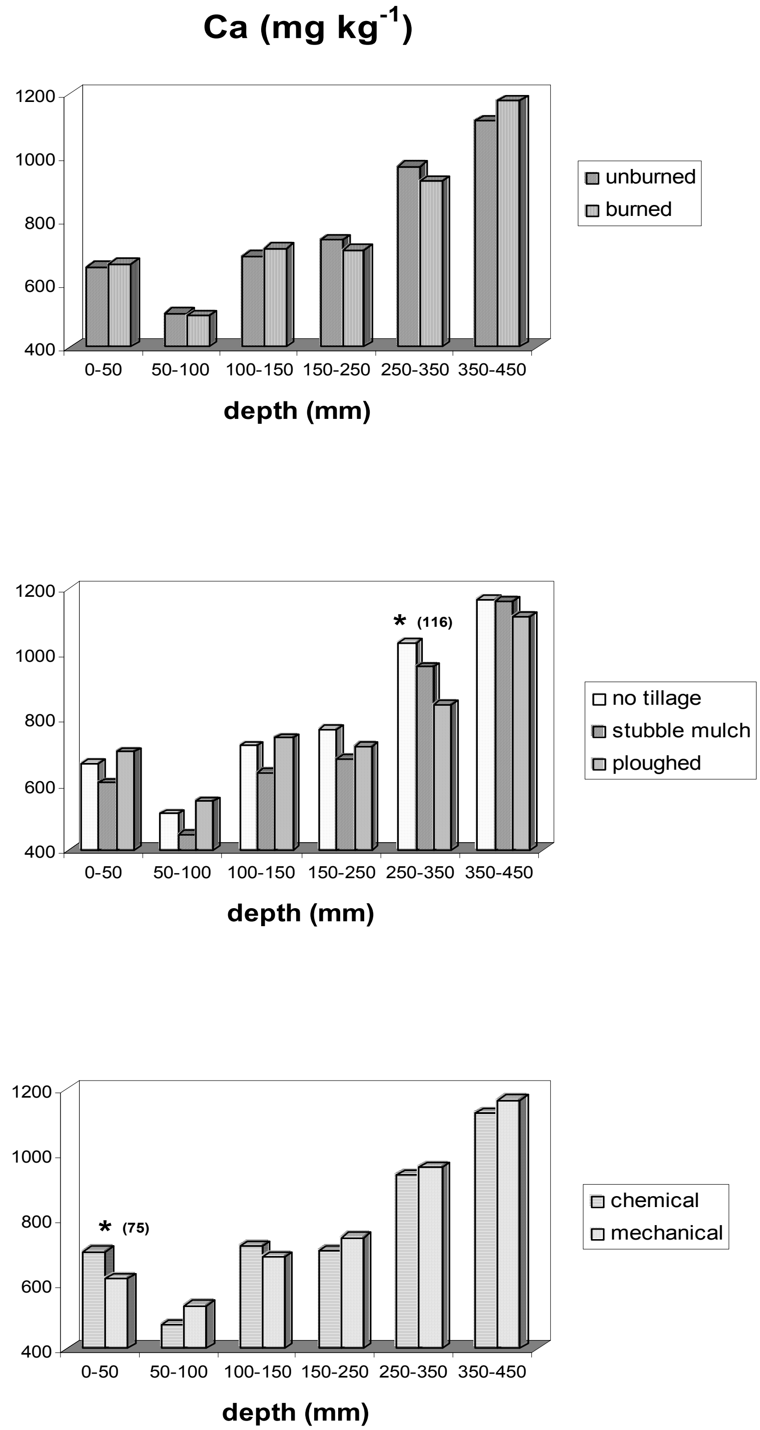

Figure 5.3 Effect of straw burning, tillage and weed control methods on Ca.

LSD_T-values are shown, where applicable.

mulched plots and then the ploughed plots. In the 250-350 mm layer the Ca content decreased significantly from the no-tilled plots to the mulched plots, and from the latter plots to the ploughed plots.

Further inspection of Figure 5.3 shows that the Ca content of only the 0-50 mm layer was significantly higher in the chemically-weeded than mechanically-weeded plots. The same trend is observed in the 100-150 mm layer, and in the other four soil layers, the trend is reversed.

Interactions

The data on the interactions between the different treatments with regard to Ca is summarized in Table 5.6. There were no significant interactions between any of the treatments (Table 5.5). It is however interesting to note that the unburned plots that were ploughed had the highest Ca content and the unburned plots that were mulched had the lowest Ca content to a depth of 100-150 mm. Below 100-150 mm there does not seem to be any specific pattern for this interaction of burning and tillage. The other interactions of burning and weeding as well as tillage and weeding did not result in any trends worth mentioning.

From the preceding results it seems that Ca started to show some trends after 20 years on account of the annual application of the tillage and weeding treatments. This was not the case 11-12 years after commencement of the trial according to Du Preez *et al.* (2001)

Table 5.6 Effect of the interactions between straw burning, tillage and weed control methods on Ca (mg kg^{-1})

		Tillage		Weeding	
		None	Mulched	Ploughed	Chemical	Mechanical
0 – 50 mm layer						
Straw	Unburned	660	590	709	691	615
	Burned	670	623	694	707	618
Weeding	Chemical	734	621	742		
	Mechanical	596	592	661		
50 – 100 mm layer						
Straw	Unburned	523	424	573	466	547
	Burned	500	470	525	480	517
Weeding	Chemical	513	391	516		
	Mechanical	511	503	582		
100 – 150 mm layer						
Straw	Unburned	702	587	773	685	689
	Burned	738	685	713	746	678
Weeding	Chemical	730	631	787		
	Mechanical	710	641	700		
150 – 250 mm layer						
Straw	Unburned	788	671	756	694	783
	Burned	751	688	681	710	703
Weeding	Chemical	720	635	751		
	Mechanical	819	724	686		
250 – 350 mm layer						
Straw	Unburned	1049	981	883	945	997
	Burned	1021	942	809	926	922
Weeding	Chemical	973	942	892		
	Mechanical	1096	981	800		
350 – 450 mm layer						
Straw	Unburned	1113	1143	1089	1079	1151
	Burned	1217	1181	1138	1174	1183
Weeding	Chemical	1128	1088	1164		
	Mechanical	1201	1236	1064		

5.2.4 Exchangeable Mg

The summary of the analyses of variance given in Table 5.7 shows that Mg was significantly influenced by the tillage and weeding treatments but not by the burning treatments.

Table 5.7 Summary of the analyses of variance indicating the significant effects on Mg at a 95% confidence level

	Layer (mm)					
Treatments[a]	**0-50**	**50-100**	**100-150**	**150-250**	**250-350**	**350-450**
A						
B	*					*
AB						
C	*					
AC						
BC	*					
ABC						

[a]A : burning, B : tillage and C : weeding

Main effects

The effect of the burning treatments on Mg although not significant is illustrated in Figure 5.4. It is however interesting to note that the unburned plots tend to have slightly higher Mg contents than the burned plots in all the soil layers, except the 50-100 and 100-150 mm layers.

By comparing the tillage methods with each other, it can be seen in Figure 5.4 that in all soil layers higher Mg contents were recorded in the no-tilled than in either the mulched or ploughed plots. These differences were only significant in the 0-50 and 350-450 mm soil layers. There were no significant differences between the mulched and ploughed plots with regard to Mg content in any soil layer.

Further inspection of Figure 5.4 shows that weeding only had a significant effect on Mg in the 0-50 mm soil layer. However, with chemical weeding, higher Mg contents than with mechanical weeding were recorded in the upper three layers. This trend is reversed in the lower three layers.

Interactions

Data on the interactions between the different treatments with regard to Mg is presented in Table 5.8. As displayed in Table 5.7 the only significant interaction was observed between tillage and weeding methods in the 0-50 mm layer with an LSD_{Tukey} of 22 mg kg^{-1}. In this layer the no-tilled plots with chemical weeding had the highest Mg content of 120 mg kg^{-1} and the ploughed plots with chemical weeding had the lowest Mg content of 82 mg kg^{-1}. The same trend was also recorded in the 50-100 and 100-150 mm layers. In the lower three layers the lowest and highest Mg contents were measured respectively in the mulched and no-tilled plots that were both chemically-weeded.

Du Preez *et al.* (2001) reported that the distribution of Mg was not influenced significantly after 11-12 years of application of the treatments. However, after 20 years trends in the distribution of Mg had emerged which could be attributed to the treatments.

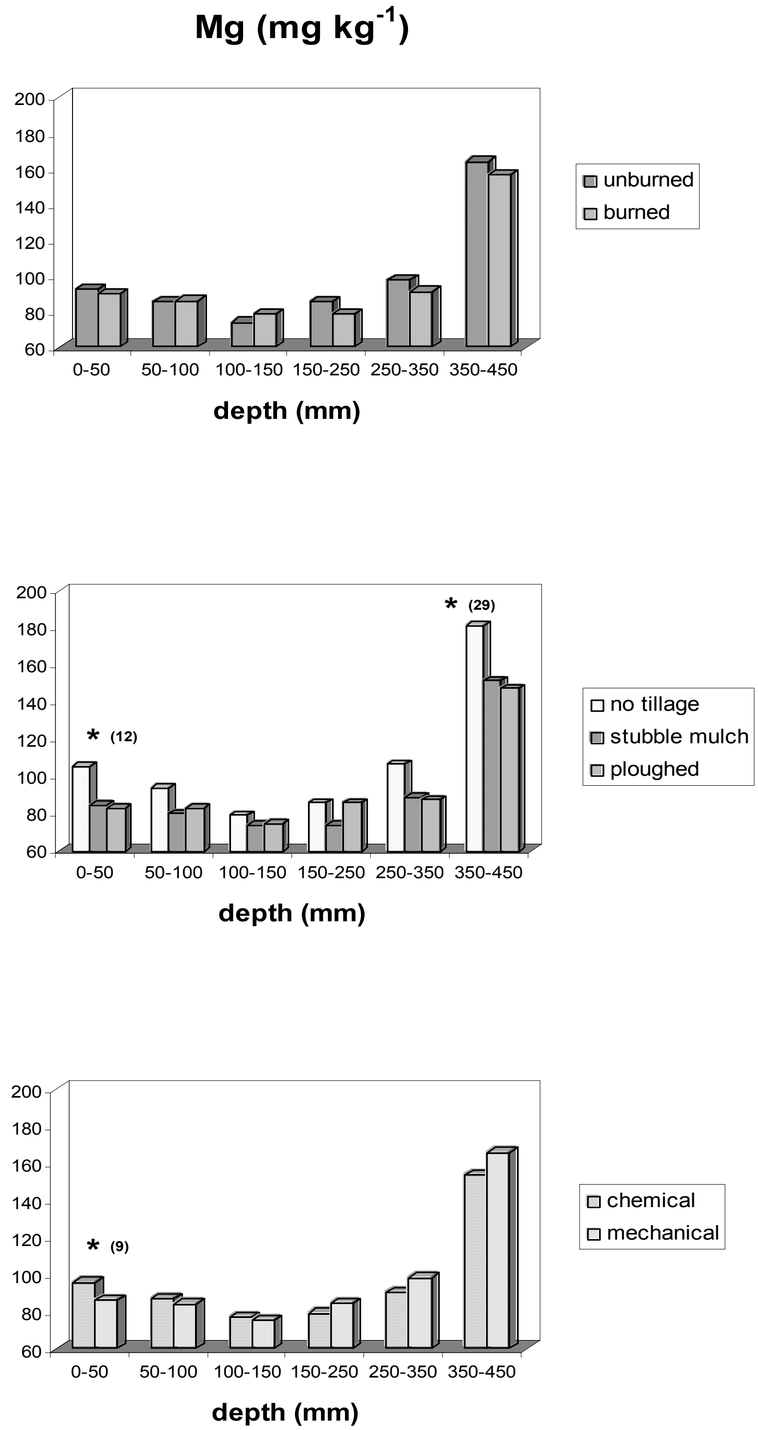

Figure 5.4 Effect of straw burning, tillage and weed control methods on Mg. LSD_T-values are shown, where applicable.

Table 5.8 Effect of the interactions between straw burning, tillage and weed control methods on Mg (mg kg^{-1})

		Tillage			Weeding	
		None	Mulched	Ploughed	Chemical	Mechanical
0 – 50 mm layer						
Straw	Unburned	106	84	87	96	88
	Burned	106	85	79	96	84
Weeding	Chemical	120	86	82		
	Mechanical	92	84	83		
50 – 100 mm layer						
Straw	Unburned	91	78	88	86	85
	Burned	97	82	78	88	83
Weeding	Chemical	100	79	82		
	Mechanical	88	81	84		
100 – 150 mm layer						
Straw	Unburned	76	70	76	72	76
	Burned	82	78	74	82	75
Weeding	Chemical	84	74	72		
	Mechanical	74	74	78		
150 – 250 mm layer						
Straw	Unburned	88	74	95	82	88
	Burned	84	74	77	76	91
Weeding	Chemical	81	69	87		
	Mechanical	91	78	85		
250 – 350 mm layer						
Straw	Unburned	105	95	93	93	102
	Burned	109	83	82	88	94
Weeding	Chemical	96	85	89		
	Mechanical	117	92	86		
350 – 450 mm layer						
Straw	Unburned	174	165	152	157	170
	Burned	188	139	143	151	162
Weeding	Chemical	170	139	153		
	Mechanical	192	164	142		

5.2.5 Exchangeable Na

From the summary of the analyses of variance in Table 5.9, it is clear that the different treatments did not influence Na significantly at all.

Table 5.9 Summary of the analyses of variance indicating the significant effects on Na at a 95% confidence level

	Layer (mm)					
Treatments[a]	**0-50**	**50-100**	**100-150**	**150-250**	**250-350**	**350-450**
A						
B						
AB						
C						
AC						
BC						
ABC						

[a]A : burning, B : tillage and C : weeding

Main effects

In the first five soil layers almost similar Na contents were recorded in the unburned and burned plots (Figure 5.5). A slightly higher Na content was however, measured in the sixth soil layer of unburned than burned plots, but the difference was not significant.

Further inspection of Figure 5.5 shows that the tillage practices that were applied as well as the method of weeding had neither a significant nor a consistent effect on the Na content of the six soil layers.

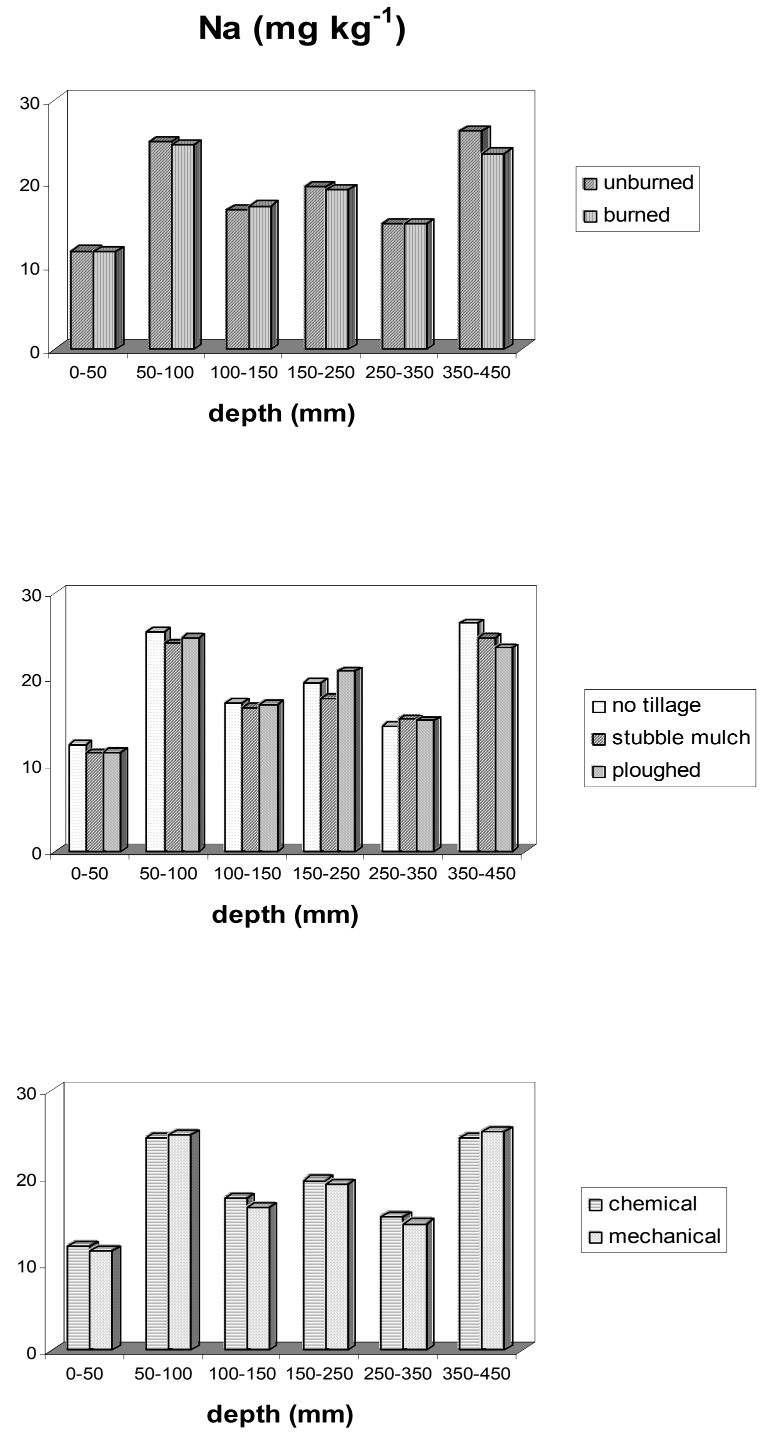

Figure 5.5 Effect of straw burning, tillage and weed control methods on Na. LSD_T-values are shown, where applicable.

Interactions

Data on the interactions between the different treatments with regard to Na is presented in Table 5.10. As mentioned earlier none of the interactions between the different treatments were significant (Table 5.9). Consequently, no trends were observed that are worth mentioning. In an earlier study Du Preez *et al.* (2001) also found that Na was not influenced significantly by any of the treatments applied in this trial.

Table 5.10 Effect of the interactions between straw burning, tillage and weed control methods on Na (mg kg^{-1})

		Tillage		Weeding	
	None	Mulched	Ploughed	Chemical	Mechanical
0 – 50 mm layer					
Straw Unburned	12.5	11.2	11.8	12.3	11.4
Burned	12.3	11.6	11.2	11.8	11.6
Weeding Chemical	12.6	11.8	11.7		
Mechanical	12.1	11.0	11.3		
50 – 100 mm layer					
Straw Unburned	26.0	24.3	24.6	25.0	25.0
Burned	25.0	24.0	24.8	24.3	24.9
Weeding Chemical	25.7	23.6	24.5		
Mechanical	25.3	24.6	24.9		
100 – 150 mm layer					
Straw Unburned	16.9	16.0	17.4	17.3	16.3
Burned	17.5	17.4	16.8	17.8	16.7
Weeding Chemical	17.7	17.2	17.7		
Mechanical	16.7	16.2	16.5		
150 – 250 mm layer					
Straw Unburned	20.2	18.0	20.6	19.7	19.4
Burned	19.0	17.5	21.2	19.6	18.9
Weeding Chemical	19.9	18.00	21.2		
Mechanical	19.3	17.6	20.6		
250 – 350 mm layer					
Straw Unburned	14.3	16.9	13.9	14.8	15.3
Burned	14.8	13.9	16.5	16.0	14.1
Weeding Chemical	14.3	15.6	16.4		
Mechanical	14.8	15.1	14.0		
350 – 450 mm layer					
Straw Unburned	27.3	26.2	25.3	26.0	26.5
Burned	25.6	23.3	21.9	23.2	24.0
Weeding Chemical	25.5	23.0	25.2		
Mechanical	27.4	26.4	21.9		

5.2.6 Exchangeable Cu

The summary of the analyses of variance in Table 5.11 shows that Cu was affected significantly by the burning and weeding treatments. The tillage treatment had no influence on Cu.

Table 5.11 Summary of the analyses of variance indicating the significant effects on Cu at a 95% confidence level

	Layer (mm)					
Treatments[a]	**0-50**	**50-100**	**100-150**	**150-250**	**250-350**	**350-450**
A			*			
B						
AB						
C				*		
AC			*			
BC						
ABC						

[a]A : burning, B : tillage and C : weeding

Main effects

As shown in Figure 5.6, the unburned and burned plots had almost similar Cu contents in the upper two soil layers. In the 100-150 mm layer the Cu content of the unburned plots was significantly higher than that of the burned plots. This trend, although not significant, was also recorded in the 150-250 mm layer. The Cu contents in the bottom two soil layers of the unburned and burned plots were again very much the same.

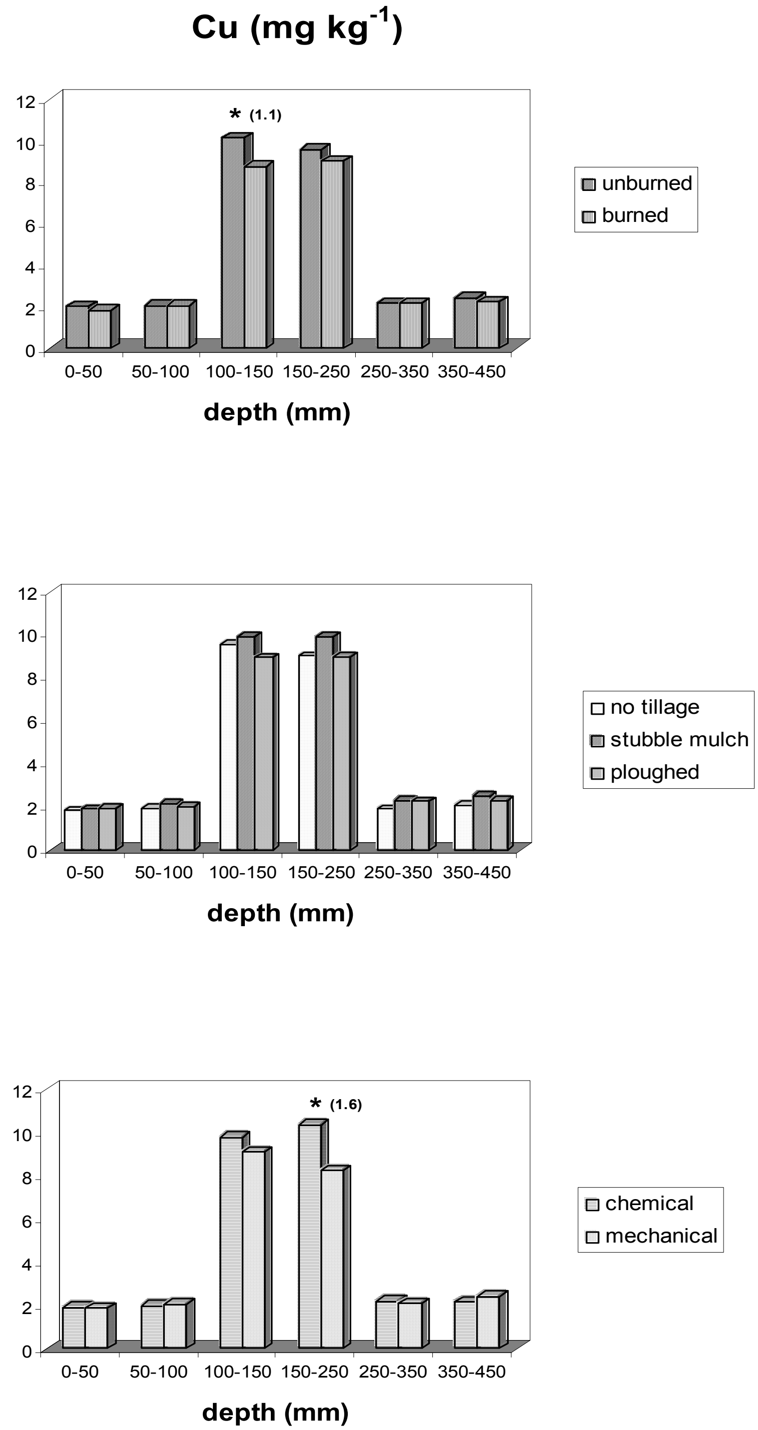

Figure 5.6 Effect of straw burning, tillage and weed control methods on Cu.

LSD_T-values are shown, where applicable.

The tillage methods had no significant influence on Cu as illustrated in Figure 5.6. However, the 100-150 and 150-250 mm layers show slight differences in Cu content on account of the tillage methods.

Inspection of Figure 5.6 indicates very much the same Cu contents in the upper two layers of the chemical- and mechanically-weeded plots. The chemically-weeded plots had a higher Cu content than the mechanically-weeded plots in the 100-150 and 150-250 mm layers, with a significant difference only in the latter layer. In the bottom two layers the Cu contents of the chemically- and mechanically-weeded plots were similar.

Interactions

Data on the interactions between the different treatments with regard to Cu is given in Table 5.12. The only significant interaction was recorded between the burning and weeding treatments in the 100-150 mm layer with an LSD_{Tukey} of 2.1 mg kg^{-1} (Table 5.11). The unburned plots with chemical weeding had the highest Cu content of 11.1 mg kg^{-1} and the burned plots with chemical weeding had the lowest Cu content of 8.5 mg kg^{-1}. No general trends in Cu content could be observed for any of the three interactions.

Unfortunately, Du Preez *et al.* (2001) did not investigate the distribution of Cu after the treatments had been applied for 11-12 years. No comparison is therefore possible with the distribution of Cu recorded in this study after the treatments had been applied for 20 years.

Table 5.12 Effect of the interactions between straw burning, tillage and weed control methods on Cu (mg kg^{-1})

		Tillage			Weeding	
		None	Mulched	Ploughed	Chemical	Mechanical
0 – 50 mm layer						
Straw	Unburned	1.9	2.0	2.0	2.1	1.9
	Burned	1.8	1.8	1.9	1.7	1.9
Weeding	Chemical	1.9	1.8	2.1		
	Mechanical	1.8	2.1	1.8		
50 – 100 mm layer						
Straw	Unburned	2.0	2.2	1.9	2.0	2.0
	Burned	1.9	2.2	2.1	2.0	2.1
Weeding	Chemical	2.1	1.9	2.0		
	Mechanical	1.8	2.4	2.0		
100 – 150 mm layer						
Straw	Unburned	10.3	11.4	8.8	11.1	9.2
	Burned	8.8	8.4	9.1	8.5	9.1
Weeding	Chemical	10.0	10.4	9.1		
	Mechanical	9.1	9.4	8.8		
150 – 250 mm layer						
Straw	Unburned	9.4	10.4	9.0	11.1	8.1
	Burned	8.7	9.4	9.0	9.7	8.4
Weeding	Chemical	10.6	10.8	9.6		
	Mechanical	7.4	9.0	8.3		
250 – 350 mm layer						
Straw	Unburned	1.8	2.3	2.4	2.3	2.1
	Burned	2.0	2.3	2.2	2.1	2.2
Weeding	Chemical	2.2	2.1	2.3		
	Mechanical	1.6	2.5	2.3		
350 – 450 mm layer						
Straw	Unburned	2.0	2.7	2.5	2.4	2.4
	Burned	2.1	2.4	2.2	2.0	2.4
Weeding	Chemical	2.1	2.3	2.2		
	Mechanical	2.1	2.7	2.5		

5.2.7 Exchangeable Fe

The burning and tillage treatments had a significant influence on Fe as indicated in the summary of the analyses of variance in Table 5.13. The weeding treatment showed no influence on Fe.

Table 5.13 Summary of the analyses of variance indicating the significant effects on Fe at a 95% confidence level

	Layer (mm)					
Treatments[a]	**0-50**	**50-100**	**100-150**	**150-250**	**250-350**	**350-450**
A	*					
B	*				*	*
AB	*					
C						
AC						
BC						
ABC						

[a]A : burning, B : tillage and C : weeding

Main effects

A significantly higher Fe content was measured in the 0-50 mm layer of the unburned than burned plots (Figure 5.7). This trend, although not significant, was reversed in the 50-100 mm layer. In the other four layers the Fe content was similar despite the burning treatment.

Inspection of Figure 5.7 shows that the Fe content of the no-tilled and mulched plots was significantly higher than that of the ploughed plots in the 0-50 mm layer.

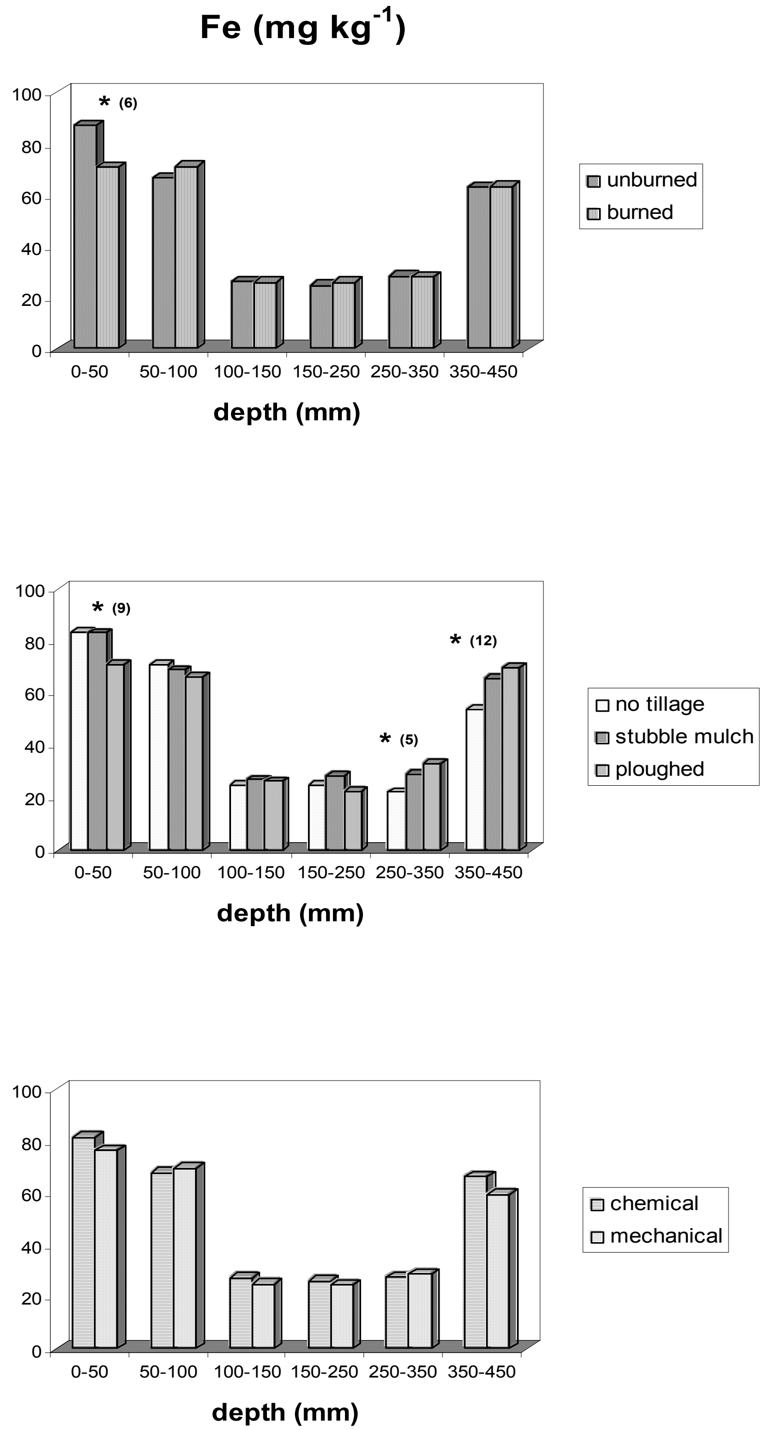

Figure 5.7 Effect of straw burning, tillage and weed control methods on Fe. LSD_T-values are shown, where applicable.

In the 50-100 mm layer a gradual decline in Fe content was recorded with an increasing intensity of tillage. No real trend in the Fe content was observed for the 100-150 and 150-250 mm layers as a result of the tillage methods. In the 250-350 and 350-450 mm layers a significant increase in Fe content was measured from the no-tilled to mulched to ploughed plots.

There was no significant difference in the Fe content of the soil layers on account of the different weeding methods (Figure 5.7). However, chemical weeding resulted in slightly higher Fe contents than mechanical weeding in four of the six soil layers.

Interactions

The data on the interactions between the different treatments with regard to Fe is summarized in Table 5.14. The only significant interaction was recorded between the burned and tillage treatments in the 0-50 mm layer with an LSD_{Tukey} of 16 mg kg^{-1} (Table 5.13). In this layer the mulched plots that were not burned had the highest Fe content of 96 mg kg^{-1} and the mulched plots that were burned had the lowest Fe content of 70 mg kg^{-1}. For this particular interaction there does not seem to be a similar trend in the other soil layers.

On further inspection of Table 5.14 some trends in the 0-50 mm layer are worth mentioning. A higher Fe content was measured in the unburned than burned plots regardless of the tillage or weeding method applied. The only exception was with ploughing where the unburned and burned plots had a Fe content of 71 mg kg^{-1}. Both no-tilled and mulched plots had, with chemical weeding, a higher Fe content than with mechanical weeding.

The different treatments resulted, after 20 years of application, in definite Fe distribution trends. It is unknown whether these trends were already manifested 11-12 years after commencement of the trial. Du Preez *et al*. (2001) did not determine the distribution of Fe at that stage.

Table 5.14 Effect of the interactions between straw burning, tillage and weed control methods on Fe (mg kg^{-1})

		Tillage			Weeding	
		None	Mulched	Ploughed	Chemical	Mechanical
0 – 50 mm layer						
Straw	Unburned	95	96	71	93	82
	Burned	71	70	71	70	71
Weeding	Chemical	87	72	86		
	Mechanical	80	70	80		
50 – 100 mm layer						
Straw	Unburned	71	66	62	65	68
	Burned	71	72	70	71	71
Weeding	Chemical	69	66	69		
	Mechanical	73	72	64		
100 – 150 mm layer						
Straw	Unburned	25	27	26	27	25
	Burned	24	27	27	27	25
Weeding	Chemical	28	26	28		
	Mechanical	22	28	25		
150 – 250 mm layer						
Straw	Unburned	22	28	24	26	24
	Burned	27	29	21	26	25
Weeding	Chemical	28	28	23		
	Mechanical	22	29	22		
250 – 350 mm layer						
Straw	Unburned	24	28	33	29	28
	Burned	21	30	33	27	29
Weeding	Chemical	23	29	31		
	Mechanical	22	29	35		
350 – 450 mm layer						
Straw	Unburned	55	68	66	69	57
	Burned	53	64	74	64	62
Weeding	Chemical	59	71	70		
	Mechanical	49	61	69		

5.2.8 Exchangeable Mn

Only the burned and tillage treatment had a significant influence on Mn as indicated in the summary of the analyses of variance in Table 5.15.

Table 5.15 Summary of the analyses of variance indicating the significant effects on Mn at a 95% confidence level

	Layer (mm)					
Treatments[a]	**0-50**	**50-100**	**100-150**	**150-250**	**250-350**	**350-450**
A	*	*			*	*
B			*		*	*
AB						
C						
AC						
BC						
ABC						

[a]A : burning, B : tillage and C : weeding

Main effects

As shown in Figure 5.8, the burned plots had a higher Mn content than the unburned plots in five of the six layers. This difference in Mn content was significant in the 0-50, 250-350 and 350-450 mm layers. However, in the 50-100 mm layer a significantly higher Mn content was measured in the unburned than burned plots.

Inspection of Figure 5.8 shows that significant differences in Mn content resulted from the tillage methods in the 100-150, 250-350 and 350-450 mm soil layers. The

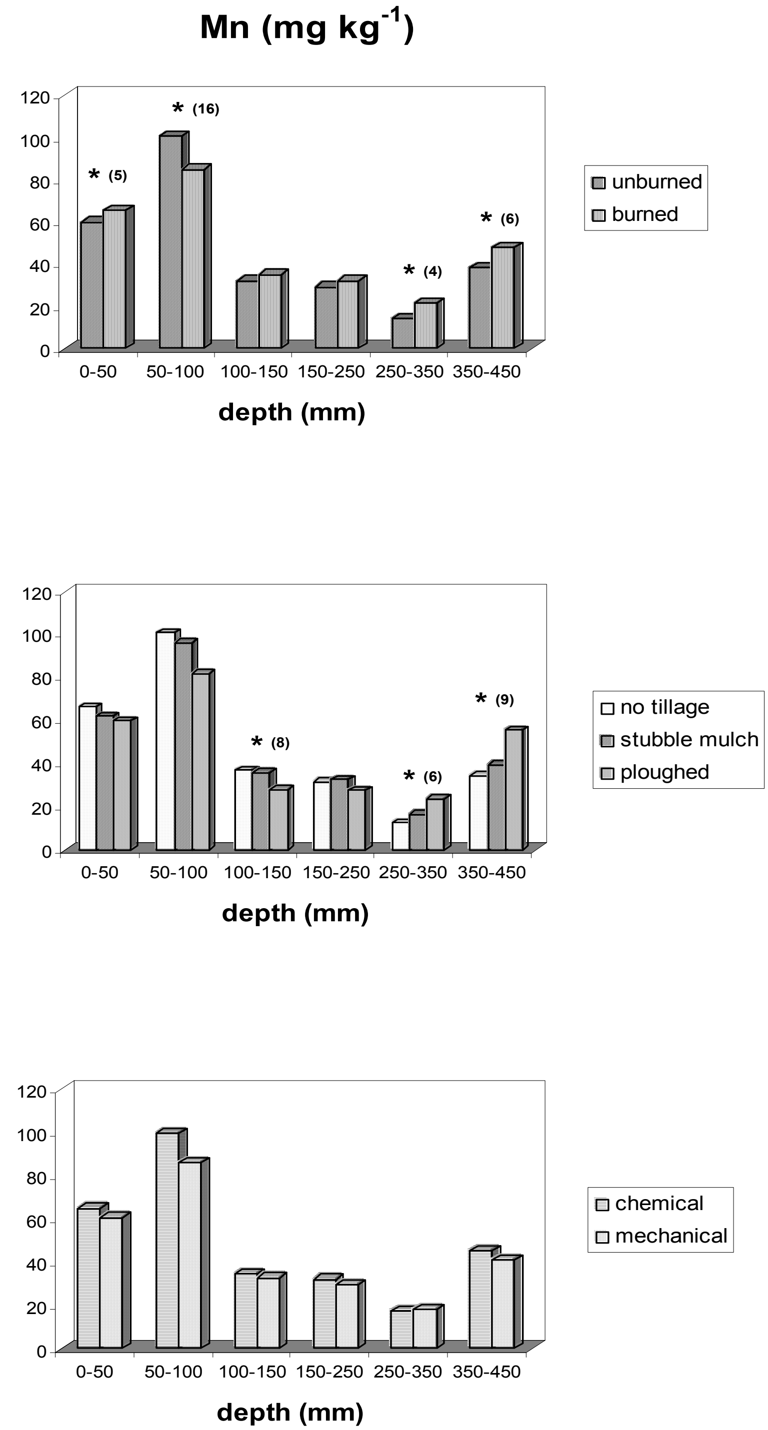

Figure 5.8 Effect of straw burning, tillage and weed control methods on Mn. LSD_T-values are shown, where applicable.

general trend in the upper four layers is a decline in the Mn content with increasing tillage intensity. This trend is reversed in the bottom two layers.

No significant difference in Mn content was recorded in any of the soil layers between the two weeding methods (Figure 5.8). The plots with chemical weeding had slightly higher Mn contents than the plots with mechanical weeding in all except the 250-350 mm soil layer.

Interactions

Data on the interactions between the different treatments with regard to Mn is presented in Table 5.16. No significant interactions between any of the different treatments were recorded (Table 5.15). However, a few trends in the upper two soil layers are of importance. Despite the tillage or weeding methods that were applied, the burned plots contained more Mn in the 0-50 mm layer than the unburned plots, but in the 50-100 mm layer this trend is reversed. The chemically-weeded plots contained more Mn in these two upper layers than the mechanically-weeded plots irrespective of tillage method.

The distribution of Mn was also not determined by Du Preez *et al.* (2001) 11-12 years after commencement of this trial. A comparison of the Mn distribution patterns observed in this study with previous ones is therefore impossible.

Table 5.16 Effect of the interactions between straw burning, tillage and weed control methods on Mn (mg kg^{-1})

		Tillage			Weeding	
		None	Mulched	Ploughed	Chemical	Mechanical
0 – 50 mm layer						
Straw	Unburned	64	60	57	62	58
	Burned	69	64	63	68	64
Weeding	Chemical	69	63	63		
	Mechanical	64	61	57		
50 – 100 mm layer						
Straw	Unburned	117	103	83	115	87
	Burned	85	89	80	85	85
Weeding	Chemical	111	103	86		
	Mechanical	91	89	78		
100 – 150 mm layer						
Straw	Unburned	34	35	28	32	33
	Burned	40	37	28	37	33
Weeding	Chemical	39	36	29		
	Mechanical	35	36	27		
150 – 250 mm layer						
Straw	Unburned	27	33	28	30	29
	Burned	36	33	28	34	30
Weeding	Chemical	36	32	28		
	Mechanical	27	34	28		
250 – 350 mm layer						
Straw	Unburned	10	11	21	13	15
	Burned	16	22	27	22	21
Weeding	Chemical	13	17	22		
	Mechanical	12	16	25		
350 – 450 mm layer						
Straw	Unburned	29	35	51	40	36
	Burned	40	44	61	51	46
Weeding	Chemical	38	42	57		
	Mechanical	32	37	54		

5.2.9 Exchangeable Zn

According to the summary of the analyses of variance in Table 5.17, Zn was significantly influenced by the burned and tillage treatments. The weeding treatment had no influence on Zn whatsoever.

Table 5.17 Summary of the analyses of variance indicating the significant effects on Zn at a 95% confidence level

	Layer (mm)					
Treatments[a]	**0-50**	**50-100**	**100-150**	**150-250**	**250-350**	**350-450**
A			*	*		
B	*	*				
AB						
C						
AC						
BC						
ABC						

[a]A : burning, B : tillage and C : weeding

Main effects

As shown in Figure 5.9, the unburned and burned plots had almost similar Zn contents in the upper two soil layers. In the 100-150 and 150-250 mm layers, significantly higher Zn contents were measured in the burned plots than unburned plots. The unburned and burned plots also had very similar Zn contents in the bottom two soil layers.

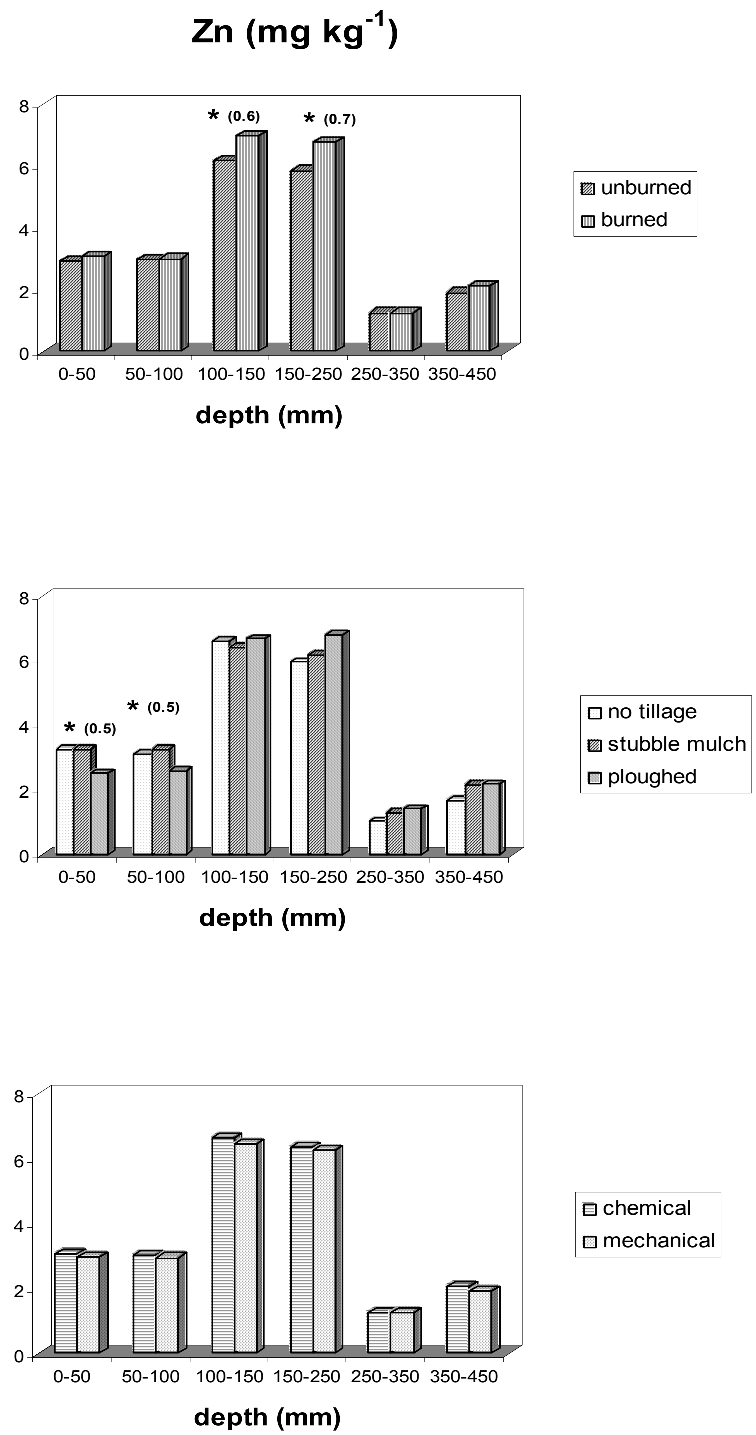

Figure 5.9 Effect of straw burning, tillage and weed control methods on Zn. LSD_T-values are shown, where applicable.

The tillage methods had a significant effect on Zn in the 0-50 and 50-100 mm soil layers (Figure 5.9). In these two layers the ploughed plots had the lowest Zn content while the mulched and no-tilled plots had very similar Zn contents. No real trends were observed for Zn in the deeper soil layers that could be attributed to the tillage practices.

Inspection of Figure 5.9 shows that chemical weeding increased Zn slightly compared to mechanical weeding, although no significant difference was recorded in any soil layer.

Interactions

The data on the interactions between the different treatments with regard to Zn is displayed in Table 5.18. As indicated in Table 5.17 no significant interactions were recorded between any of the treatments. The only trend worth mentioning is that to a depth of 250 mm, higher Zn contents were measured in the burned than unburned plots despite the tillage practice applied.

Samples analyzed by Du Preez *et al.* (2001) 11-12 years after commencement of the trial, also indicated that Zn was influenced significantly by mainly the burning and tillage methods. They found that burning increased the Zn content in the 0-50 mm layer of the no-tilled, mulched and chemically-weeded plots but not the Zn content of the ploughed and mechanically-weeded plots. Burning however increased Zn in the 50-150 mm layer despite the tillage or weeding method. In general Zn of the unburned, burned and chemically-weeded plots decreased as the degree of tillage intensified.

Table 5.18 Effect of the interactions between straw burning, tillage and weed control methods on Zn (mg kg^{-1})

		Tillage			Weeding	
		None	Mulched	Ploughed	Chemical	Mechanical
0 – 50 mm layer						
Straw	Unburned	3.2	3.2	2.5	2.9	3.0
	Burned	3.4	3.3	2.6	3.2	3.0
Weeding	Chemical	3.4	3.2	2.6		
	Mechanical	3.1	3.3	2.5		
50 – 100 mm layer						
Straw	Unburned	3.1	3.2	2.6	3.0	3.0
	Burned	3.1	3.3	2.6	3.1	2.9
Weeding	Chemical	3.3	3.1	2.6		
	Mechanical	2.9	3.4	2.6		
100 – 150 mm layer						
Straw	Unburned	6.2	6.2	6.2	6.3	6.0
	Burned	7.0	6.7	7.2	7.0	6.9
Weeding	Chemical	6.4	6.6	7.0		
	Mechanical	6.8	6.3	6.3		
150 – 250 mm layer						
Straw	Unburned	5.4	5.9	6.2	5.9	5.8
	Burned	6.5	6.4	7.4	6.8	6.7
Weeding	Chemical	6.1	5.9	7.1		
	Mechanical	5.8	6.5	6.5		
250 – 350 mm layer						
Straw	Unburned	0.9	1.4	1.5	1.3	1.2
	Burned	1.2	1.2	1.4	1.2	1.3
Weeding	Chemical	1.2	1.2	1.3		
	Mechanical	0.9	1.4	1.5		
350 – 450 mm layer						
Straw	Unburned	1.4	2.1	2.1	1.9	1.8
	Burned	1.9	2.2	2.2	2.2	2.0
Weeding	Chemical	1.8	2.2	2.1		
	Mechanical	1.5	2.1	2.2		

From the preceding results it is clear that after 20 years the distribution of all the plant nutrients under investigation, except Na, were influenced to some extent by the treatments. In an earlier study Du Preez *et al.* (2001) reported that after only 11-12 years the treatments had already influenced the distribution of P, K and Zn, but not that of Ca, Mg and Na. Unfortunately, the distributions of Cu, Fe and Mn were not investigated by Du Preez *et al.* (2001) as in this study.

In general the burned plots contained more P, K, Cu, Fe, Mn and Zn, even as deep as 100 to 350 mm, than the unburned plots. This observation corresponds with findings in a few other studies of this nature as reviewed by Kumar & Goh (2000).

No tillage, and to a lesser extent also mulched tillage, resulted in an accumulation of P, K, Ca, Mg, Cu, Fe, Mn and Zn in especially the upper 100-150 mm soil when ploughing served as reference. This trend was also observed with chemical weeding when compared to mechanical weeding. Similar results were obtained in many other studies of this nature (Shear & Mossler, 1969; Juo & Lal, 1979; Hargrove *et al*., 1982; Dick, 1983; Langdale *et al*., 1984; Evangelou & Blevins, 1985; Hargrove, 1985; Shuman & Hargrove, 1985; Follett & Peterson, 1988; Unger, 1991; Edwards *et a*l., 1992; Horne *et al*., 1992; Ismail *et al*., 1994; Fransluebbers & Hons, 1996; Luna-Orea *et al*., 1996; Selles *et al*., 1997; Lal, 1997; Vyn & Yin, 1999; Pekrun *et al*., 2003;).

The accumulation of nutrients in the upper 100-150 mm soil that coincide with conservational tillage practices is mainly attributed to the placement of crop residues. For example Allmaras, Copeland, Copeland & Oussible (1996) found that mouldboard ploughing to a depth of 250 mm, buried 70% of the residue at a depth of

120-240 mm, where chisel ploughing to a depth of 150 mm left nearly 60% of the residue at a depth of 0-60 mm. Nearly all of the residue was left at or above the soil surface by no tillage. Upon residue decomposition nutrients are released and seem to remain largely in the vicinity, especially those nutrients regarded as immobile in soil.

However, with conservational tillage practices, the application of nutrients through fertilization can also contribute to an accumulation of nutrients in the upper 100-150 mm soil (Pekrun *et al.*, 2003). In this particular trial P and Zn were applied and thorough mixing into the soil, as with conventional ploughing, was almost absent with stubble mulch and no tillage (Section 2.2). However, some of the other nutrients could have been applied as impurities in the fertilizer.

The accumulation of nutrients in the upper 100-150 mm soil on account of conservational tillage practices may influence their availability for uptake and ultimately crop yield. This matter warrants further research to establish all the benefits and detriments of conservational tillage practices.

As stated in Section 2.1 no baseline analyses of the nutrients under investigation are available for the experimental soil. However, if the nutrient contents of the headlands given in Table 2.2 are used as reference then it is clear that the fertility status of the experimental soil changed considerably from 1979 to 1999 when the treatment effects are ignored (Table 5.19). Only the weighted means to respectively 150 mm and 250 mm are given since soil samples are usually taken in this depth range for fertilization recommendations.

Inspection of Table 5.19 showed that, although not statistically verified, higher P, K, Cu, Fe, Mn and Zn contents and lower Ca, Mg and Na contents occurred in the experimental than in the headlands soil. The higher contents of P and Zn can be attributed *inter alia* to fertilization but not those of K, Cu, Fe and Mn which probably resulted through redistribution from deeper soil. Losses of Ca, Mg and Na are common in cropped soils for several reasons as listed in Section 4.1. These changes in nutrient content may have an even greater influence on crop performance than the changes in nutrient content induced by the treatments.

Table 5.19 Weighted mean nutrient contents to 150 mm and 250 mm depth in the headlands with perennial grass outside the trial, and inside the trial cropped annually with wheat

Nutrient ($mg\ kg^{-1}$)	**0-150 mm**		**0-250 mm**	
	Headlands	**Trial**	**Headlands**	**Trial**
P	11	31	10	31
K	336	362	216	327
Ca	894	620	830	661
Mg	157	84	178	83
Na	101	18	93	18
Cu	3	5	3	6
Fe	46	58	34	45
Mn	47	63	36	56
Zn	3	5	3	6

5.3 Conclusion

Based on the results of this study it is clear that the content of P, K, Cu, Fe, Mn and Zn in this Avalon soil were increased to substantial depths when the wheat straw was burned in comparison with when it was not burned. No tillage and to a lesser extent also mulched tillage resulted in an accumulation of P, K, Ca, Mg, Cu, Fe, Mn and Zn in the upper 100-150 mm soil when ploughing served as reference. This trend in nutrient accumulation was also observed with chemical weeding when compared to mechanical weeding.

The accumulated nutrients are unlikely to be taken up by wheat cultivated under dryland conditions in summer rainfall regions that are semi-arid. In such conditions the chance is good that the uptake of the accumulated nutrients will be restricted by the dry soil in the winter when wheat needs it most. This aspect warrants thorough research in future to establish whether the performance of wheat is hampered or not by the nutrient accumulation resulting from conservational tillage practices.

CHAPTER 6

General discussion and recommendations

Crop residue management is known to both directly or indirectly affect soil quality and therefore soil fertility. Any changes in soil fertility as a result of residue management can have a variable effect on grain yield. It is therefore important to determine soil fertility changes associated with residue management practices under local conditions, before it is propagated to farmers for implementation. The objective of this study was therefore to determine the temporal and spatial influences of wheat residue management practices on some soil fertility indicators. A secondary objective was to establish whether differences in wheat grain yield could be attributed to the temporal and spatial changes in the soil fertility indicators.

A long-term wheat trial at the ARC-Small Grain Institute near Bethlehem in the Eastern Free State on an Avalon soil has been running since 1979, where the effects of some residue management practices, *viz*. burning of residues, tillage practices and weeding methods, were examined. Soil samples were taken in 1999 for this study about 20 years after the trial commenced. Samples were taken from the headlands with perennial grass outside the trial as well as inside the trial, in order to determine the temporal and spatial influences of the different wheat residue management practices on various soil fertility indicators.

Organic C and total N were determined as indices of soil organic matter. The different tillage practices had a bigger effect on organic matter than that of either straw burning or weeding method, especially in the upper 100 mm soil. No-tilled plots had higher organic matter contents than mulched or ploughed plots. The interactions showed that no tillage combined with chemical weeding resulted in the highest organic matter content and ploughing combined with mechanical weeding resulted in the lowest organic matter content, to approximately 150 mm depth.

Soil pH was determined as an index of soil acidity. Burning of residues increased pH significantly compared to no burning of residues. No tillage plots had a higher pH than that of the ploughed and mulched plots. Chemical weeding also increased the pH compared with mechanical weeding. Therefore it was concluded that no tillage combined with chemical weeding was the most beneficial combination to restrict acidification.

The contents of the following plant nutrients were determined to establish the effect that the different wheat residue management practices had on them, *viz.* P, K, Ca, Mg, Na, Cu, Fe, Mn and Zn. It was found that the contents of P, K, Cu, Fe, Mn and Zn were increased with straw burning when compared to no burning of straw. No tillage resulted in an accumulation of P, K, Ca, Mg, Cu, Fe , Mn and Zn in the upper 150 mm soil. Chemical weeding also followed the same trend of accumulation of nutrients in the upper 100 mm soil when compared with mechanical weeding.

The benefits and detriments of the changes in the soil fertility indicators that took place over the long-term as a result of the different residue management practices applied in this trial can only be rated against the grain yields. Therefore mean grain yields obtained with the main treatments were calculated for two periods, *viz*. the first five years and the last five years as presented in Figure 6.1. The first period is from 1981 to 1985 since the trial started in 1979 and no wheat was planted in 1980. In this period it could be expected that the treatments had little influence on the soil fertility. The second period is from 1995 to 1999 since the soil samples for this study were collected in 1999. In this period it could be expected that the influence of the treatments had already changed the soil fertility. By comparing the grain yield for these two periods, although not statistically verified, may give an indication whether the change in the soil fertility indicators had an influence on grain yield or not.

As shown in Figure 6.1 burning of residues increased the grain yield by approximately 125 kg ha^{-1} for both periods compared to no burning of residues. For both periods the lowest grain yield was recorded in the no-tilled plots, followed in increasing order by the mulched and ploughed plots. Mechanical weeding resulted in very similar, although slightly higher grain yields than chemical weeding for the 1981 to 1985 period. This trend was reversed for the 1995 to 1999 period with chemical weeding resulting in higher grain yield compared to mechanical weeding. Except for the weeding method it seems that over the long-term, when comparing the two periods with each other, that the different residue management practices had the same influence on grain yield. Therefore it seems that the change in soil fertility that followed on the application of the different residue management practices for 20 years did not have an influence on the grain yield trends.

Unfortunately the nutrient content of the wheat plants at critical growth stages was not determined. Such information could help to establish the plant availability of the nutrients that accumulated in the upper 50-100 mm soil of the mulched and

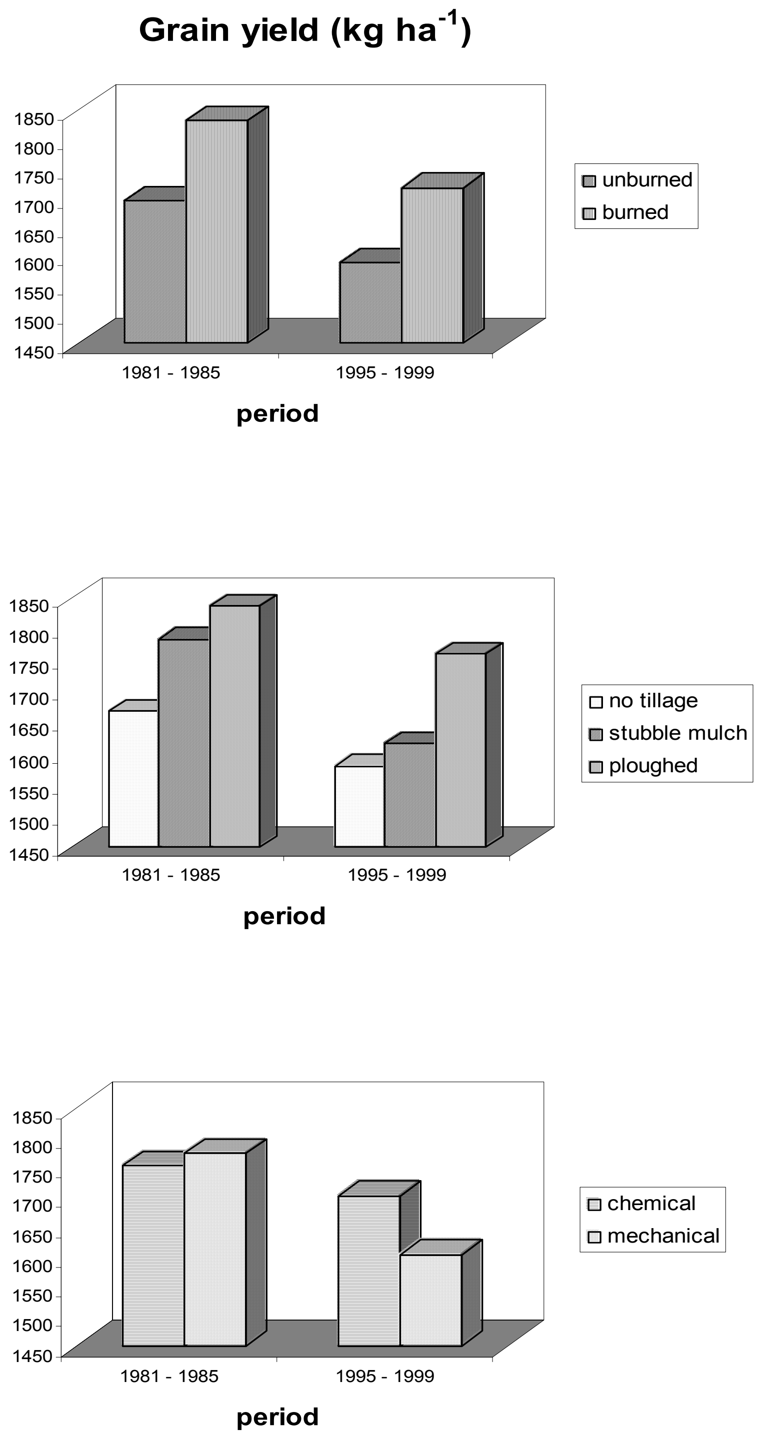

Figure 6.1 Effect of straw burning, tillage and weed control methods on the grain yield of wheat for the periods 1981 to 1985 and 1995 to 1999.

especially the no-tilled plots. However, it seems that the ploughed plots where the nutrients are more evenly distributed within the soil, had the highest grain yields for both periods which may indicate higher plant availability.

Based on the results of this study the following recommendations can be made:

- In order to conserve or even increase the organic matter content of this Avalon soil when cropped annually with wheat, preference should be given to no tillage and to a lesser extent mulch tillage instead of mouldboard ploughing.

- It seems possible to retard the acidification of this Avalon soil by introducing either mulch or no tillage instead of mouldboard ploughing. In addition the burning of wheat residue is also beneficial for combating acidification to some extent.

- Despite above mentioned beneficial effects of mulch and no tillage on this Avalon soil, lower grain yields were recorded with them than with mouldboard ploughing. A reason may be that the accumulated nutrients in the upper 150 mm soil are not so readily available for uptake due to dessication. This aspect warrants thorough investigation in future.

- Another aspect that must be investigated thoroughly in future is the effect of straw burning on the organic matter content of this Avalon soil. In this study contrasting results were obtained with organic C and total N as indices of organic matter.

REFERENCES

ALLMARAS, R.R., COPELAND, S.M., COPELAND, P.J. & OUSSIBLE, M., 1996. Spatial relations between oat residue and ceramic spheres when incorporated sequentially by tillage. *Soil Sci. Soc. Am. J.* 60, 1209-1216.

ARC-ISCW, 2002. Agrometeorological data base. ARC-Institute for Soil, Climate and Water, Pretoria.

BIEDERBECK, V., CAMPBELL, C.A., BOWREN, K.E., SCHNITZER, M. & MCIVER, R.N., 1980. Effect of burning cereal straw on soil properties and grain yields in Saskatchewan. *Soil. Sci. Soc. Am. J.* 44, 103-111.

BIRRU, T.C., 2002. Organic matter restoration by conversion of cultivated land to perennial pasture on three agro-ecosystems in the Free State. M.Sc. Agric. Dissertation, University of the Free State, Bloemfontein.

BLEVINS, R.L., THOMAS, G.W., SMITH, M.S., FRYE, W.W. & CORNELIUS, P.L., 1983. Changes in soil properties after 10 years continuous no-tilled and conventionally tilled corn. *Soil Till. Res.* 3, 135-146.

BUSCHIAZZO, D.E., PANIGATTI, J.L. & UNGER, P.W., 1998. Tillage effects on soil properties and crop production in the sub-humid and semiarid Argentinean Pampas. *Soil Till. Res.* 49, 105-116.

DEMARIA, I.C., MNABUDE, P.C. & DE CASTRO, O.M., 1999. Long-term tillage and crop rotation effects on soil chemical properties of a Rhodic Ferralsol in southern Brazil. *Soil Till. Res.* 51, 71-79.

DICK, W.A., 1983. Organic carbon, nitrogen and phosphorus concentrations and pH in soil profiles as affected by tillage intensity. *Soil Sci. Soc. Am. J.* 47, 102-107.

DORAN, J.W., 1980. Soil microbial and biochemical changes associated with reduced tillage. *Soil Sci. Soc. Am. J.* 44, 765-771.

DU PREEZ, C.C., STEYN, J.T. & KOTZE, E., 2001. Long-term effects of wheat residue management on some fertility indicators on a semi-arid plinthosol. *Soil Till. Res.* 63, 25-33.

DU TOIT, M.E., DU PREEZ, C.C., HENSLEY, M. & BENNIE, A.T.P., 1994. Effek van bewerking op die organiese materiaalinhoud van geselekteerde droëlandgronde in Suid-Afrika. *S.A. J. Plant Soil* 11, 71-80.

EDWARDS, J.H., WOOD, C.W., THURLOW, D.L. & RUF, M.E., 1992. Tillage and crop rotation effects on fertility status of a Hapludult soil. *Soil Sci. Soc. Am. J.* 56, 1577-1582.

EVANGELOU, V.P. & BLEVINS, R.L., 1985. Soil-solution phase interactions of basic cations in long-term tillage systems. *Soil Sci. Soc. Am. J.* 49, 357-362.

FAO, 1998. World reference base for soil resources. World Soil Resources Report 84, FAO, Rome.

FOLLETT, R.F. & PETERSON, G.A., 1988. Surface soil nutrient distribution as affected by wheat-fallow tillage systems. *Soil Sci. Soc. Am. J.* 52, 141-147.

FRANZLUEBBERS, A.J. & HONS, F.M., 1996. Soil-profile distribution of primary and secondary plant-available nutrients under conventional and no tillage. *Soil Till. Res.* 39, 229-239.

HARGROVE, W.L., 1985. Influence of tillage on nutrient uptake and yield of corn. *Agron. J.* 77, 763-768.

HARGROVE, W.L., REID, J.T., TOUCHTON, J.T. & GALLAHER, R.N., 1982. Influence of tillage practices on the fertility status of an acid soil double-cropped to wheat and soybeans. *Agron. J.* 74, 684-687.

HAVLIN, J.L., BEATON, J.D., TISDALE, S.L. & NELSON, W.L., 1999. Soil fertility and fertilizers: an introduction to nutrient management. 6th Edn. Prentice Hall, New Jersey.

HINTZE, J.L., 1997. Number cruncher statistical systems 2000, Kaysville, Utah.

HOFFMAN, J.E., 1990. Die invloed van grondbewerkingspraktyke op die waterbalans van 'n Avalongrond onder koring te Bethlehem. M.Sc. Agric. Verhandeling, Universiteit van die Vrystaat, Bloemfontein.

HORNE, D.J., ROSS, C.W. & HUGHES, K.A., 1992. Ten years of maize/oats rotation under three tillage systems on a silt loam in New Zealand. 1. A comparison of some soil properties. *Soil Till. Res.* 22, 131-143.

ISMAIL, I., BLEVINS, R.L. & FRYE, W.W., 1994. Long-term no-tillage effects on soil properties and continuous corn yields. *Soil Sci. Soc. Am. J.* 58, 193-198.

JUO, A.S.R. & LAL, R., 1979. Nutrient profile in a tropical Alfisol under conventional and no-till systems. *Soil Sci.* 127, 168-173.

KUMAR, K. & GOH, K.M., 2000. Crop residues and management practices: effects on soil quality, soil nitrogen dynamics, crop yield and nitrogen recovery. *Adv. Agron*. 68, 197-319.

LAL, R., 1997. Long-term tillage and maize monoculture effects on a tropical Alfisol in western Nigeria. II. Soil chemical properties. *Soil Till. Res.* 42, 161-174.

LAL, R., 2001. World cropland soils as a source or sink for atmospheric carbon. *Adv. Agron.* 71, 145-191.

LAND TYPE SURVEY STAFF, 2001. Land types of South Africa. ARC-Institute for Soil, Climate and Water, Pretoria.

LANGDALE, G.W., HARGROVE, W.L. & GIDDENS, J., 1984. Residue management in double-crop conservation tillage systems. *Agron. J.* 76, 689-694.

LOBE, I., AMELUNG, W. & DU PREEZ, C.C., 2001. Losses of soil carbon and nitrogen with prolonged arable cropping from sandy soils of the South African Highveld. *Eur. J. Soil Sci.* 52, 93-101.

LUNA-OREA, P, WAGNER. M.G. & GUMPERTZ, M.L., 1996. Decomposition and nutrient release dynamics of two tropical legume cover. *Agron. J.* 88, 758-764.

MACVICAR, C.N., DE VILLIERS, J.M., LOXTON, R.F., VERSTER, E., LAMBRECHTS, J.J.N., MERRYWEATHER, F.R., LE ROUX, J., VAN ROOYEN, T.H. & HARMSE, H.J. VON M., 1977. Soil classification: a binomial system for South Africa. Dept. Agric. Tech. Serv. Sci. Bull. no. 390, Pretoria.

MATAWO, P.R., PIERZYNSKI, G.M., WHITNEY, D. & LAMOND, R.E., 1999. Soil chemical properties as influenced by tillage and nitrogen source, placement, and rates after 10 years of continuous sorghum. *Soil Till. Res.* 50, 11-19.

MOSS, S.R. & COTTERILL, E.G., 1985. The influence of straw ash on some soil properties that can affect herbicide performance. *Soil Till. Res.* 5, 361-370.

PARR, J.F. & PAPENDICK, R.I., 1978. Factors affecting the decomposition of crop residues by microorganisms. In W.R. Oschwald (Ed.). Crop Residue Management Systems. Am. Soc. Agron., Madison, Wisconsin.

PAUSTIAN, K, ELLIOTT, E.T. & CARTER, M.R., 1998. Tillage and crop management impacts on soil C storage: use of long-term experimental data. *Soil Till. Res.* 47, vii-xii.

PEKRUN, C., KAUL, H.P., & CLAUPEIN, W., 2003. Soil tillage for sustainable nutrient management. In A.E. Titi (Ed.). Soil Tillage in Agroecosystems. CRC Press, London.

PRASAD, R. & POWER, J.F., 1991. Crop residue management. *Adv. Soil Sci*. 15, 205-251.

RASMUSSEN, P.E., ALBRECHT, S.L. & SMILEY, R.W., 1998. Soil C and N changes under tillage and cropping systems in semi-arid Pacific Northwest agriculture. *Soil Till. Res.* 47, 197-205.

RASMUSSEN, P.E., ALLMARAS, R.R., ROHDE, C.R. & ROAGER, N.C., 1980. Crop residue influences on soil carbon and nitrogen in a wheat-fallow system. *Soil Sci. Soc. Am. J.* 44, 596-600.

RASMUSSEN, P.E. & COLLINS, H.P., 1991. Long-term impact of tillage, fertilizer and crop residue on soil organic matter in temperate semi-arid regions. *Adv. Agron*. 45, 93-134.

SELLES, F., KOCHHANN, R.A., DENARDIN, J.E., ZENTNER, R.P. & FAGANELLO, A., 1997. Distribution of phosphorus fractions in a Brazilian Oxisol under different tillage systems. *Soil Till. Res.* 44, 23-34.

SHEAR, G.M. & MOSCHLER, W.W., 1969. Continuous corn by the no-tillage and conventional tillage methods. *Agron. J.* 61, 524-526.

SHUMAN, L.M. & HARGROVE, W.L., 1985. Effect of tillage on the distribution of manganese, copper, iron, and zinc in soil fractions. *Soil Sci. Soc. Am. J.* 49:5.

SMITH, J.L. & ELLIOT, L.F., 1990. Tillage and residue management effects on soil organic matter dynamics in semi-arid regions. *Adv. Soil Sci*. 13, 69-88.

SOIL CLASSIFICATION WORKING GROUP, 1991. Soil classification – a taxonomic system for South Africa. *Mem. agric. nat. Resour. S. Afr*. No. 15, Dept. Agric. Dev., Pretoria.

SOIL SURVEY STAFF, 1987. Keys to soil taxonomy. SMSS technical monograph no. 6, Ithaca, New York.

THE NON-AFFILIATED SOIL ANALYSIS WORK COMMITTEE, 1990. Handbook of standard soil testing methods for advisory purposes. Soil Sci. Soc. of S.A., Pretoria.

UNGER, P.W., 1991. Organic matter, nutrient, and pH distribution in no and conventional tillage semiarid soils. *Agron. J.* 83, 186-189.

UNGER, P.W. & MCCALLA, T.M., 1980. Conservation Tillage Systems. *Adv. Agron*. 33, 1-58.

VYN, T.J. & YIN, X., 1999. Nutrient stratification in long-term no-till fields in Ontario. *http://www.ontariocorn.org/feb99art6.html.*

WILTSHIRE, G.H. & DU PREEZ, C.C., 1993. Long-term effects of conservation practices on the nitrogen fertility of a soil cropped annually to wheat. *S. Afr. J. Plant Soil* 10, 70-76.