COMPARISON OF SOIL EROSION UNDER NO-TILL AND CONVENTIONAL TILLAGE SYSTEMS IN THE HIGH RAINFALL MLONDOZI AREA, MPUMALANGA PROVINCE, SOUTH AFRICA

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DECLARATION

I hereby certify that this thesis is my own work, except where duly acknowledged. I also certify that no plagiarism was committed in writing

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Michael Vernon Kidson 31-03-2014

ACKNOWLEDGEMENTS

The Mlondozi Dryland Maize project that developed into the Mlondozi LandCare project was a project that was aimed at developing the agricultural practices of the people in Mlondozi. It was the first LandCare project in South Africa. We learnt a lot, but more importantly we achieved a lot of successes. Special thanks are due to Hester Jansen van Rensburg, project leader, scientist, leader and motivator extraordinaire.

This was a project for a community. Due to the complexities of the project, a number of experts were included in the project team. This included the farmers in Mlondozi, the Mpumalanga Department of Agriculture, especially Simon Tshabalala for his tireless enthusiasm and energy; Dr Jim Findley who taught us to teach the communities; Johann Adendorff, an inspiration and pioneer in community development; our sister Institutes the Plant Protection Research Institute, Jacomina Bloem and Dr Jolisa Pakela, the Institute for Agricultural Engineering Johan Fuls, Johan van Biljon and Gawie Stols; Animal Production Institute Gerry Trytsman, as well as Marie Smith for her much valued contribution with the statistical analysis.

A special thank you to Nicolene Thiebaut for assistance with statistical analysis and the re-write; also Prof. Robin Barnard who has been my supervisor.

To the host of unmentioned people, who contributed to the development of the Mlondozi community, thank-you.

To my family who have been my inspiration and untiring support.

Michael Kidson

ABSTRACT

Comparison of soil erosion under no-till and conventional tillage systems in the high rainfall Mlondozi area, Mpumalanga province, South Africa

By

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Degree: M. Inst Agrar (Land-use planning)

Rural agriculture in Mlondozi, as for South Africa, is has a low productivity, which is the result of poor knowledge, information, beliefs and land tenure which limits the acquiring of loans for inputs.

A LandCare Project was conducted for four years. Training was in the form of farmer managed research demonstrations which included the taught Conservation agriculture farming system which they compared to the Traditional farming system. Eighteen farmers initially joined the program and their soils were monitored for four years. At the end of the project undisturbed soil samples were taken from their fields where maize was cultivated following no-till (NT) farming system, and the conventional tillage system (CT).

The soils from the two farming systems were compared using a laboratory rainfall simulator for run-off, erosion and infiltration. Each storm event in the rainfall simulator lasted for a period of 110 minutes (50 rotations). There were two statistical analyses done on the results. The first was a t-test was applied to the data to test for differences between the two systems, with a sample size of 72, at 18 sights with 4 replicates, except for carbon which was 36 analyses for the 18 sights. There was a significantly higher soil loss for NT soils for storm 1, compared to the CT soil, and a non significant difference for run-off for

storms 1 and 2. Infiltration was significantly lower for the NT soil for the first storm, and not significantly higher for the NT soil for the second storm.

The CT soils had a significantly higher infiltration rate for the first 16 rotations. After 68 minutes (rotation 34) the NT soils infiltration rate was higher. For simulated storm 2 the CT soils had a slightly higher infiltration rate up to 32 minutes (16 rotations) where after NT soils had a higher infiltration rate. Between 48 and 80 minutes (rotations 24 and 40) the NT soils had a significantly higher infiltration rate. From the results it can be concluded that the NT soils maintained the aggregate stability far longer than the CT soils.

The initial and final infiltration rates were compared for the NT and CT soils for the simulated storms 1 and 2. The CT soils' initial and final infiltration rate was similar, while the NT soils had a higher initial and final infiltration rate for the second storm, due to the soils settling with the first storm. The results question current literature that states that sealing of soils is a permanent feature. The carbon content of the NT soils was not significantly higher than the CT soils, which corresponded with the results.

DEDICATION

To God my saviour,

My father who led by example

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ABBREVIATIONS

ARC	Agricultural Research Council
CA	Conservation Agriculture:
CT	Conventional tillage
CO2	Carbon dioxide
EO	Extension Officer
FIR	Final Infiltration Rate
IIR	Initial infiltration rate
ISCW	Institute for Soil, Climate and Water
KCl	Potassium chloride
LAN	Limestone ammonium nitrate
MDACE	Mpumalanga Department of Agriculture, Conservation and Environment
MDC	Mpumalanga Development Corporation
MLPC	Mpumalanga Liming Project Committee
MDML	Mlondozi Dryland Maize liming project
NDA	National Department of Agriculture
NGO	Non-Government Organisation
NLP	National LandCare program
NT	No Till
PDA	Participatory Development Approach
PPRI	Plant Protection Research Institute
SOC	Soil organic carbon
SOM	Soil organic material

CHAPTER 1

INTRODUCTION

This study investigates soil erosion under two tillage systems: No-Till and Conventional tillage. The two systems differ in a number of respects, all of which contribute to some extent to the relative disturbance of the soil that occurs.

The “Conventional tillage” (CT), included:

- typical low input;
- ploughing of the soil;
- grazing the crop residue and minimum weed and pest control;

as typically practised in traditional rural farming systems.

The “No-Till” (NT), curtailed soil disturbance, on the other hand, included a number of additional enhancements, normally associated with Conservation Agriculture (CA), such as:

- Minimum soil disturbance;
- Keeping the soil covered with living or dead mulch;
- Crop rotation;
- Integrated soil fertility, weed control and pest and disease control.

The LandCare programme, adopted by the Department of Agriculture in 1995, is an activity that gets the community actively involved in improving the delivery and adoption of soil conservation practices. It had its origins in Australia, where it became a national programme in 1992. One of the main objectives of the LandCare Program was to demonstrate the differences between the two tillage systems in order to achieve a paradigm shift with the farmers. Any differences in yield and chemical characteristics experienced cannot be explained in terms of soil tillage, *per se,* but rather to the differences in inputs and management between the two systems.

1.1 GENERAL BACKGROUND

Mlondozi was one of three blocks in Mpumalanga, which made up the district of KaNgwane. This so-called homeland was formed in 1982, and on 27 April 1994 the territory was reincorporated into South Africa (KaNgwane, 2010). Mlondozi is located in a high rainfall area and contains many highly weathered and highly leached soils. Consequently high soil acidity is a major problem. Over 90% of the soils were found to have a pH KCl below 4.2. The arable soils have a high potential for good yields, but the soils are not delivering the full production potential due to poor farming practices. The Mlondozi district has a Land tenureship system, which means that the land is distributed by the chiefs, so that the farmers do not own fields of their own. There exists the risk of the field being taken away by the chief, especially if the field is not planted for a particular season.

Because the farmers do not have ownership of the lands they are not able to get production loans for the purchasing of inputs such as lime and fertilizer (D'Haese and Kirsten, 2006). The insecurity of tenure has further resulted in little incentive for soil conservation (Xaba, 2002). The final result is that the average maize yield is very low - at only 0,5 ton ha^{-1}, whereas the potential was 4,5 ton ha^{-1}. With the circumstances above, especially the generally good rainfall, there exists a need to improve the yield without excessive cost and effort. The improved farming system would lead to the protection of the natural resources and improved productivity.

1.2 THE MLONDOZI LANDCARE PROJECT

The Agricultural Research Council – Institute for Soil, Climate and Water (ARC-ISCW) initiated the Mlondozi LandCare project under the SoilCare theme of the National Landcare Programme (NLP). The project was conducted in collaboration with the Southern Highveld Region Extension, Mpumalanga Department of Agriculture, Conservation and Environment (MDACE), Mlondozi farmers and the farmers' associations. The goal of the Mlondozi LandCare project was to demonstrate and assess sound land management practices, by involving local communities, who would contribute to sustainable and profitable agricultural production in the district.

As the main thrust of this project "No-Till" (Conservation Agriculture (CA)), was introduced with the objective of improving yields, following a sustainable farming system with low input costs. This was compared to conventional tillage system typically used in the area.

In this thesis the two farming practices, "No-Till" and "Conventional Tillage", were compared, mainly for soil erosion effects.

1.3 LOCATION AND GENERAL DESCRIPTION OF THE STUDY AREA

Mlondozi is situated in the eastern Highveld of Mpumalanga, bordering Swaziland, as indicated in Figure 1.1. The borders are formed by the Lochiel - Oshoek road (N17) while the Amsterdam municipal district borders the area on the western and southern sides. It is situated between 26° 05' and 26° 30' S and 30° 44' and 31° 00' E.

Mlondozi occupies an area of approximately 54 000 ha. About 3 553 ha (7%) of Mlondozi is occupied by villages and 13 497 ha (25%) is under exotic timber plantations. It has approximately 12 746 ha (23.6%) potentially arable land, including 5 619 ha (10.4%) high potential arable land. The proportions of total arable and high potential arable land are much higher than the respective averages for South Africa, viz. 13% for total arable land and 3% for high potential arable land. An estimated 4000 ha of the potentially arable land is currently being cultivated. Maize is the dominant crop, while there are a number of vegetable gardens, often under supplemental irrigation, largely managed by women's clubs. The crops are very important to livelihoods, providing the basic food requirements of the people (Jansen van Rensburg, 2009).

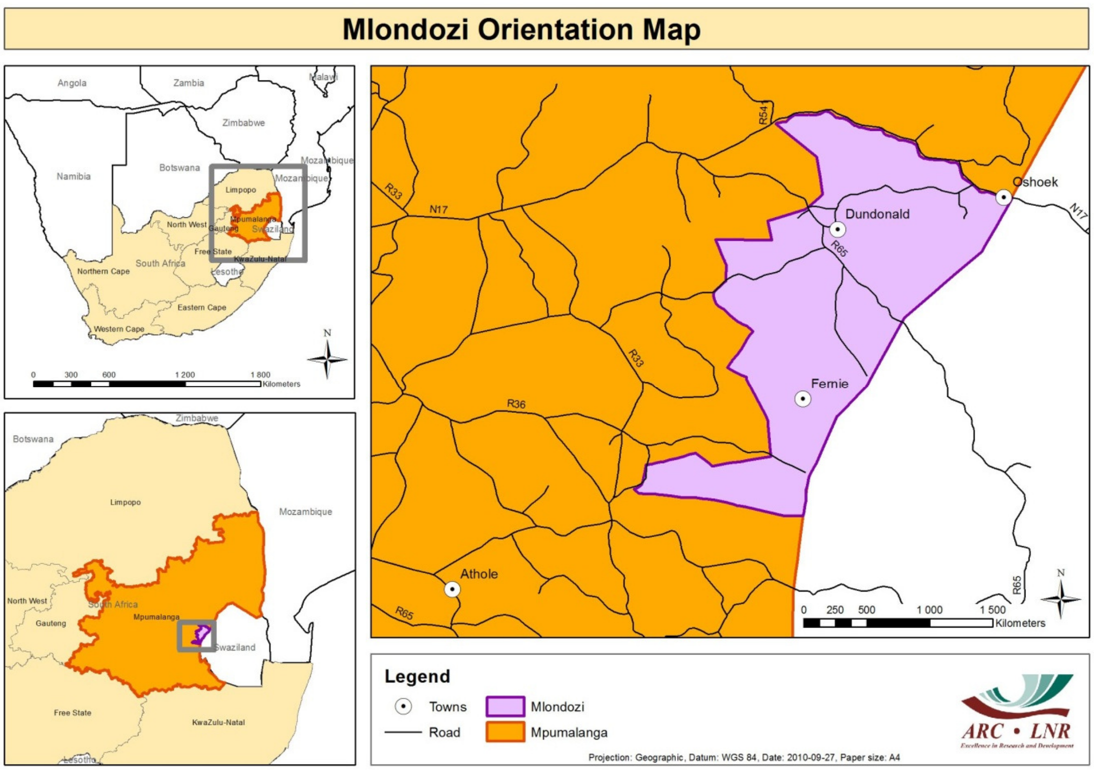

Figure 1.1 Orientation maps, showing Mlondozi on the eastern border of Mpumalanga, and on the western border of Swaziland. Included are the farmers

1.4 PHYSICAL AND BIOLOGICAL RESOURCES OF MLONDOZI

1.4.1 Climate

Mlondozi has a large fluctuation of seasonal, monthly as well as day and night temperatures. The monthly average daily temperatures range from 10.4 °C for the coldest month (June) to 18.3 °C for the hottest months (December to February), with a mean frost season length of 64 days (Agromet, 2010). Long term rainfall for the district is 975 mm in the West and 892 mm in the East as indicated in Table 1.2 and Figure 1.3. Mlondozi is therefore regarded as a high rainfall region (Figure 1.4) with 800 mm plus per annum. Mlondozi has a high humidity (Figure 1.5, Agromet 2010), due to the high rainfall, low evapotranspiration and mist rain. Although Mlondozi experiences a high rainfall it has a low rainfall erosivity index (Figure 1.6).

The ARC – Institute for Soil Climate and Water has 570 automatic weather and 80 mechanical weather stations distributed across the country, giving relatively wide coverage of climatic events. The average long term data for Mlondozi district was measured at Oshoek (1965-2002) and Athole (1936-2004), representing the North and South respectively. This selection was made due to the different climatic zones (Table 1.1, Fig.1.2 & 1.3). The Athole weather station is located 10 km from the study site on the South Western border, and the Oshoek weather station, at the North Eastern corner of the study site, with the following location information:

Athole weather station:

Coordinates: Latitude -26.60; Longitude 30.58
Altitude: 1346 m
Weather station number: 16301

Oshoek weather station:

Coordinates: Latitude -26.22; Longitude 30.98
Altitude: 1470 m
Weather station number: 16486

Table 1.1 Table of long term data for Athole (1936-2004) and Oshoek (1965-2002) weather stations (Agromet, 2010).

Elem	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tx[1]	23.8	23.6	23.0	21.6	19.5	17.2	17.6	19.9	22.4	22.9	23.2	24.0
Tn[1]	12.9	13.0	12.0	9.5	6.3	3.4	3.2	5.1	8.0	10.0	11.5	12.6
Tave[1]	18.4	18.3	17.5	15.6	12.9	10.3	10.4	12.5	15.2	16.4	17.3	18.3
RHx[1]	86.8	88.8	88.0	82.0	71.9	65.5	66.9	69.5	70.9	76.8	80.8	84.9
RHn[1]	40.3	42.0	38.7	31.6	26.1	23.7	22.5	23.9	25.6	31.7	36.2	38.1
RHave[1]	63.5	65.4	63.3	56.8	49.0	44.6	44.7	46.7	48.2	54.2	58.5	61.5
Rain[1]	161.2	142.6	97.3	50.9	16.7	15.2	10.2	16.9	44.5	105.5	142.4	171.8
Rain[2]	147.33	118.26	105.19	50.09	35.1	10.04	8.89	14.78	36.58	99.71	138.56	127.34

Rain[1]: Athole weather station, 10 km from the study site on the western border (mm)

Coordinates: Latitude -26.60; Longitude 30.58

Altitude: 1346 m

Weather station number: 16301

Tx[1]: Average Daily Maximum Temperature (°C)

Tn[1]: Average Daily Minimum Temperature (°C)

Tave[1]: Average temperature (°C)

RHx[1]: Average daily maximum relative humidity (Ratio)

RHn[1]: Average daily minimum relative humidity (Ratio)

RHave[1]: Relative humidity average (Ratio)

Rain[2]: Oshoek weather station, at the north eastern corner of the study site (mm)

Coordinates: Latitude -26.22; Longitude 30.98

Altitude: 1470 m

Weather station number: 16486

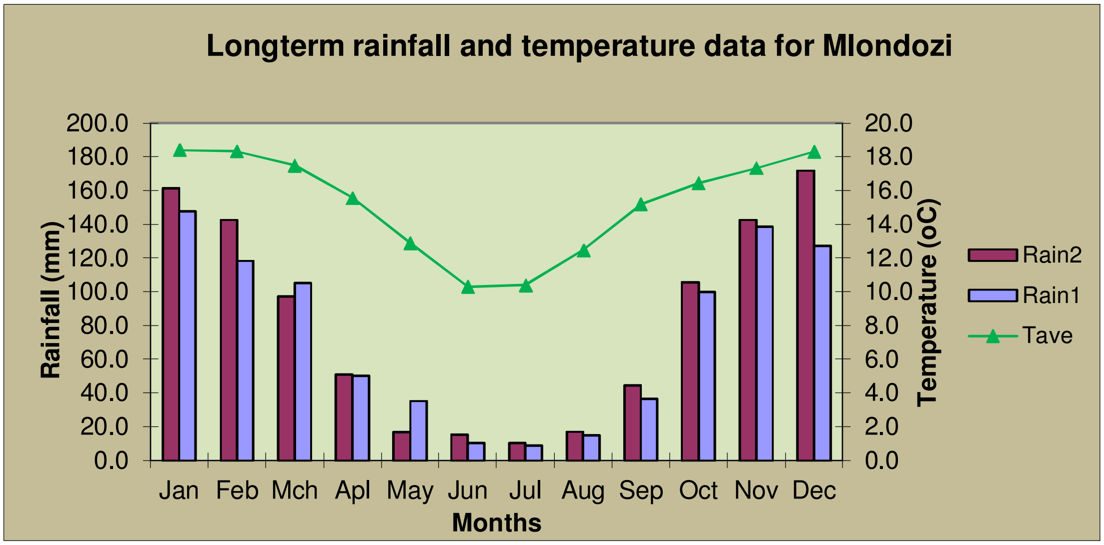

Figure 1.2 Long term average monthly, temperature and rainfall for Mlondozi (Athole(Rain[1]): 1936-2004) and (Oshoek(Rain[2]): 1965-2002)

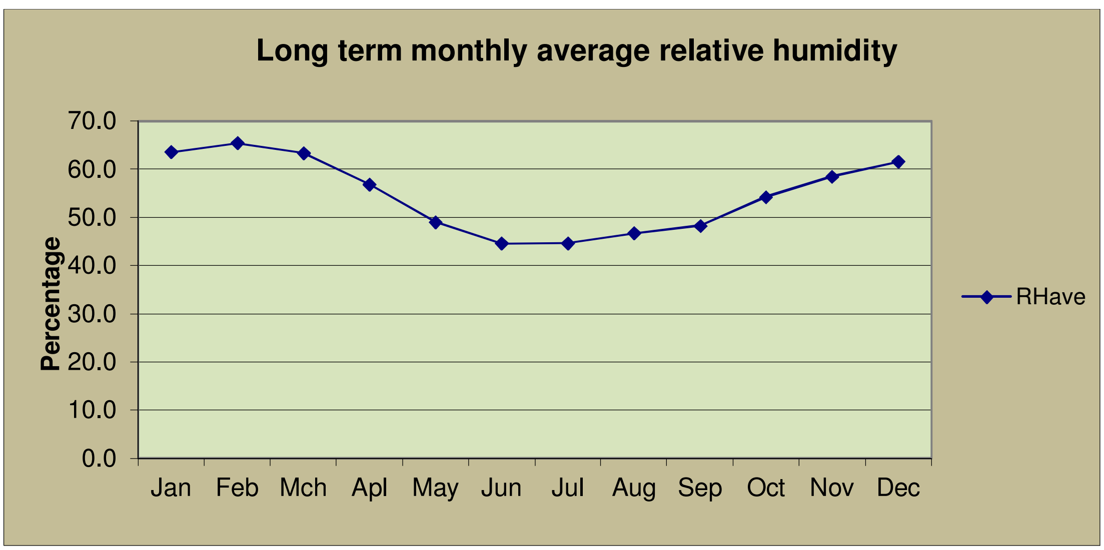

Figure 1.3 Long term average monthly relative humidity for Mlondozi (Athole; 1936-2004 only)

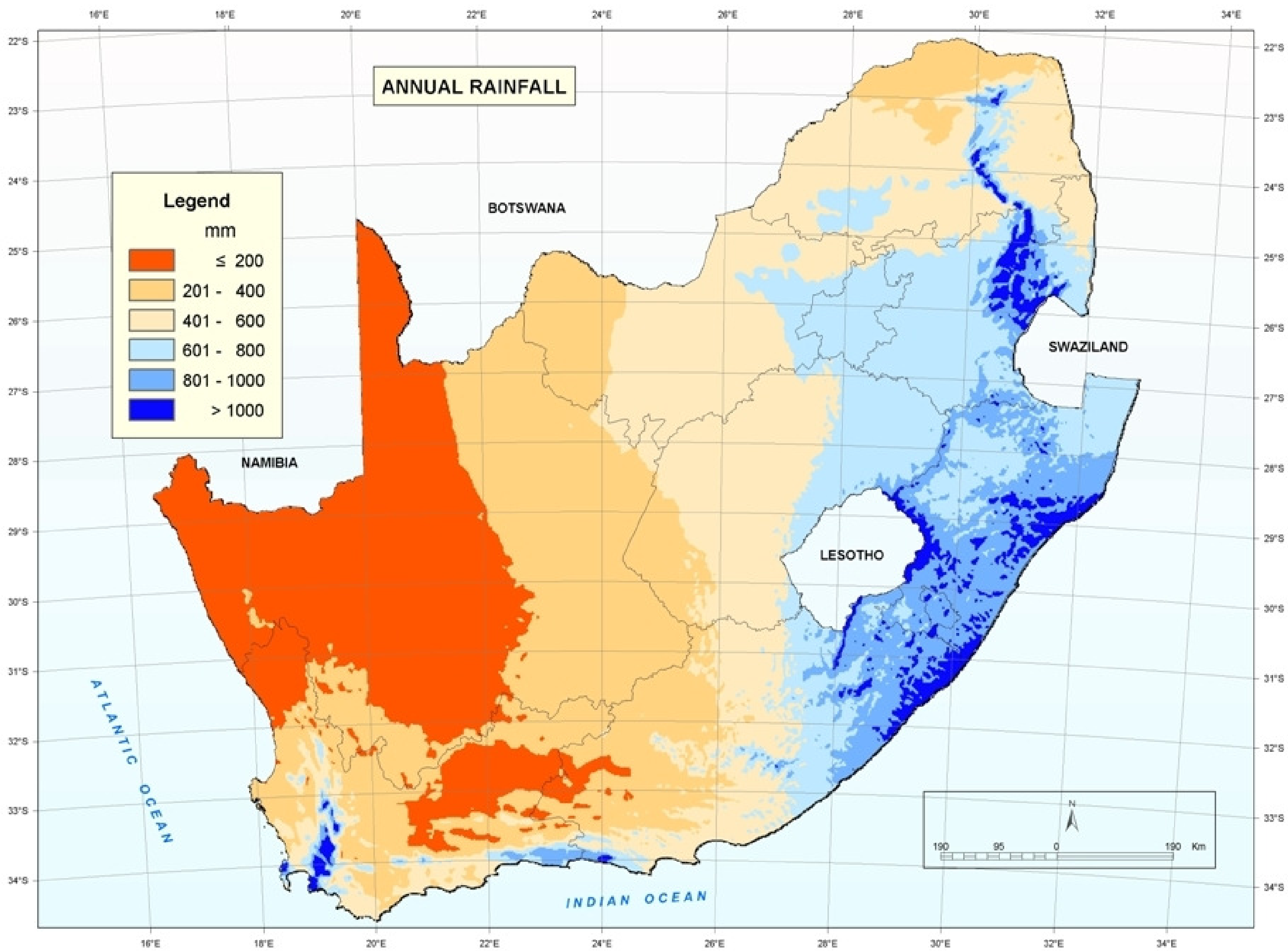

Figure 1.4 Broad rainfall patterns of South Africa. (ARC-ISCW, 2004)

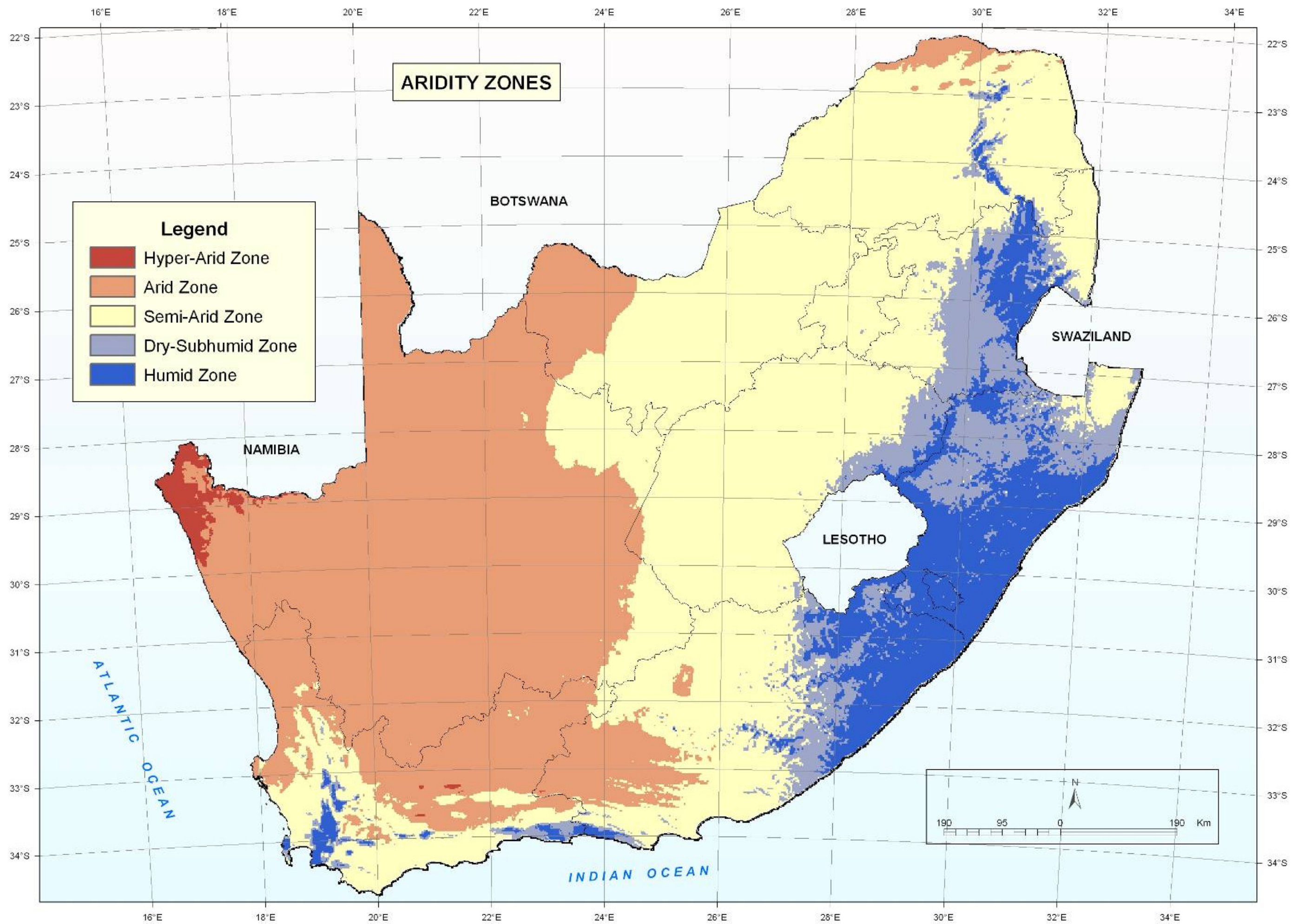

Figure 1.5 Aridity zones of South Africa. (ARC-ISCW, 2004)

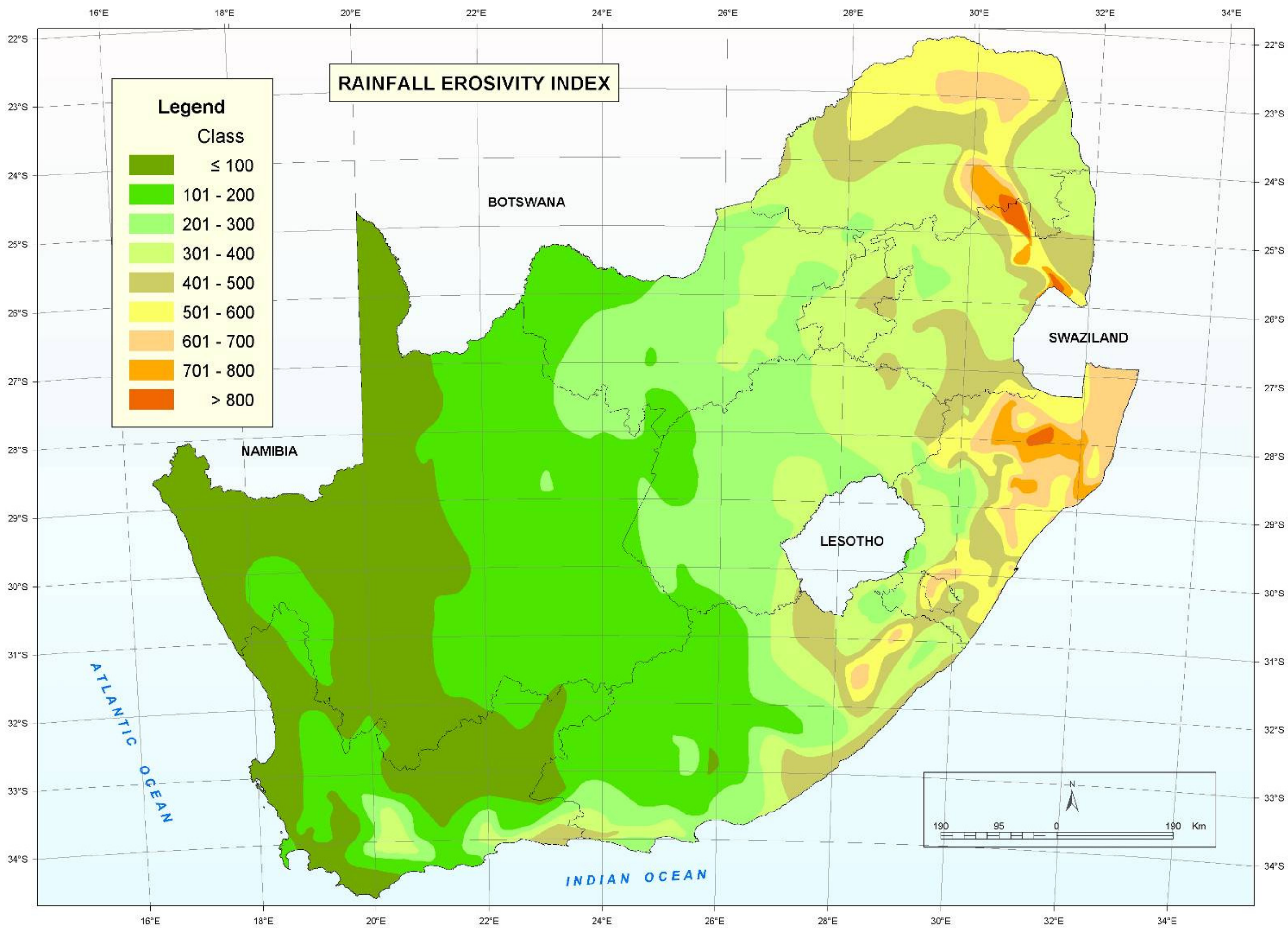

Figure 1.6 Rainfall erosivity map of South Africa (ARC-ISCW, 2004)

1.4.2 Geology

Granites occurring in Southern Mpumalanga and KwaZulu-Natal are located in three zones, and are of Swazian, Swazian to Randian and Namibian ages. The mapping unit is described as the Transvaal belt of granitization and metamorphism (Geological Survey, 1970 as cited by Turner, 2004). In a subsequent edition (Geological Survey, 1984) it is described as a number of units including the Mpulusi Granites in the south. It comprises unnamed potassic granite (light coloured granite) along with granodiorite (biotite granite) labelled ZB (Kent, 1980; Alberts, 1986, as cited by Turner, 2004). Dolerite intrusions are common in the district (Personal communication, Chris de Jager, 2010).

1.4.3 Soils

Prior to the start of the Mlondozi LandCare project, the only available soil data for the region were the data from the national land type survey at 1:250 000 scale. During the project a semi-detailed survey was conducted (Booyens, Potgieter & Matlawa, 2000). Observations were made at 500 m intervals, using a fixed grid system, for areas which were intensively cultivated, amounting to one observation per 25 ha. Plantations and very rocky areas were surveyed with observations at intervals of up to 1 000 m. The soil map units consisted of soil associations. The soil map was published at a scale of 1:50 000. Due the low density of observations, even in the most intensively surveyed areas, the nature of the composition of map units and the medium scale of the map, the map is only suitable for the identification of promising areas for crop production. It cannot be used for farm planning, especially for small-scale agriculture.

The soils were classified according to Soil Classification: A Taxonomic System for South Africa (Soil Classification Working Group, 1991). The dominant soils in each map unit were classified at family level and sub-dominant soils at form level. Soils of the Mispah form (shallow soils on hard rock) and rock outcrops dominate most of the surveyed area (Booyens, Potgieter & Matlawa, 2000). Patches of deep, high quality soils of the Clovelly form are found throughout these areas. It would be important to identify these by means of detailed soil surveys, where applicable.

The Clovelly and Magwa soil forms (Figure 1.7 & Table 1.2) are the most prominent (dominant) soils found in the surveyed area. The soils reflect the influence of the two major soil forming factors, viz. climate and geology. Magwa and Inanda soils have humic A horizons, i.e. topsoil horizons with high organic matter contents and low base status. Clovelly and Hutton soils of the area are dystrophic families of these two forms, i.e. highly weathered, highly leached soils with a low base status. This means that all these soils have low fertility and are strongly acidic. The high rainfall has led to intensive weathering and leaching, while the moderate temperatures and high humidity produce and preserve high levels of organic matter. The predominantly granite parent material (a felsic or "acid" igneous rock) contributed further to the situation mentioned above.

The topography of the area led to the development of the sub-dominant soils, viz. shallow soils (Mispah, Glenrosa) on the top slopes, the dominant Magwa/ Clovelly /Inanda/ Hutton soils on the middle slopes and soils with sub-soils showing different degrees of wetness (Avalon, Pinedene, Longlands, Kroonstad, Katspruit) on the foot slopes.

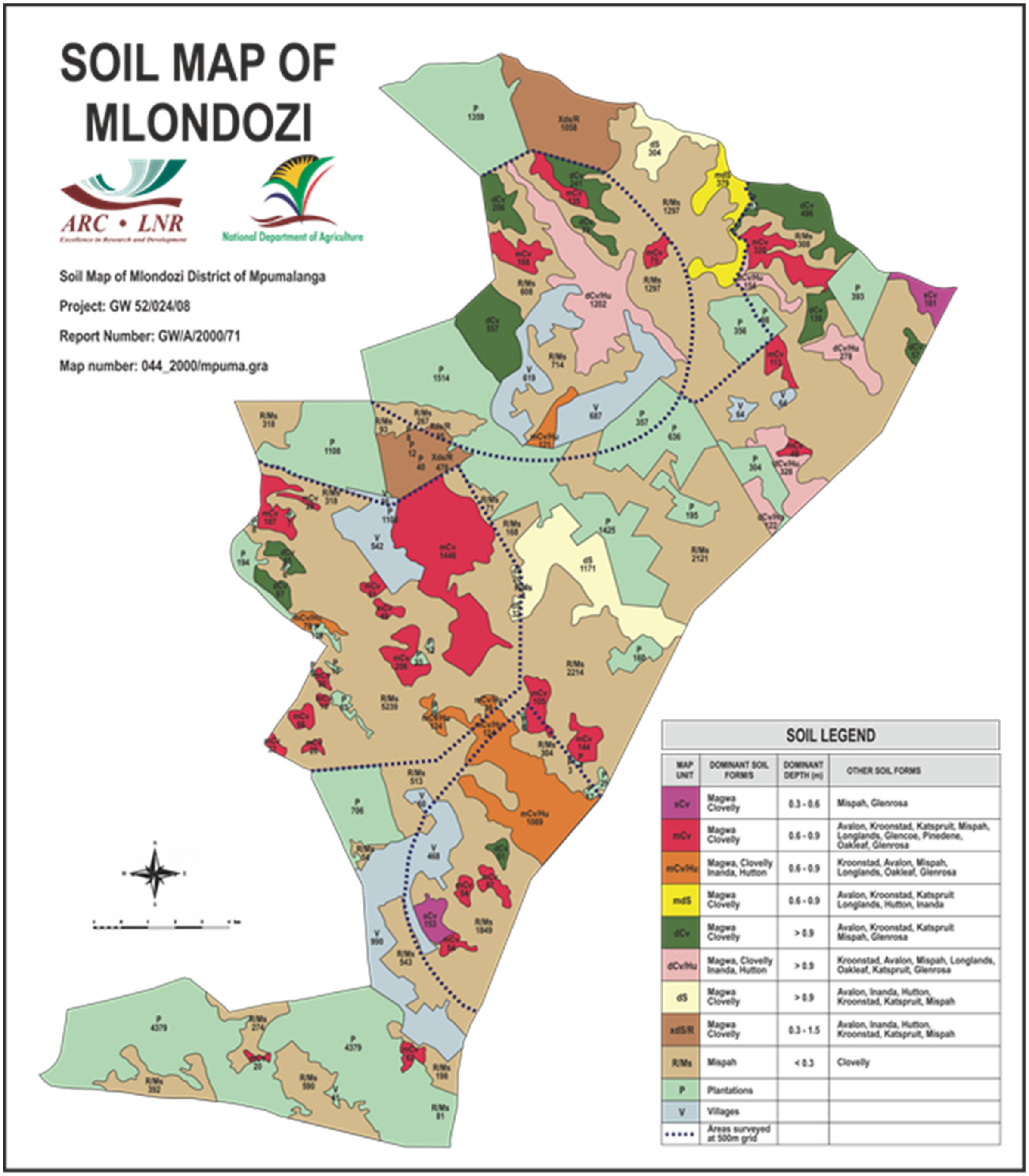

Figure 1.7 Soil map of Mlondozi (Booyens, Potgieter and Matlawa 2000).

Table 1.2 Extended legend for the soil map of Mlondozi, Figure 1.7 (Booyens, Potgieter & Matlawa, 2000)

Dominant soil form	Dominant depth (m)	Other soil forms	Description
Magwa Clovelly	0.3 – 0.6	Mispah, Glenrosa	Shallow to moderately deep, strong brown to dark yellowish brown, structureless, sandy clay loam soil on highly weathered rock and solid rock. Deeper soil forms occur. Rock outcrops comprise between 0-15% of mapping unit.
Magwa Clovelly	0.6 – 0.9	Avalon, Kroonstad Katspruit, Mispah, Longlands, Glencoe, Pinedene, Oakleaf, Glenrosa	Moderately deep, strong brown to dark yellowish brown, structureless, sandy clay loam soil on highly weathered rock and solid rock. Rock outcrops comprise between 0-15% of mapping unit
Magwa, Inanda Clovelly, Hutton	0.6 – 0.9	Kroonstad, Avalon, Mispah, Longlands, Oakleaf, Glenrosa	Moderately deep, strong brown to dark yellowish brown to yellowish red, structureless, sandy clay loam soil on highly weathered rock and solid rock. Rock outcrops comprise between 0-15% of mapping unit
Magwa Clovelly	0.6 – 0.9	Avalon, Kroonstad, Katspruit, Longlands, Hutton, Inanda	Moderately deep soils. Rock outcrops comprise between 0-15% of mapping unit
Magwa Clovelly	> 0.9	Avalon, Kroonstad, Katspruit, Mispah, Glenrosa	Deep, strong brown to dark yellowish brown, structureless, sandy clay loam soil on highly weathered rock and weathered rock. Shallower soil forms do occur. Rock outcrops comprise between 0-15% of mapping unit

Table 1.2 Extended legend for the soil map of Mlondozi, Figure 1.7 (Booyens, Potgieter & Matlawa, 2000)

continued

Dominant soil form	Dominant depth (m)	Other soil forms	Description
Magwa Clovelly	> 0.9	Avalon, Inanda, Hutton, Kroonstad, Katspruit, Mispah	Deep structureless soils. Rock outcrops comprise between 0-15% of mapping unit
Magwa Clovelly	0.3-1.5	Avalon, Inanda, Hutton, Kroonstad, Katspruit, Mispah	Structureless soils with variable depth. Rock outcrops comprise between 20-30% of mapping unit.
Mispah	<0.3	Clovelly	Rock outcrops dominant. Some deep soils do occur.

1.5 VEGETATION

The district of Mlondozi is situated in a Grassland Biome (Rutherford & Westfall, 1986). Acocks (1988) classified the veld as Veld Types 63 or Piet Retief Sourveld with a small intrusion of veld type 57 or North-eastern Sandy Highveld. The reason for the inclusion as a false grass-veld type is because there are indications that the area was previously Bushveld or Thornveld of an open sour type. The condition of the veld was regarded as good (Myburg & Breytenbach, 2001).

1.6 INTERVENTION AND TRADITIONAL PRODUCTION SYSTEM PRACTISED IN MLONDOZI

In the Mlondozi area the traditional farming system followed generally gave low maize yields. An average yield of 0,4 ton per ha was determined at the inception of the project. The practice consisted of relatively low inputs, no liming although the soils were acidic, shallow ploughing, limited weed control, late planting and generally low levels of management.

With the current intervention, it was decided to compare the conventional tillage (CT) with the “No Till” (NT) approach, using realistic fertilization, liming, herbicides, pesticides, hybrid seed and appropriate planting dates.

The “No Till” (NT) farming system consisted of farmer led trials, involving 18 farmers who were taught how to implement this farming system. This system is a basket of technologies starting with three main components, namely:

- Minimum soil disturbance
- Keeping the soil covered with a mulch
- Crop rotation

This was augmented by adopting integrated fertility, and integrated weed and pest management.

The farmers' training followed the 80/20 principle. The 20% consisted of a short theoretical training session on conservation agriculture and the implementation thereof. This was followed by support in the practical implementation of the new farming system, starting with liming of the fields in winter, followed by spraying of weeds in spring. The necessary resources were given to each of the 18 farmers, to plant a quarter hectare, with maize, following the NT farming and CT systems with the layout as a spilt-plot design. The logic behind supplying inputs to the farmers was two-fold:

1) To reduce the risk to the farmer while implementing the new technology and

2) For the farmer to produce sufficient maize for household consumption and selling the remaining maize so as to purchase more inputs to expand "No Till" to the rest of his/her farm.

In 1997 the Mlondozi Liming Project started, where lime was distributed to registered farmers. This was followed in 1999 by the LandCare project, where the "No Till" (NT) and CT were compared.

1.7 OBJECTIVES OF THE STUDY

- Determine the differences between the NT and CT treatments for infiltration, run-off and soil loss, at the end of a five year implementation period, by using a laboratory rainfall simulator.

- Compare the treatments for biological measurables such as fertility, root counts, yields and mulch cover.

CHAPTER 2
LITERATURE STUDY

2.1 A BRIEF OVERVIEW OF AGRICULTURE IN RURAL AREAS

The agriculture production systems in the rural communities of South Africa are complex and have developed under the influence of the climate, labour, economics, traditional beliefs, and the communal land tenure system. Due to maize being the staple diet, the crop planted is mainly maize while other crops, such as pumpkin and cowpeas, are intercropped or rotated. In some areas crop rotation is practised although maize is mostly planted every year. The seed used the following season is generally the previous year's seed held over, which is graded by the selection of the larger kernels of the harvested maize. When seed is bought it is generally of the older hybrid variety, such as Pioneer 4141 in Mlondozi (Jansen van Rensburg 2002). In areas such as Hluhluwe KwaZulu Natal, Round Up Ready® seed is planted by the farmers, who are normally older and who control weeds by spraying with Round Up®, to avoid the manual weed control.

The method of planting varies from community to community. Soils are prepared by animal- or tractor drawn ploughs, where the ploughing depth is shallow. This is due to the limitation of the plough design as well as to the animals being weak after the winter, so that the plough cannot be pressed deep into the soil when ploughing. The tractors used are generally poorly maintained, which includes having well-worn rear tyres, resulting in poor traction. After the soils are ploughed the soil is smoothed over by the use of hand hoes. Planting is done after furrows are drawn, using hoes (Jansen van Rensburg 2002). If fertilizer is used, it is spread in the furrow and covered with a thin layer of soil, and the seed is dropped in the furrow and covered with soil. In some districts, such as Giyani, the seed is broadcast over the soil then ploughed in.

The fertilization of the crop on the traditionally planted fields is mostly with 'kraal' manure or a mixture of 'kraal' manure and chemical fertilizer. The nutrient value of the manure varies greatly due to the quality of the grazing, the bedding, whether the liquid excrement has been retained and the amount of leaching that has taken place in the 'kraal'. In a study conducted in the Eastern Cape the nutrient content of dairy manure varied considerably as indicated in Table 2.1. From the table the nitrogen content varied between 1,4 kg to 9 kg per ton of manure. (Jezile, 2004) For the rural farmer to supply the recommended 200 kg of 2:3:2 (22), two ton of manure per hectare would need to be applied. On the traditional plots, the applied quantity of manure was far below the recommended amount.

Table 2.1 Nutrient composition of dairy manure

Manure type	Total Nitrogen kg ton^{-1}	Phosphorus kg ton^{-1}	Potassium kg ton^{-1}
Manure scraped from 'kraal'	4,5	2,7	4,1
Range of nutrients	1,4 to 9	0,3 to 5,8	0,9 to 9

Weed control is made difficult by the fact that there is intercropping. The weeding is done in December and in some areas a follow up weeding in January. Harvesting is made difficult as the result of certain weeds germinating late in the season like the Black Jack (*Bidens pilosa*). Women would pull large plastic bags over themselves to protect themselves from the Black Jack seeds when harvesting.

Harvesting is done manually, by picking the cobs by hand, by pulling the sheath leaves apart and twisting the cob off. The cobs are stored in a slatted wooden structure that is raised off the ground. Due to the slats being wide apart the cobs are able to dry off to the desirable 12% moisture content to prevent harmful fungal growth such as Diplodia ear rot (*Diplodia maydis) or Fusarium ear rot (Fusarium moniliforme*). Older women in the family unit do the threshing. The method followed is by rubbing the cobs against each other or against a stone. The threshed seed is stored in bags with ash sprinkled over the seed, to prevent possible insect damage (Jansen van Rensburg *et al,* 2001, 2002, Jansen van Rensburg 2002).

D'Haese & Kirsten (2006) describe land tenure as the relationship of one person to another with respect to land resources. These motivate production efforts by the land occupier. For example farmers would not plant a crop if it were to be taken by a third party. Tenure determines who can do what with the property in question and under what circumstances they can do it. Tenure is often misunderstood as defining relationships between people and property, whereas in fact, tenure defines social relationships between people.

Most African farmers hold their land under indigenous usufruct land tenure systems irrespective of the formal legal position under national law. Evidence has shown that land titling and registration has not yielded positive benefits. On the other hand, there is growing evidence that indigenous tenure systems are dynamic and evolve with changing social, economic and political circumstances. Rukuni (1998) argues that traditional or customary tenure systems offer as much security as any other system provided that communities have legal ownership and authority over their land and natural resources.

Under communal land tenure individual farmers have no incentive for implementing sustainable land use systems. The farmers are given land to farm, but without full ownership. There is the proviso that if the land is not worked there is a chance of losing the land. As a result farmers are reluctant to invest in the land by liming or fertilizing. Arable land is usually allocated to individual families but there is no security of acquiring loans for inputs (Jansen van Rensburg et al, 2001, Laker, 2012). The net result is the underutilization of high potential land, with resultant unbearable pressure on marginal land and often a serious degree of degradation. The farming enterprise is furthermore made difficult by the distance to large centres.

Extension officers supply a limited amount of support to farmers due to their poor technical training. In performing their day to day tasks, support is limited by aspects such as availability of vehicles, as well as limited kilometres to visit farmers. In KwaZulu Natal (personal communication, 2010) some extension officers would take a taxi, at their own expense, to attend meetings.

LandCare was initially developed in Australia around 1997, to have a community based approach for the raising of awareness, influencing farming and land management practices and delivering positive environmental outcomes (Klucas, 1999). LandCare was adapted for South Africa as reflected in the goal of the National LandCare Program to develop and implement integrated approaches to natural resource management. The approaches were efficient, sustainable, equitable and consistent with the principles of ecologically sustainable development. LandCare, in the ARC, was initiated with a project in Mlondozi, a community on the western border of Swaziland, followed by the Bergville LandCare project. The long term and short term goals are outlined in the Department of Agriculture LandCare Policy document (Molope, 1999).

LandCare success is attributed to: "… the universal recognition that the best way to tackle the on-ground problems is to have the community deciding what their local priorities are" (Klucas, 1999). This approach gave the community the opportunity to take ownership of their project. Community development is generally a slow process, including the need for development of monitoring and evaluation: The three criteria targeted for monitoring and evaluation were social acceptability, bio-technical feasibility and economic viability. At the end of the project an Impact Assessment Survey was conducted which showed the project had a significant impact on the community (Jansen van Rensburg, Engelbrecht & Smith, 2003).

There are a number of doomsday messages pertaining to soil erosion in South Africa which are regarded as "*often misguided*" by Garland, Hoffman & Todd (2000). Scientific assessments indicate the situation may not be as severe as popular literature suggests. Popularly quoted figures of sediment yield including by Midgley (1952), Schwartz & Pullen (1966) and Rooseboom (1976) are of 363 million tonnes (3 t $ha^{-1}yr^{-1}$); 233 million tonnes (1,9 t $ha^{-1}yr^{-1}$) and 100 to 150 million tonnes (0,82 – 1,22 t $ha^{-1}yr^{-1}$) respectively. These figures are based on sediment yields of main rivers. There are other published values which are less reliable, due to the methodology followed to determine the figures, which was not often clearly explained. The mean Africa value is 7,15 t $ha^{-1}yr^{-1}$ (Garland, Hoffman & Todd, 2000).

South Africa is largely semi-arid, with most of the land affected by agriculture which means the figures are regarded as not being unreasonable. South Africa's erosion figure is lower compared to all continents except Europe. It is to be noted that these are sediment yields which are not directly comparable to soil loss, although there will be a relationship. Soil loss is the quantity of soil lost at a point source or catchment, while the sediment is the quantity of soil transported by water which can be as much as 5 times lower than soil loss (Scott & Van Wyk, 1992).

2.2 CONSERVATION AGRICULTURE

There is an increasing number of farmers adopting Conservation Agriculture as a farming system, which includes No-Till (Horowitz, Ebel & Ueda, 2010). The beneficial effects of conservation agriculture include reduced erosion, and run off, increased infiltration (Aon, Sarena, Burgos, & Cortassa, 2001; Stubbs, Kennedy & Schillinger, 2004; *No-Till, Advantages and benefits in crop production*, 2005; Chivenge, Murwira, Giller, Mapfumo & Six, 2007; Diallo, Boli & Roose, 2008, So, Grabski & Desborough, 2009). Further advantages include the retention of nutrients due to the charges on humus (No-till club, 2005). This would be due to the increased organic carbon and mycorrhiza concentration (Jehne, 1981). In West Africa, for instance, the organic carbon content of the soil is used as an indicator of soil health (Bationo & Buerkert, 2001). The '*Cornell soil health training manual'* has organic content as one of its 39 indicators, for the rapid assessment (Gugino *et al,* 2009).

The aim of implementing Conservation Agriculture is to improve crop yields while reducing production costs, maintaining or improving soil fertility and conserving water, in other words implementing an improved and sustainable farming system. It is a system that can be adapted to a variety of farming situations. In its original form it is based on three principles (FAO, 2001; FAO, 2007):

- Disturb the soil as little as possible
- Keep the soil covered as much as possible through dead or living mulch
- Crop rotation

Furthermore other farming processes, such as weed and pest control as well as nutrient management, are addressed in an integrated manner. Weed control is through the use of herbicides, along with cover crops. The cover crops brought into the system are chosen to rectify problems such as soil compaction or increasing soil organic carbon levels, in the system. Farmers in Dakota have found that by bringing in a winter cover they have reduced the weed pressure as well as the amount of fertilizer required to zero, in some cases (Video: *The next step, 2013*). Other problems controlled by cover crops include:

- Japanese radish for compacted soil

- Cabbage and Sunhemp to control nematodes
- Oats as a cover crop to reduce weed pressure
- Black oats to improve phosphorus levels

The implementation of Conservation Agriculture improves soil health more holistically, including physical, chemical and biological properties. Farms such as the ZZ2 estates are using the “Cornell soil health assessment training manual” (Gugino, Dowu, Schindelbeck, van Els, Wolf, Moebius-Clune, Thies. & Abawi, 2009) to test their soils as to their farm’s soil health. Over the years the concepts and understanding of the soil’s physical and chemical properties have been well accepted. It is not until recently that the improvement of soil biology has become the focus. The definition adopted by the Cornell team is: “Soil health is the concept that deals with the integration and optimization of the physical, chemical and biological properties of soil for improved productivity and environmental quality”. The characteristics of a healthy soil include good soil tilth, sufficient depth, sufficient but not excess nutrients, large population of beneficial organisms, free of chemicals and harmful toxins and a small population of plant pathogens and pests.

Their approach has been to address soil degradation matters that result in degraded soils which in turn result in low crop yields. The issues include soil compaction, surface crusting, and low organic matter. There are thirty nine indicators listed in the rapid assessment for soil health. The indicators are divided into three categories, namely physical, biological and chemical.

Traditionally soils have been ploughed to control weeds and improve the soil structure for the seed bed. In reality, in the long term, the soil structure has been gradually broken down, along with a reduction in organic carbon. The practice of CA keeps the soil covered by the crop residue or cover crops to reduce erosion by water and wind. Crop rotation is incorporated into the system to improve soil fertility as well as control pests and diseases (Stubbs, Kennedy & Schillinger, 2004).

Cultivated soils' susceptibility to erosion is demonstrated by studies that indicate that soil erosion is 3 to 15 times higher on recently tilled soils compared to untilled soils (Box & Bruce, 1996). An aim when implementing CA as a farming system, is to reduce soil erosion due in part to the increased organic content (Kundu, Bhattacharyya, Prakash, Gosh & Gupta, 2007) which would be beneficial especially in South Africa, which is a country with a generally low soil organic content (Barnard, van der Merwe, De Villiers, van der Merwe, & Mulibana, 2000). Observed benefits of CA by Jan Dube, a farmer in Mlondozi was the reduced frequency of irrigation required, and reduced insect damage in his vegetable garden (personal communication, 2003).

A minimum of 30 % soil surface covered with crop residues is required in conservation tillage. As the cover approaches 100% soil erosion approaches zero. With a 50% soil cover the erosion is reduced to by about 83 %, and 10% cover the erosion is about 30% (Nyakatawa, Reddy & Lemunyon 2001).

In a cotton study conducted at the Alabama Agricultural Experiment Station, with kaolinitic soils, three cultivation systems were implemented i.e. conventional, mulch-till and no-till; two cropping systems i.e. cotton in summer and fallow in winter and summer cotton followed by winter rye; and three nitrogen levels i.e. 0, 100 and 200 kg N ha^{-1}; and two nitrogen sources: ammonium nitrate and chicken litter. Measured differences for the treatments included:

- The no-till and mulch-till system produced on average 10 cm taller cotton than the conventional tillage system
- Higher cotton lint yield under no-till compared to conventional till

- The soil moisture measurements for the top 7 cm were higher for the no-till plots compared to the conventional tilled plots with and without winter rye cover crop. The increased soil water resulted in earlier seed emergence, seedling vigour and plant growth.
- Soil erosion for no-till was about one third that of conventionally cultivated soils (Nyakatawa, Reddy & Lemunyon, 2001).

The reduced erosion in CA farming systems can be attributed to the increased aggregate stability due to increased mycorrhiza hyphae concentration (Goddard *et all,* 2008, Kladivio, 2001). Arbuscular mycorrhiza fungi hyphae lengths range from 3 to 30 m g^{-1} of soil, but have been measured to be 68 to 101 m g^{-1} of soil in undisturbed grassland (Jones, Nguyen & Findley, 2009). Soil aggregate stability is influenced by *Basidiomycetes mycelia* that excrete polysaccharides. Stable clay-humus complexes further good structure and increase water reserves. (Husson, 2003). Soil structure is further improved by the root exudates on soil particles which also improve soil structure by increasing aggregate stability (Beare, Hendrix & Coleman, 1994).

There is a reduction in soil bulk density due to the implementation of No-till along with controlled traffic. A study conducted in Australia on a soil cultivated for a period of 100 years of conventional tillage, had a 22 month period of controlled traffic. There was an improvement of bulk density from 1,4 g cm^{-3} to 1,25 g cm^{-3}. The available water capacity improved from 10,2 mm per 100 mm soil depth to 15,4 mm per 100 mm depth of soil (McHugh, Tullberg & Freebairn, 2009).

2.3 FACTORS AFFECTING SOIL STABILITY AND INFILTRATION

When water is applied to soil, whether in the form of precipitation or irrigation, some water will flow into the soil. The remaining water will not penetrate the soil, resulting in pooling on the surface or runoff occurring. Infiltration rate is defined as the volume flux of water flowing into the profile (Shainberg & Levy, 1996). The decrease in infiltration can be due to the matric suction gradient which occurs as the infiltration proceeds. Secondly the reduction could be due to the deterioration of the soil structure caused by the impact energy of water drops which leads to partial sealing of the profile.

Soil erosion is a complex process of interactions of the detachment and transport of soil particles by raindrop impact and overland flow and deposition. Factors affecting detachment include raindrop size and shape, force and impact stress (Bradford & Huang, 1996).

2.3.1 Crust formation

Crust formation is due to the impact of rain drops on the soil surface, where the soil particles detach from the aggregates, to form a dense layer in the top part of the soil surface. This in turn results in reduced infiltration and increased run-off (Morin, Benyamini & Michaeli, 1981). In brief, crust formation is due to three mechanisms:

- Physical breaking down of soil aggregates by the force of the rain drops and
- Physiochemical dispersion and movement of clay particles.
- A third mechanism proposed is the reduction in water movement into the soil and the swelling of clays which could block the conducting pores, as suggested by Quirk and Schofield (cited by Levy, 1988).

The particles clog the pores in the soil surface (Aggasi, Shainberg & Morin, 1981). The dispersion of clay particles could be affected by the exchangeable cation concentration and composition in the soil. Thus the stability and reversibility of wet crusts formed is dependable on whether the crust (or seal) is fully or partially formed. Rainfall of high intensity and of long duration would result in a fully formed crust. A high intensity short duration or low intensity long duration on the other hand would result in a partially formed crust (Aggasi, Shainberg & Morin, 1988).

2.3.2 Parent material

Parent material is arguably the most dominant of factors that determines the respective soils' characteristics, including erodability. The Department of Water Affairs (1986) put out a map of sediment production for South Africa, which demonstrated the close relationship between the geology and sediment yields. Studies in South Africa have included the collecting of soils and testing the erosivity in a laboratory rainfall simulator, showing that certain soil types are more susceptible to erosion than others (Stern, 1990; Rapp, 1998). Parent material is the fundamental building block of soils. Soils formed from basic parent materials, such as dolerites, are more stable than those from acidic parent material, such as granites, as indicated by the erosivity values. Smith (1990) studied soils developed on basic and igneous rocks with respect to stability and degree of weathering. The study focused on red soils which are inclined to be more stable due to higher free iron, aluminium and organic carbon content (Smith, 1990). Conclusions made by Smith were that the most stabile were those soils derived from basic rocks such as dolerite, and secondly soils high in kaolinites.

As the result of excessive erosion taking place in the Transkei, D'Huyvetter (1985) focused a study on establishing slope criteria for the prediction of erosion for different soil types. Soils derived from dolerite showed higher stability against erosion compared to mudstone derived soils. It was concluded that the role of parent material was vital in predicting erosion potential. In many areas of South Africa the "planners" implemented a blanket rule of ploughing all soils with a slope of 12% or less, without taking into account the soil type. The maximum threshold rule for slope percentages for arable land for major soils was compiled in the study by D'Huyvetter (1985). Shortlands was the only soil that had a maximum threshold value of 13%, with Hutton at 10,5%. On the opposite end of the scale the duplex soils such as Escourt and Sterkspruit had a maximum slope of 4,5%; and Swartland 5,5%. This is further elaborated on in section 2.3.8.

2.3.3 Degree of weathering

D'Huyvetter (1985) and Weaver and Van Breda (1991) both found that the degree of soil erosion was inversely correlated with the average yearly rainfall. Laker (2004) pointed out that increased rainfall leads to more advanced soil formation, resulting in more stable soils, resulting in less erosion. Van der Merwe, De Villiers, Barnard, Beukes, Laker, & Berry (2000) found the erodability of melanic soils also decreased with increasing degree of weathering.

Weathering is a combination of physical and chemical alteration of material, which must occur for soil formation to take place. Physical weathering would take place, such as cracks forming in rock due to uneven thermal expansion or contraction. Water is an essential element for all chemical and physical weathering processes. Water is furthermore involved in profile formation through percolation, evaporation, erosion (run off) and stagnation (Schroeder, 1984). Smith (1990) found that the degree of weathering is related to the rainfall of the district. The end products of acidic parent material of high rainfall areas have higher percentages of clay and predominantly kaolinites, quartz and mica in the clay fraction of the soil (Smith, 1990).

2.3.4 Free iron and aluminium oxides

Soil from the most highly weathered basic parent material, containing the highest amounts of organic carbon, clay, free iron and aluminium, was also the soil that maintained the highest Final infiltration rate and cumulative infiltration values under cultivation (Levy, 1988; Smith, 1990).

2.3.5 Clay mineralogy

In Gauteng and Mpumalanga kaolinites are the dominant clay mineral, resulting in soils that are known to form a seal and produce much runoff and erosion when exposed to rainstorms. The hydraulic conductivity (HC) of a soil is correlated to the soil texture, mainly the clay content. The higher the clay content the lower the HC. This is further affected by the sodicity, or ESP (Exchangeable sodium percentage) content of a soil (Levy, 1988). The most unstable soils are those with a high percentage of clays with a 2:1 layer of silicates, especially montmorillonite, while the most stable are those high in kaolinite (Levy, 1988). Hutton soils with predominantly kaolinitic clays are relatively stable. The stability is affected by sodium and interstratified minerals such as smectites. Soils with smectites and illites are more dispersive than soils with dominantly kaolinites (Goldberg & Glaubig, 1987; Levy 1988).

2.3.6 Sodium and magnesium

The degree of stability of a soil against disaggregation or dispersion determines its resistance to erosion. There are two main factors that bring about structural stabilization namely organic matter and iron oxides (Sumner, 1957 and Smith, 1990). South African soils' organic matter is generally low and even lower when cultivated. A number of soils lose their structure when cultivated due to breakdown of organic matter. Soils of a dolerite parent material retain their structure due the cementing effects of iron oxides. Smith (1990) found in his study that soils derived from acidic igneous rocks were less stable than the soils derived from the basic igneous rocks.

D'Huyvetter (1985) found a significant correlation between the ESP of the soil and the degree of erosion. He found the highest ESP values for the Valsriver, Vilafontes and Westleigh forms, all of which have a high erodability. The more stable soils such as the

Hutton, Shortlands and Oakleaf had lower ESP values. A high ESP resulted in dispersion taking place causing dense crust formation, which reduces infiltration of water into the soil.

2.3.7 Organic material

It well known that organic material has various benefits which include improved soil structure (Abiven, Menasseri & Chenu, 2009). In West Africa where soils generally have a low organic carbon content, soil fertility is “defined” by the amount of carbon in the soils (Bationo & Buerkert, 2001). Organic material binds micronutrients and metal ions that otherwise might be leached out of the surface soil (Stevenson, 1994, Laird, 2001).

In a study compared conventional tillage to various direct drilling systems, Diallo, Boli & Roose (2008), constructed two sets of run-off plots (57 in Cameroon and 17 in Mali) on rather fragile sandy Alfisols under Sudanese savannah areas. After 3 to 4 years with 900 to 1500 mm of annual rainfall, the litter/legume/weeds/ cover had a reduced runoff of 20% and 33% reduced erosion compared to the conventional tillage system. The soil organic carbon increased from 0,69% to 0,87% in a 3 year period. There was also found to be a reduction in aluminium toxicity in the soil (Tang, Zang, Schroder, Payton & Zhou, 2007).

The practice of no-till is reported to sequester carbon. In a study the amount of carbon sequestered was found to be 0,81 metric ton per ha for minimum tillage, compared to 1.58 metric ton per ha for No-Till (Horowitz, Ebel & Ueda, 2010). When fields are cultivated the carbon is decomposed more rapidly. Loss of organic matter due to cultivation had an adverse effect on infiltration rate values as well as the total infiltration into the soils. This was further aggravated if a fallow period is included in the rotation (Tisdall & Oades, 1982, Smith, 1990)

In a study conducted in Northern Mississippi soil erosion was found to be 47% and 50%

lower for plots with 50 and 100% plant populations respectively compared to the control with 0% soil cover (Bot & Benits, 2005; Wilson, McGregor & Boykin, 2008).

There are a number of components that aid in aggregate stability including organic gels that develop due to the transformation of organic matter (D'Huyvetter, 1985). The particles would also be further stabilized by fungal hyphae coating the soil particles and the extracellular polysaccharides produced by fungal hyphae (Tisdall, Nelson, Wilkinson, Smith & McKenzie, 2012). The aggregate formation process continues by organic anions forming complexes with metal ions which favours the aggregation of clays (Jastrow & Miller, 1998; Laird, 2001).

Fungi play a major role in the stabilisation of soil, where it is estimated that up to 70% of the carbon in the soil occurs in fungi. A by-product from the fungi is glomalin which may polymerize and form hydrophobicity due to drying and exposure to air, thus protecting the hyphae from desiccation. Wessels (1996) proposed that the glue-like property and hydrophobicity aids the stabilising of aggregates exposed to rapid wetting and drying.

2.3.8 Slope

In the Ciskei during the 1970's there was alarmingly high erosion taking place in the so called "betterment schemes". Hensley & Laker (1975) identified the cause to be standard slope criteria of 12% for arable soils by "planners" without taking into account the erodabilities of the respective soils. Soil erosion is of importance because, the higher the degree of erosion, the lower is the yield. In a study conducted in Michigan, there was an average of 21% yield reduction on severely eroded soils compared to slightly eroded soils, over a five year study period (Mokma & Sietz, 1992). D'Huyvetter (1985) focused a study on establishing threshold slope criteria for the dominant arable soils in three pedosystems of the former Ciskei. For each soil form a regression analysis was carried out with the degree of erosion as a dependent variable and slope gradient as independent variable. Theoretical threshold slope percentages for arable fields were determined. Significant differences in erodability were found for different kinds of soils. The result was that each soil form had different threshold criteria (Table 2.2).

Table 2.2 Recommended slope percentages for the arable soils of Mavuso (D'Huyvetter 1985).

SOIL FORM	THRESHOLD PERCENTAGE %
Glenrosa	6,0%
Hutton	10,6%
Oakleaf	6,1%
Shortlands	13,0%
Swartland	5,5%
Escourt, Sterkspruit, Valsrivier, Vilafontes	4,5%

The parent material played a significant role in the stability of the soils. Hutton and Shortlands which are derived largely from dolorite were the most stable, compared to the majority of the other soils, mainly derived from Beaufort mudstone.

Stern (1990) conducted a study on unstable soils, which tended to seal and are highly erodible, in a laboratory rainfall simulator where the slope of the soil could be accurately set. The run-off from the control plot soils, set at a steeper slope (30°), was lower, with a higher infiltration rate compared to soil on a gentle (5°) slope. This is explained by the crust being eroded from the steeper slope, thus allowing water to infiltrate.

2.4 METHODS OF SOIL EROSION RESEARCH

Over time different methodologies have been developed to study soil erosion in the field and relevant processes in the laboratory. Basic research was normally conducted on runoff plots (1950-1960's). From the 1980's more diverse forms of apparatus were developed and used. Researchers have had a need to study and quantify the effects of rainfall on the soil by measuring soil erosion, run-off and infiltration. This study has been extended to the effects of different farming systems on the soils erosivity. Studies have made use of run-off plots laid out in field, of varying sizes (Kongo & Jewitt, 2006; Jin *et al*, 2008). The water source for field studies has been in the form of rain for in-field run-off plots, whereas distilled water has been used for rainfall simulators. The rainfall simulators vary in size. (Swanson, 1965; Roth, Meyer & Frede, 1985; Miller, 1987)

Historically in-field run-off plots were the preferred method used to determine erosion from soils. Plot size has traditionally been large (>10m^2). Large plots are more suited to hydrological studies (Kongo & Jewitt 2006), and include erosion and pesticide movement in runoff from irrigated cotton (Silburn, Hargreaves, Budd & Granville, 1996; Silburn, Waters, Connolly, Simpson & Kennedy 1998), and nutrient movement from dairy effluent applied to pastures in southern and northern Queensland (Loch *et al.* 2001).

Studies have made use of run-off plots laid out in field, of varying sizes (Munn & Huntington, 1976, Roth, Meyer & Frede 1985, Miller, 1987, Kongo & Jewitt, 2006; Jin et al, 2008). There is a recent trend for researchers to study runoff on smaller plots (<1m^2) (Roth, Meyer & Frede 1985; Claassens & van der Watt 1993; Loch, Connelly & Littleboy 2000, Seeger, 2007). The smaller plots are suited to gathering of data for modelling objectives (RUSLE, 1993). This is in line with the runoff studies using laboratory rainfall simulators.

The common method used by researchers for soil sampling for rainfall simulator studies was to use a spade to dig out the topsoil which was followed by drying and sieving of the soils, from literature cited (Levy, 1988, Smith, 1990, Stern, 1990). The dried and sieved soils were placed in perforated trays for the simulated rainfall event. No reference was found where undisturbed samples were taken for simulated rainfall events using a laboratory rainfall simulator. Undisturbed soils tested through the use of portable rainfall simulators are expensive due to the method, and are also time consuming. The motivation for the taking of undisturbed soil samples was to obtain samples that were more representative of the in-field situation. In most previous laboratory rainfall simulator studies a single large sample was taken from a point source, representing each soil type.

This study complements the erosion studies conducted previously by having multiple samples of the same parent material that were taken with minimal disturbance. The listed studies consisted of single samples of each soil type. The studies conducted in South Africa on soil erosion include:

1) Sumner, M.E. (1957) The physical and chemical properties of tall grassveld soils of Natal in relation to their erodability

2) De Huyvetter, J.H.H. (1985) Determination of threshold slope percentages for the identification and delineation of arable land in Ciskei

3) Levy, G.J. (1988) The effects of clay mineralogy and exchangeable cations on some of the hydraulic properties of soils

4) Smith, H.J.C. (1990) MSc dissertation – The crusting of red soil as affected by parent material

5) Stern, R. (1990) Effects of soil properties and chemical ameliorants on seal formation, runoff and erosion

6) Bloem, A.A. (1992) Criteria for adaption of the design and management of overhead irrigation systems to the infiltrability of soil

7) Rapp, I. (1998) The effects of soil properties and experimental conditions on the rill erodabilities of selected soils.

CHAPTER 3

MATERIALS AND METHODS

3.1 SITE SELECTION

The project ran from 1999-2003. Eighteen farmers were randomly chosen (as unbiased as possible) by the community in 1999 to be trained in the No Till farming system (Figure 3.1 and Table 3.1). The Conventional Tillage farming system was applied next to the NT farming system, for comparative and educational purposes.

The selection of the farms was influenced by the availability of arable soils and forestry plantations, particularly in the Southern half of the study area. The criteria for the selection of farms included: the soils needed to be 600 mm plus in depth; the fields needed to be fenced and easily accessible to the researchers and fellow farmers. At the start of the project, each farm was measured and marked out with a quarter hectare each for NT and CT adjacent to each other.

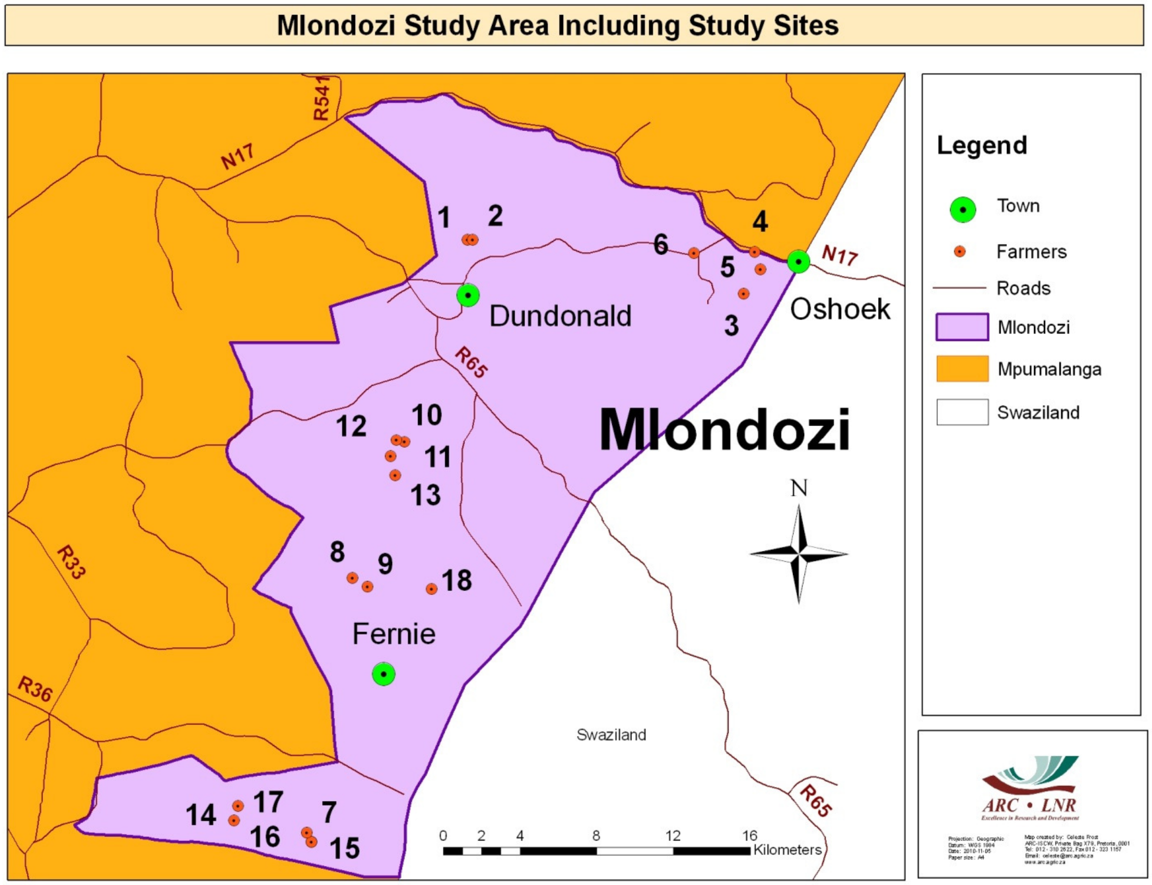

Figure 3.1 Mlondozi study area showing the distribution of the study sites.

Table 3.1 Names of farmers and co-ordinates for the 18 study sites

Numbering of study sites	Farmer name	Ward	Latitude (S)	Longitude (E)
1	Caiphus Dludlu	Belvedere	26º 12' 7.5"	30º 49' 59.1"
2	Jan Dube	Oshoek	26º 13' 37.8"	30º 57' 45.7"
3	Victoria Sheba	Oshoek	26º 12' 28.2"	30º 58' 3.8"
4	Josia Nkosi	Oshoek	26º 12' 57.3"	30º 58' 14.1"
5	Enoch Mavimbela	Oshoek	26º 12' 30"	30º 56' 22.1"
6	Vegetable garden	Mayflower	26º 29' 1.5"	30º 45' 35.7"
7	Amos Habile	Izindonga	26º 21' 37.6	30º 46' 45.0"
8	Paulos Shongwe	Ndanga	26º 21' 52.4"	30º 46' 10,5"
9	Joyce Simelane	Hereford	26º 17' 48.4"	30º 48' 12.5"
10	Albert Jele	Hereford	26º 17' 45.2"	30º 47' 58.4"
11	D.J. Nkosi	Hereford	26º 18' 12.6"	30º 47' 48.8"
12	Joseph Maseko	Hereford	26º 18' 44.4"	30º 47' 57.4"
13	James Makonsa	Syde	26º 17' 47,9"	30º 48' 38,2"
14	Meshack Mkwanazi	Syde	26º 28' 11.4"	30º 43' 24.4"
15	Absalom Makhubu	Syde	26º 29' 1.5"	30º 45' 35.7
16	David Ndlanganlandla	Syde	26º 28' 46.5"	30º 45' 27.4"
17	Mbuti Mkhonza	Syde	26º 28' 1.1"	30º 43' 31.6
18	Filemon Matunjwa	Dumbarton	31º 18' 29"	28º 52' 42"

Sites 1 and 18 were researcher managed trials. The remaining 16 sites were managed by the respective farmers.

3.2 PRODUCTION SYSTEMS PRACTICED IN MLONDOZI

Two methods of production were followed. The two systems referred to – Conventional Tillage (CT) production system and "No Till" production system (NT). They are described in more detail below:

3.2.1 Conventional tillage (CT) production system

Tillage - The traditional method of tillage in the community was with animal drawn mouldboard plough or tractor drawn mouldboard plough. Both methods resulted in a shallow ploughing depth of 10 to 18 cm. The minority of farmers budgeted for or had money to have the soil disced to break up the clods to prepare a seed bed, after ploughing. The seed bed was mostly prepared by hand using a hand hoe.

Seed – Most of the farmers planted their traditional seed, or seed held over from the previous season's harvest. If a hybrid was planted, the most popular was Pioneer 4141, an old hybrid. Some farmers planted by tractor drawn planter, although most planting was done manually using a hand hoe. The process followed was the making of a furrow and placing the fertilizer or manure in the furrow, then closing it with a thin layer of soil. The seed was then placed in the furrow and closed with the remaining soil.

Weed control - The first weed control operation was the ploughing of the soil, which occurred after the first rains, while the second weed control process was mid-December, which was by hand hoe. This is a much less destructive technology than mechanical weed control by tractor. Thereafter there were no further weed control operations, because the maize plant was regarded to be mature enough to compete with the weeds.

Fertilizer - The fertilizer application by the traditional farmers depended on the farmers' income. No lime was applied by any of the farmers under the conventional system. The fertilizer application rates were zero for low income farmers who did not have access to manure; dry powdered 'kraal' manure; or a mixture of 'kraal' manure and a chemical fertilizer such as 2:3:2. If a chemical fertilizer was applied, it was applied at a rate up to 100 kg 2:3:2 (22) ha^{-1}, although the recommended rate was 200 kg ha^{-1}. The application of manure as a fertilizer is good, as organic material is supplied, along with macro and micro elements. A large quantity of this would need to be applied i.e. at a rate of 2000 kg ha^{-1}, to supply the equivalent amount of nutrients of 200 kg 2:3:2 (22) ha^{-1}.

Pest control - The pest control practice followed to control Stalk borer, (*Busseola fusca*) was to plant late in spring. By planting late in spring, it was the farmers' objective and belief that the stalk borer flights would be missed, and in turn reduction in larvae damaging the crop. The late planting led to other problems, however, such as flowering of the plants late in the season and the cobs not reaching physiological maturity before winter.

Fodder - In winter, animals were allowed to graze on the crop residue, reducing the mulch covering the soil surface.

3.2.2 "No Till" (NT) production system

The method of training of the farmers in the "No Till" agriculture farming system was by farmer led demonstration trials. Sufficient inputs were given to the participating farmers for a quarter hectare. The rationale was to take the risk away from the farmer for the new production system, and produce sufficient food for the family and still have sufficient crop to sell so as to buy more inputs to expand the area under the NT production system. The inputs consisted of hybrid seed (5 kg per 0.25ha: for a plant density of 35 000 plants per hectare); 50kg 2:3:2 (22) fertilizer, 25kg LAN, 1 litre Round Up®, 1 litre Bullet® and 40cm^3 insecticide (Bulldock®), which was sufficient for two spray applications per 0.25 ha. A knapsack sprayer was also provided to each participating farmer. The inputs were given with the proviso that:

- The farmer would follow the NT production system;
- The researcher was able to do a yield estimate;
- The farmer would plant an additional quarter hectare of maize following their traditional method of maize production alongside the NT plot.

By planting maize following the two methods each farmer was able to compare the growth, labour input for each system and the crops' reaction to stresses such as the dry period between precipitations.

Field preparation - The fields were firstly limed, at an application rate of 5 ton ha^{-1}. The fields were mechanically (tractor drawn) ripped to break up any compacted layer, and then ploughed using a mouldboard plough to incorporate the lime. This was to correct the topsoil acidity before starting with the NT farming system. The seedbed was prepared by a tractor drawn disc, thereafter there was no vehicular traffic on the fields. The only soil disturbance was planting, which was done by hand. This involved the making of a furrow 50 to 60 mm deep for fertilizer and the planting of seed, using a hand hoe. The seed was placed in the furrow at an intra-row spacing of 30 cm and row spacing of 90cm. The fertilizer was measured out using a Coca Cola cool drink bottle lid (volume of 7 cm^3) of fertilizer placed in the furrow between every second seed. The seed and fertilizer was covered with soil.

Fertilizer – A general fertilizer recommendation for Mlondozi was 200 kg 2:3:2: (22) per hectare. Limestone Ammonium Nitrate (LAN) was applied as a top dressing, six weeks after planting, at a rate of 100 kg ha^{-1}.

Seed - A Carnia hybrid, CG 2969, was planted at a plant density of 35 000 plants per hectare.

Weed control – The programme followed was: Two weeks after the first summer rains, Round Up® was sprayed at a rate of 4 l ha^{-1} to kill the young weeds, and retain the residue as mulch on the soil surface. Planting took place seven days after spraying with Round Up®. Within three days after planting, Bullet®, a residual herbicide, was sprayed onto the soil at the rate of 4 l ha^{-1}. The spraying of the herbicides was done using the supplied16 litre Knap sack sprayers.

Pest control - Bulldock®, a pyrethroid based insecticide, was sprayed at a rate of 20 cm^{-3} per quarter hectare, every two weeks for a period of four weeks to control stalk borer larvae. The spraying programme commenced when the crop was six weeks old.

3.3 CLASSIFICATION AND PROPERTIES OF THE SOILS OF THE STUDY SITES

At the start of the project a profile pit was dug in the two fields (per cultivation system NT and CT) to classify the soils, at each participating farmer. This was to classify the soils and sample with expectations that differences over time would develop.

The procedure to classify soils, as described in the book Soil classification: A taxonomic system for South Africa (1991) is:

- Demarcating the master horizons present in the profile
- Identifying diagnostic horizons or materials
- Establishing the soil form using the key
- Identifying the family differentiae
- Establishing the soil family
- Determining the texture class of the A horizon and adding it to the name or code of the soil family

3.4 THE LABORATORY RAINFALL SIMULATOR

The laboratory scale rainfall simulator at the ARC-ISCW used in this study, was identical to that described by Morin, Goldberg and Seginer (1967) (Figure 3.2).

The simulator consists of two parts; namely:

- The applicator;
- The soil box carousel.

The applicator consists of a pump which supplies water at a given pressure to a rotating nozzle and a rotating metal disc that can be altered for different apertures. The water drops from the nozzle are able to spray out onto the boxes when the aperture is under the nozzle.

A high pressure rain was obtained when the water was at 60 kPa from a full cone spray type no.1.5 H30 nozzle at a height of 2 m from the soil surface

A rain intensity of 45 mm h^{-1} was used, with a drop diameter of 1,9 mm diameter, with a terminal velocity of the drop of 6,02 ms^{-1} and kinetic energy of the rain of 19,1 J mm^{-1} m^{-2} (Morin et al. 1967).

In previous work it was found that it was unnecessary to use soil layers thicker than 25 mm since infiltration rates are unaffected even if thicker layers are used (Morin *et al.,* 1967). A piece of cloth was placed between the sand and the soil to ensure continuous flow of water from the soil to the sand. The plastic trays containing the samples were placed in sealed boxes containing sand. A hose was attached to a nipple on the underside. The sample was wetted until saturation by tap water (EC = 1mS/m) forced through the sand, thus wetting the sample by capillary action. When the sample was saturated the water supply was switched off and the simulated storm event commenced, using distilled water. The angle of the samples on the carousel was 5 degrees. This was used as all the previous rainfall simulation studies conducted were at 5 degrees, thus the results could be compared to previously conducted rainfall simulations.

The samples were placed in the rainfall simulator for two storm events. The first storm was to settle the soil sample. The trays with the soils were removed after the first storm, dried for seven days and then replaced in the carousel for a second storm event. Each storm lasted for 50 rotations, with each rotation taking 2 minutes, thus each storm lasted for 100 minutes, giving an application of 75 mm per storm.

The amount of water that infiltrated the soil was recorded for every second rotation, along with the runoff. The run-off was collected in volumetric cylinders, measured, and then transferred to beakers, of which the mass had been pre-determined. A teaspoon tip of magnesium chloride ($MgCl_2$) (about one gram) was added to the slurry and mixed in, to aid flocculation of the suspension. The excess water was decanted, and then the slurries in the beakers were dried for 48 hours in an oven at 80 °C. The standard temperature of 105 °C, was not used due to the beakers being made of plastic (ARC-ISCW QMS procedure, 2007).

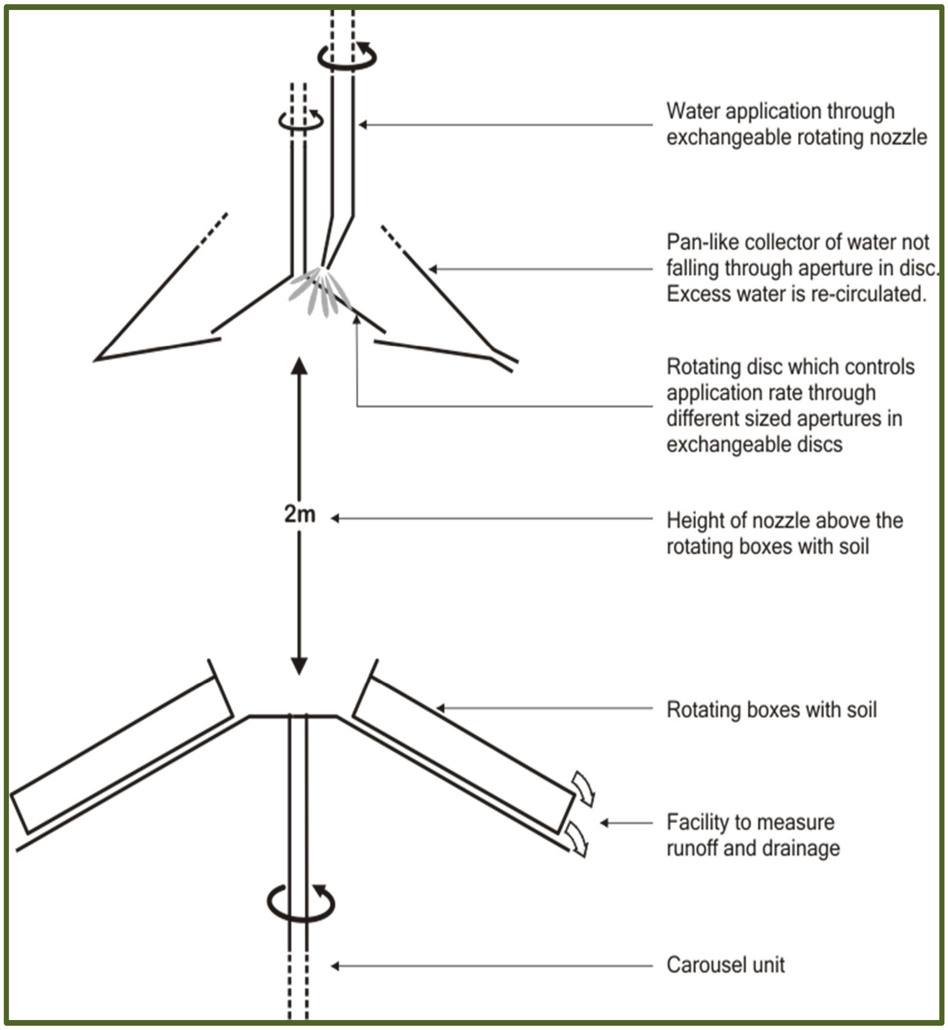

Figure 3.2 Schematic diagram of the main parts of the laboratory rainfall simulator (Morin, Goldberg and Seginer, 1967)

3.5 SOIL SAMPLING FOR THE RAINFALL SIMULATOR

The objective of the pan method was to take undisturbed topsoil samples for a laboratory rainfall study. Secondly a faster turnaround time was sought under more controlled conditions using the laboratory rainfall simulator.

The pan method of taking undisturbed soil samples developed in this study proved to be a good alternative to the traditional methods of soil loss determination and run-off achieving all of the above objectives. The traditional method of taking soil samples was digging out the soil using a spade, then sieving the soils, which were tested in a rainfall simulator.

3.5.1 Sampling equipment

Mild steel sampling trays were constructed to take undisturbed topsoil samples. The trays were made from 2 mm metal sheet. The metal was bent to shape to the dimensions of 350 x 500 x 50 mm. An opening was left on one long side (Figure 3.2).

Figure 3.2 Metal tray used to take samples in field

3.5.2 Sampling procedure

- A shallow hole was dug, one and a half times the width of the tray and about 60 mm deep. The face of the soil was squared so the soil would be flush with the inside of the tray.
- The tray was tapped horizontally into the soil using a 2 kilogram hammer, with minimal disturbance, for a constant thickness of 50 mm.
- After sampling the open edge was carefully cut with a spade for minimal disturbance of the sample.
- The metal boxes were wrapped in plastic cling wrap after the samples were taken.
- On arriving back at the Institute from the field, the plastic wrap was immediately removed to prevent possible decomposition of the mulch and to allow the sample to air dry.

3.5.3 Transferring the soil samples to the plastic trays

Transferring of the soil samples from the metal trays in which the samples were collected to the plastic trays used in the rainfall simulator was done as follows:

- The soil samples were wetted with deionised water, using a 500 ml plastic squirt bottle (with the squirt attachment removed so as to supply a low energy jet of water) – for a friable sample.
- A wooden laboratory tray was placed, upside down, over the sample while still in the metal sampling tray. The sample was then flipped over so the top of the sample lay on the wooden laboratory tray, with the sample lying upside down. The underside was scraped to achieve a constant thickness of 50 mm and a flat bottom surface.
- A muslin cloth was placed in the bottom of the plastic perforated rainfall simulator tray to prevent soil seeping through the holes during the simulated storm event.

- The perforated plastic tray was placed, upside down, over the sample that had been worked on the laboratory tray. The sample was then flipped over into the perforated plastic tray.
- Along the edges of the sample, where there was not a good fitting of the sample in the plastic tray, the soil that was scraped off, was pressed into the gaps (Figure 3.3).
- A mask was made to cover the soil that had been disturbed along the edges, so as not to influence the results. This was made using 50 x 50 mm angle iron, 3 mm thick. A 2 mm diameter round rubber strip was glued on the edge of the angle iron closest to the soil to prevent possible accumulated water running onto the soil surface (Figure 3.4). The resultant area of the exposed soil surface was 240 x 470 mm = 0, 1128 m^2.

Figure 3.3 Soil sample transferred to the plastic tray

Figure 3.4 Example, of a perforated plastic tray

3.6 YIELD ESTIMATION

- Yield estimation was conducted yearly during the winter months of June or July during the study period. Yield estimates were conducted in the NT and CT plots as well as the researcher managed trial plots. Only accurate yield data was used for data analysis due to the fact that some farmers harvested before time. The inter-row spacing was 90cm and the intra row spacing was round about 31cm.

The procedure for yield estimation was as follows:

- A row in the field where the yield estimation was to be conducted was randomly chosen. The row had to be at least three rows in from the edge of the field, and three meters from the end of the row, to avoid any boundary effect.
- A five meter length of the row was measured and marked out.
- The number of plants in the five meter row was counted for plant population.
- The cobs were picked then placed into a large plastic bag which was previously marked along with the details of the plant numbers.

- This process was done in triplicate in each field.
- At the laboratory the cobs were threshed and the moisture content determined; weighed; and data recorded in the field book.
- All the yields were converted to 12,5% moisture in the seed so as to have comparable results.
- Correction of seed water content to 12,5% moisture

$$= 1 - \frac{\text{average \% seed moisture} - 12{,}5\%}{100} \times \frac{\text{yield}}{\text{ha}}$$

- Formula for yield per hectare (kg per ha)

$$= \frac{10\ 000m^2}{Row\ length \times Interrow\ width} \times \frac{Mass\ of\ seed\ at\ 12.5\%\ moisture}{1}$$

3.7 DETERMINATION OF IN-FIELD MULCH COVER

The mulch cover has a direct relationship with the erodability of the soil. It has further benefits such as reducing weed infestation and reducing evaporation from the soil surface .Mulch cover percentage was estimated by using a series of photos with known percentage cover of maize or soya beans. The sampling was done at the same time each year in winter. The mulch cover was classified, using photos of a 25, 50, 75 and 90 percentage cover. It is estimated that a person can be accurate to within 10 to 20% (Shelton and Jasa, 1998; Eck and Brown, 2004).

Photo-comparison method consists of:

- A representative area randomly chosen in the field. Row ends or places where there was an excess of weeds or other disturbances were avoided.
- Making at least three observations, and then averaging the individual estimates to obtain a percentage for the whole field.
-

3.8 DETERMINATION OF THE ROOT COUNT IN FIELD

When farmers adopted the NT farming system, it was expected that there would be a higher root count per volume of soil for the NT fields compared to the CT fields. It was thus deemed necessary to monitor the root count as a biological property to determine if changes took place in the soils. The soils were monitored each year in winter for the top and sub soils. A surrogate root count was used for comparative purposes. The method consisted of a profile pit being dug in both the CT and NT fields. Root count was determined by placing a 20 x 20 cm piece of cardboard, with a previously cut out hole, of 10 x 10 cm, against the side of the profile pit. This was done in the middle of the A and B horizons. The number of roots observed in the window of the horizon were counted and recorded in the field book.

3.9 OTHER LABORATORY ANALYSES

3.9.1 *Clay mineralogical composition* was determined by X-ray diffraction (XRD), using a CoKα source for x-rays and graphite monochromator. A semi quantitative evaluation of the amount of the various clay minerals was obtained from the relative peak areas of the XRD of the clays. This was done for completeness, but was not further elaborated on for the purpose of this study.

3.9.2 The *chemical analyses* done on the soil samples followed the procedures described in the handbook of standard soil testing methods for advisory purposes (The non-affiliated soil analysis work committee, 1990). These procedures were as follows:

- Extractable phosphorus: Bray 1, as described by Bray and Kurtz (1945)
- Extractable cations: Ammonium acetate (1 mol dm^{-3}, pH 7)
- Organic Carbon: Walkley-Black method as described by Walkley Black (1934)
- pH (H_20); a 1: 2,5 soil - water ratio
- Cation exchange capacity using lithium chloride.

3.10 STATISTICAL ANALYSIS

All the data used was gathered by the use of a random sampling system. Samples were taken as described for each observation. The following statistical procedures were done:

3.10.1 Fertility

In winter each year topsoil samples were taken using an auger, to a depth of 30 cm. Three samples were randomly taken per cultivation system (0,25 ha). The samples were mixed together and a representative sample was taken for nutrient status analyses.

The plot layout (NT and CT) on the farms was as a split-plot design replicated eighteen times (each farmer as a replicate). Analysis of variance (ANOVA) was used to test for differences between the 2 treatment-systems (NT and CT) as main-plots and the 4 years, 1999-2002 as sub-plots, as well as for their interaction. The data was acceptably normally distributed and were separated using Fishers' protected t-test least significant difference (LSD) at the 5% level of significance (Snedecor & Cochran, 1980). The software programme, SAS 9.2, was used to test the soil fertility elements (pH, P, Ca, Mg, K and CEC).

3.10.2 Maize yield

The same statistical design, as well as analysis as described above, was applied to the maize yield data. Method of yield determination is described under point 3.6.

3.10.3 Mulch cover and Root count

Tabulation of the mulch and root counts for each farming system (NT and CT) is presented.

3.10.4 Runoff, Infiltration and Soil loss

At the end of the project, four undisturbed soil samples were taken from each cultivation treatment, using the metal trays described in 3.5. Soil sampling for the rainfall simulator study was under-taken during July 2003, on moist soils.

3.10.4.1 Statistical Analysis part I

Statistical analyses for comparison of the two storms separately, were conducted on sampled soils, to the soils for runoff, infiltration and soil loss on the data sets. The two sample t - test was applied to the data to test for differences between the two systems means and totals of the tests (sample size was = 72 at 18 sites with 4 replicates, (figure 4.5 and figure 4.6) The "students" t-test for two independent samples was applied to the data to test for differences between the two systems means (sample size was = 72 at 18 sites with 4 replicates). Significance was obtained at the 5% level of significance ($P < 0.05$; Snedecor & Cochran, 1980). Data was analysed using the statistical programme GenStat® (Payne *et al*., 2007).

3.10.4.2 Statistical analysis part II

The two storms were combined by analysing the data, as a split-plot analysis with the treatment farming systems (NT and CT) as main plots and the storm and rotations as sub-plots. This dataset was analysed with SAS 9.2.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Soil Classification and Mineralogy

The farmer's soils were classified and listed, along with the horizon depths in Table 4.1. The soils, although mostly having high carbon content in the topsoil, were not classified as humic horizons due to the exchangeable cations being too high.

Table 4.1 Soil classification (Soil classification working group, 1991)

Sampling point	Soil form	Soil series	Horizon A (mm)	Horizon B (mm)
1	Clovelly	Caledon	200	650
2	Clovelly	Lundini	220	800
3	Clovelly	Oatsdale	220	800
4	Hutton	Williamson 15	260	600
5	Hutton	Farningham	300	520+
6	Clovelly	Oatsdale 12	250	800
7	Clovelly	Oatsdale 12	300	500+
8	Kroonstad	Swellengift 12	200	700
9	Clovelly	Leeufontein 16	260	600
10	Clovelly	Oatsdale 16	280	800
11	Hutton	Hutton 16	250	800
12	Clovelly	Oatsdale 16	250	800
13	Avalon	Newcastle 25	250	550
14	Hutton	Hutton 16	300	1200
15	Hutton	Hutton 16	380	900
16	Hutton	Hutton 16	200	700
17	Hutton	Hutton 16	300	600
18	Hutton	Hutton 16	260	650

Clay mineralogical composition of the study site soils are listed in Table 4.2. The dominant minerals are kaolinite and quartz. Common mineralogical end points after weathering are goethite, gibbsite, hematite and coarse-grained quartz. In most samples there are a high percentage of end-point minerals (0 to 34%), which is an indication of highly weathered soils. (Jackson, Tyler, Willis, Boubeau and Pennington, cited by Mulibana, 2001).

Table 4.2 Clay mineralogical analysis of the soils from the 18 study sites (ARC – ISCW).

Profile no	Qz	Mi	Kt	Go	Gb
	%	%	%	%	%
1	23	-	60	17	-
2	62	-	38	-	-
3	29	-	50	6	15
4	14	-	62	5	19
5	17	3	50	7	9
6	17	-	45	14	24
7	31	4	50	10	5
8	19	4	48	13	16
9	24	4	67	-	-
10	45	-	50	-	-
11	15	6	64	6	9
12	39	-	42	10	9
13	35	-	49	16	-
14	29	-	52	9	10
15	35	3	41	-	21
16	50	-	21	12	17
17	11	5	70	7	4
18	23	-	59	19	-

Qz – Quartz
Mi – Mica
Kt – Kaolinite
Go - Goethite
Gb – Gibbsite

4.2 Soil samples using the pan method.

The pan method was not compared with in-field run-off plots or an in-field portable rainfall simulator. The constant similarity of the replicate infiltration rates indicates a method that produces results that are constantly repeatable. The simulated storm events, in the laboratory rainfall simulator, deliver consistently precise simulated storm intensity and drop size with purified water. The objectives achieved included:

- Taking undisturbed soil samples
- The samples were tested in the laboratory rainfall simulator for two simulated storm events under controlled conditions.
- The turnaround time was quick, making this a more economical method.
- Within two hours after sampling the result could be obtained, using the rainfall simulator.

4.3. RESULTS AND STATISTICAL ANALYSIS

4.3.1 Fertility

Due to soils being derived from granite and acidic in nature they have a low fertility, as indicated by the base line soil samples of the 18 study sites taken in 1999 (Fig. 4.1- 4.3; Table 4.3). Soil samples taken annually from the NT fields, to the end of the study period, were compared to the base line samples taken at the start of the project. Although dolomitic lime was applied at the start of the study period and there were no follow-up applications, the Ca and Mg concentration and pH increased during the study period and were statistically different at 5% level (between 1999 and 2002 - Table 4.3). Although a *2:3:2 fertilizer mixture* was applied, potassium decreased over time, (significantly lower), but phosphorus and carbon were not significantly lower between 1999 and 2002.

The fertilizer recommendation for the NT plots was aimed at improving soil fertility by supplying the plant nutritional requirements and raising the base line nutrition levels in the soil. A noticeable occurrence was an increasing trend in soil pH over the study period. During the first season most of the extractable acid was neutralised and the soil pH (H_2O) showed a lag period of 2 to 3 years. The crops cultivated following the CT farming system continued to have leaves that were yellow and purple due to nitrogen and phosphorus deficiencies.

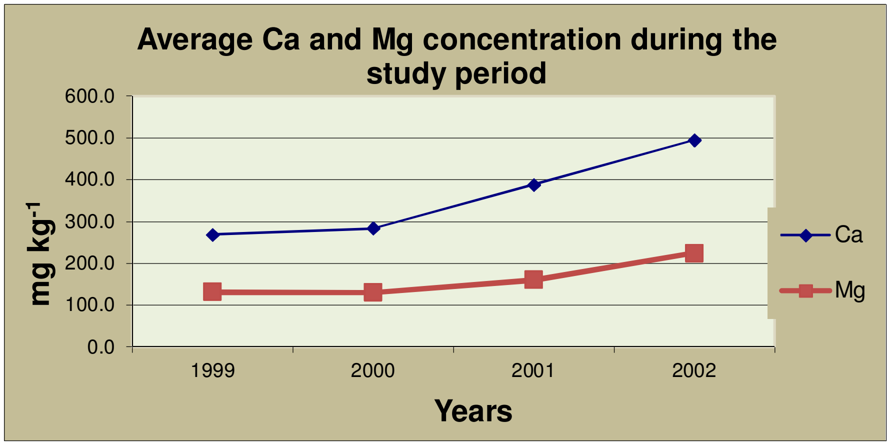

Figure 4.1 Average of the Ca and Mg, of the NT soils for the 18 study sites.

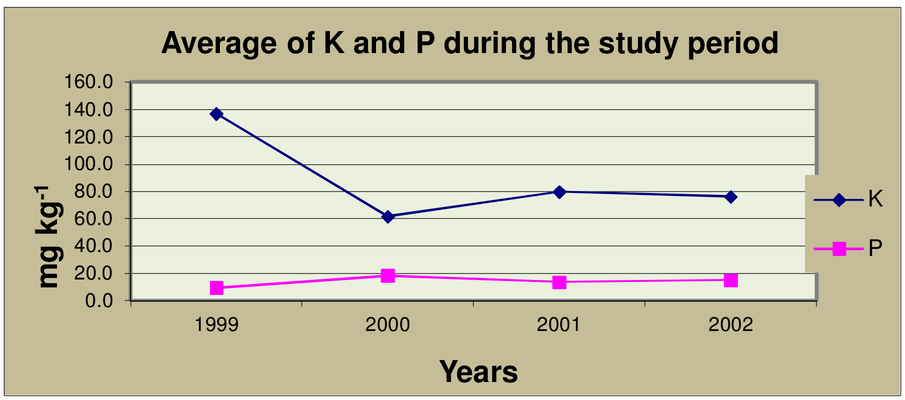

Figure 4.2 Average of the K and P of the NT soils for the 18 study sites.

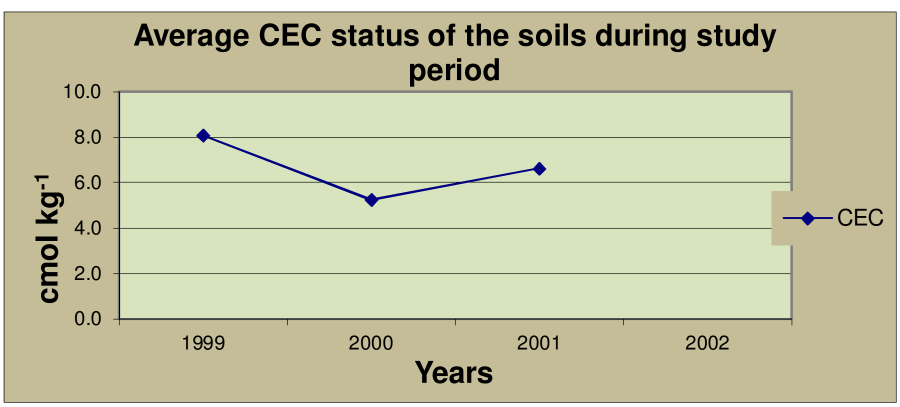

Figure 4.3 Average of the CEC of the soils in the NT fields of the 18 study sites.

A combined ANOVA statistical analysis was done over the four seasons and farms, using SAS 9.2 version (SAS Institute Inc., 1999) to test for differences (table 4.3). The data was normally distributed with acceptable homogeneous variances over years. The means were separated using Fishers' protected t-test least significant difference (LSD) at the 5 % level of significance (Snedecor & Cochran, 1980).

Table 4.3 Combined ANOVA over seasons

Years	Ca	Mg	K	P	CEC	pH`	C
1999	268.56 b	131.20 b	137.19 a	9.54 b	8.08 a	5.22 c	1.975 a
2000	283.82 b	129.94 b	61.76 b	18.33 a	5.25b	5.49bc	1.897 a
2001	388.0 ab	160.14ab	79.89 b	13.70ab	6.64ab	6.03 a	1.849 a
2002	494.68 a	224.11 a	76.35 b	15.07ab	.	5.92ab	1.887 a
MSE	36738.31	10336.78	1634.99	122.01	5.950	0.391	0.043
F probability	0.0052	0.0375	<.0001	0.1407	0.0074	0.0008	0.802
LSD(5%)	134.72	70.5	27.92	7.706	1.77	0.432	0.149

[1]Means per column followed by a different letter were significantly different at the 5% level.

[1]MSE is the Mean Square Error

4.3.2 The Comparison of NT and CT farming systems - Yield

"No Till" (NT) is regarded as an improved farming system over the traditional farming system (CT) and includes the use of correct fertilizer quantity and type, hybrid seed, herbicides and insecticides, planting without ploughing and residue retention as mulch. In comparison the traditional farming system used little to no fertilizer, seed held over or traditional seed and planting late to avoid stalk borer damage.

Indicators used to gauge the two farming systems included yield. The yield increased from 0.51 ton per hectare at the start of the project to 4.6 ton per ha for the 2001 season and 2.76 ton ha^{-1} for the 2001/2 season. Following the implementation of the NT farming system, the farmers observed that the crop on the NT managed fields was less prone to wilting between rainfall events. That indicates a higher infiltration rate during rain events, which would allow the soil to reach field capacity quicker, due to lower run-off. With a higher infiltration rate, a larger reservoir of water was retained in the soil. In comparison the CT farming system maize plants remained dwarfed with stunted root systems due to the acidic soils, which resulted in the plants wilting relatively soon after rain events.

Table 4.4 Yields of the NT and CT field of the 18 farmers.

	NT yields			CT yields		
Farmer	**1999/2000**	**2000/1**	**2001/2**	**1999/2000**	**2000/1**	**2001/2**
	ton ha^{-1}	ton ha^{-1}	ton ha^{-1}	ton ha^{-1}	ton ha^{-1}	ton ha^{-1}
1	1.9	3.7	6	1.5	2	2.8
2	4.074	7.22	2.88	-	2.65	-
3	2	4.26	2.88	-	-	-
4	3.829	5.33	2.4	2.82	1.58	-
5	-	6.41	2.88	-	5.59	-
6	1.304	4.26	-	1.469	-	-
7	-	4.88	-	-	-	-
8	-	2.13	-	-	-	-
9	2.253	3.39	-	-	-	-
10	1.674	3.11	2.88	2.38	-	-
11	2.463	4.8	3.36	-	2.65	-
12	3.288	4.64	3.36	1.461	-	-
13	2.556	5.2	-	0.997	-	-
14	5.089	4.52	-	-	-	-
15	4.319	4.4	3.36	-	-	-
16	3.656	4.94	-	-	-	-
17	-	-	-	-	-	-
18	1.7	4.6	2.9	0.8	2	3.8
Average	2.86	4.58	3.29	1.43	2.75	3.3

The yield estimation was conducted in July of each year. Some farmers harvested before the researcher could do the yield estimation. There are 16 missing data points for the 2001/2 season because the farmers were gradually implementing the NT farming system on the rest of their farms. The yield estimation was therefore, not representative for 2001/2 season as well the two previous seasons.

Due to the improved combination of technologies for NT, there was an improvement of yield over the seasons and over CT. For 2001-2002 season there was a decrease in yield due to a drier season.

At the start of the project the farmers agreed to continue cultivating maize on the traditional plots following the traditional farming system. Over time they gradually started to implement the NT technologies which is the main cause of the increased yield. NT and CT gave the same yield results for 2001/2002 season, because of the dry season and higher fertilizer input.

A split-plot (ANOVA) over years, treatments and farms was done using SAS 9.2 to test for differences between years, treatments and years X treatment interactions (table 4.6-4.8). The data was normally distributed with acceptable homogeneous variances over years. The means were separated using Fishers unprotected t-test least significant difference (LSD) at the 5 % level of significance (Snedecor & Cochran, 1980).

Table 4.5: ANOVA table for yields

		Yield	
SOURCE	**DF[1]**	**MS[2]**	**P[3]**
Farm	16	2.076	0.0742
Treatment	1	16.128	**0.0008**
Error(1)	9	0.895	
Year	1	10.314	**.0009**
Treatment X Year	2	4.646	**0.0261**
Error(2)	25	1.097	
Corrected	55		

Where DF[1] = Degrees of freedom, MS[2] = Means Square and p[3]= Significant level of F-Ratio. A significant level less than 0.05 is considered as a significant effect and indicated in bold

Table 4.6 shows the mean yield for the two treatments, table 4.7 the mean yield over the different seasons, for the study period and table 4.8 the mean yield for the two treatments over different seasons.

Table 4.6 – Means of yield for the two treatments

Tmt	Yield[1]	N	
NT	3.68	41	a
CT	2.30	15	b
LSD(p=0.05)=	0.65		

[1] Yield in ton ha^{-1}

Table 4.7 – Mean yield over the different years for both farming systems.

Year	Yield	N	
2000/01	4.10	23	a
2001/02	3.29	12	b
1999/2000	2.45	21	c
LSD[1](p=0.05)=	0.74		

[1]LSD is the least significant difference.

Table 4.8 – Mean yield for different treatments over the seasons

Year	Tmt	Yield	N	
2000_01	NT	4.58	17	a
2000_01	CT	2.75	6	bc
2001_02	NT	3.29	10	b
2001_02	CT	3.30	2	b
99_2000	NT	2.86	14	bc
99_2000	CT	1.63	7	c
LSD[1](p=0.05)=	1.27			

[1]LSD is the least significant difference.

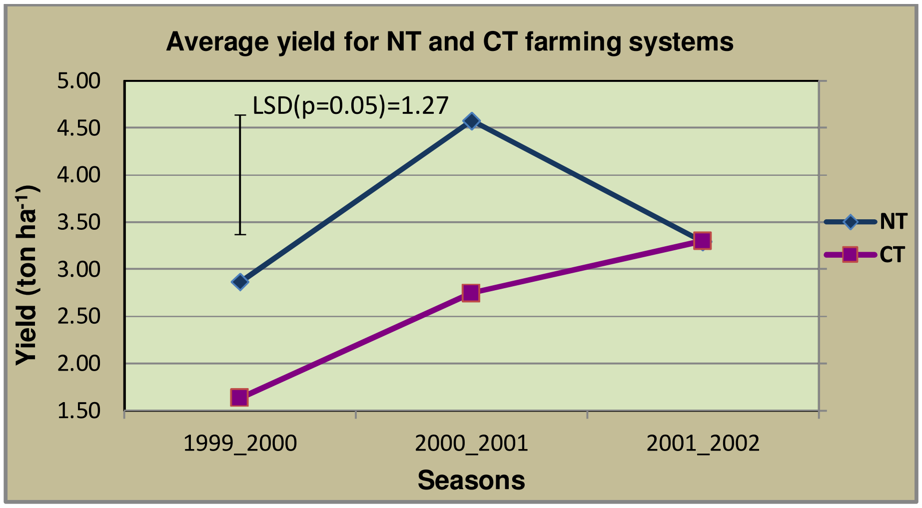

Figure 4.4 Average of the NT and CT yields for the study period.

4.3.3 Mulch cover and Root count

Traditionally the farmers would allow the cattle to graze on the crop residue. By keeping the cattle out of the NT fields and the farmers cutting down the residue after harvest of the maize crop, there was a higher percentage of soil cover, going up from an average of 30% cover, which was the base line estimation, to 55% soil cover (Table 4.9). The FAO recommendation for the implementation of NT is for the soil to have a minimum of 30% soil cover. The retention of the mulch on the soil reduced evaporation from the soil surface, reducing run-off resulting in improved infiltration. With reduced run-off there would be a reduction in soil erosion taking place.

Table 4.9 The average mulch of the NT plots over the study period (Jansen van Rensburg, 2002).

	Baseline value at initiation of project (1999)	Values in 2000	Values in 2001	Values in 2002
% Mulch	30	60	55	55

The root count (Table 4.10) went up from 30 in 1999, to 41 in 2001 and dropped to 35 *per 10 by 10 cm area* in 2002, which was an overall 16% improvement in the top soil. For the subsoil, the root count went up from 7 in 1999 to 16 in 2001, and dropped to 13 in 2002, still an increase of 76% from the baseline in 1999. Again, for the NT treatments, there was an improvement of root count due to the reduction of acidity due to liming. This in turn further improved the nutrient and water uptake. Improved nutrient uptake resulted in an optimal crop. An improved rooting system resulted in the crop not wilting as quickly as the crop produced following the traditional farming system.

Table 4.10 Average root counts for the NT fields

Indicator	Baseline root count at initiation of project (1999)	Root count in 2000	Root count in 2001	Root count in 2002
▪ Roots per 100 cm^2 – subsoil	7	14	16	13
▪ Roots per 100 cm^2 – topsoil	30	39	41	35

With there being an increase in yields there was an equivalent increase in biomass, which, when left on the field, had improved percentage mulch and root counts. This resulted in the observed reduction in erosion taking place. There is a correlation between the above-, and below, ground root biomass. With an increase in below ground biomass there was an increase in root counts in both the top and sub soil horizons for the NT crops. This was due to the correction of the soil acidity and the breaking of the plough sole. Eighty percent of the feeder roots occur in the top soil, which was supported by the retention of the mulch due to the reduction of soil water evaporation. In turn the higher root count would lead to an improved nutrient and water uptake and would potentially improve the quantity of organic material, over time in the soil. There would be channels left after decomposition which would further improve water infiltration.

4.3.4 Runoff, Infiltration and Soil loss for the NT and CT treatments

Two statistical analyses for above heading were performed.

4.3.4.1 Statistical Analysis part I

. The first part consists of: Two sample t - test was applied to the data to test for differences between the two system means and totals of the tests (sample size was = 72 at 18 farms with 4 replicates - table 4.11). Significance was obtained at the 5% level of significance ($p < 0.05$; Snedecor & Cochran, 1980). Data was analysed using the statistical programme GenStat® (Payne *et al.*, 2007).

Table 4.11 Mean soil loss, run-off and total infiltration (n=72)

	Soil loss (g)		Run off (cm^3)		Total infiltration (cm^3)	
System	**Storm 1**	**Storm 2**	**Storm 1**	**Storm 2**	**Storm 1**	**Storm 2**
NT	8.46a	7.39a	1984a	1644a	2865a	3364a
CT	6.45b	7.43a	1786a	1817a	3176b	3207a
Probability	0.043	0.965	0.127	0.22	0.015	0.291

Means within each column with the same letter or letters do not differ significantly at the 5% significant level.

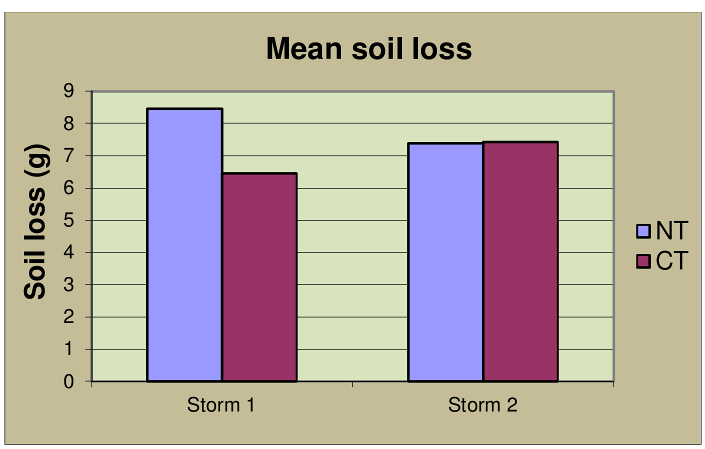

Figure 4.5 Graph of the mean soil loss

Fig 4.5 showing a higher soil loss for NT soils, for the first simulated storm event, (significant) and slightly lower for the second storm (not significant)

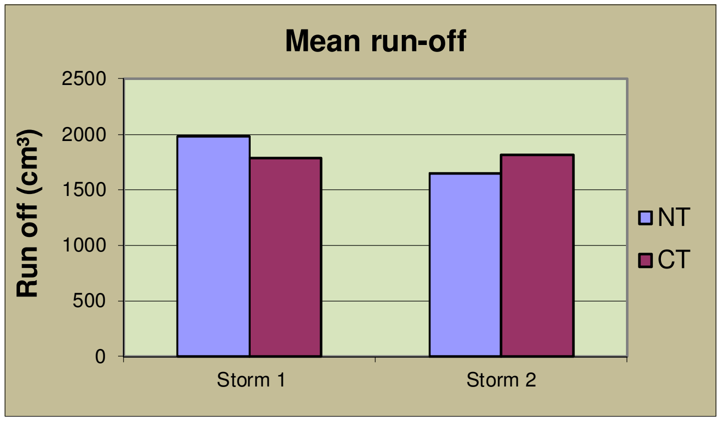

Figure 4.6 Graph of the mean run-off

Fig 4.6, showing a higher run-off for the NT soils for the first simulated storm event, and lower for the second (results for both the storm events are not significantly different).

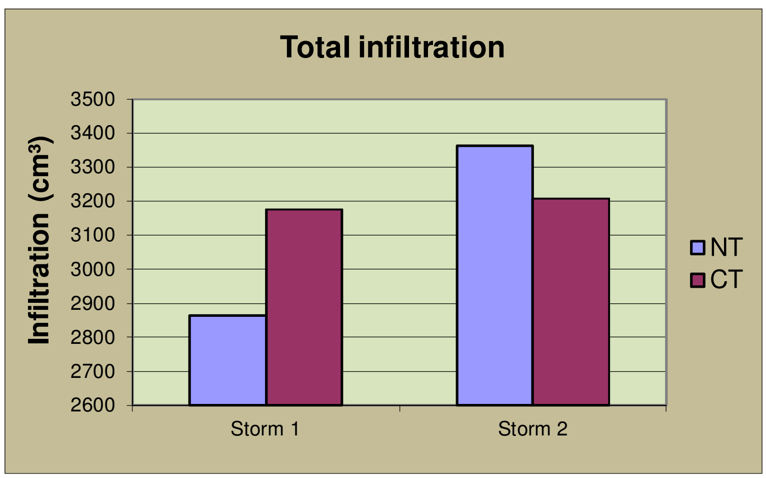

Figure 4.7 Graph of total infiltration for the first and second simulated storm event.

The infiltration for the CT soil (fig. 4.7) is significantly higher than for the NT soil; while for the second storm event the NT soil had higher infiltration, though not significantly different.

For the first simulated storm event soil loss and run off were higher than expected for the NT soil compared to the CT soil, while for the simulated storm event 2 the soil losses were about the same (Figure 4.5 and Figure 4.6). Storm event 1 was statistically significant at the 5% level, which is denoted in table 4.11 by different letters (i.e. **a** and **b**). Storm event 2 was not significantly different denoted by the same letter after the number. This would probably be due to the aggregates being broken up and the clay particles clogging the pores of the CT soil. Similarly the run-off was higher for the NT soil for the simulated storm event 1. Run-off was slightly lower for the NT soil compared to the CT soil. Both storms' means were not significant. This was probably to be expected as the ploughed soils were loosened by the ploughing action.

In Table 4.11, the NT soils show a decrease in soil loss as well as a decrease in run-off, while with the CT soils the reverse occurs. Total infiltration increases from the first to the second storm event for the NT soils. The first storm event settles the soils and with the second storm event the more stable soils give lower soil loss and run-off and higher infiltration. The deduction that can be made is that the NT soils, due to their greater stability, have a higher infiltration rate, resulting in the reduced run-off. The CT soils, due to the reduced stability, have a reduced infiltration rate, possibly due to crust formation, leading to increased run-off and soil loss.

The traditionally cultivated soils were loosened by the cultivation process, therefore it was to be expected that the infiltration would be higher for storm event 1. For the simulated storm event 2, the NT soil had a higher infiltration rate due to the soil structure being maintained. Storm event 1 was significantly different. For the simulated storm event 2 the infiltration was higher for the NT soil (Figure 4.7 & Table 4.11).

The average infiltration for each second rotation of the rainfall simulator, for the 18 NT and CT soils, is given in Table 4.12; and Figures 4.8 and 4.9. The result illustrates the NT soils remained stable over a longer period of time. Although the NT soils had a lower initial infiltration rate for both simulated storm events, the CT soils' infiltration rate decreased more rapidly. The infiltration rate was significantly different for rotations 2 to 16 for the simulated storm event 1. For simulated storm event 2, the NT soils had a significantly higher infiltration rate for rotations 24 to 40 (Table 4.12).

Table 4.12 Average infiltration means for the eighteen NT and CT soils (n=72).

Simulated storm event 1			
Rotation	**NT**	**CT**	**p[1]**
2	186.2	211.5	0.001 a
4	180.8	206.3	0.001 a
6	174.5	201.7	0.001 a
8	170.5	198.3	0.001 a
10	165.3	190.4	0.001 a
12	160.3	182.5	0.001 a
14	154.7	172.5	0.004 a
16	148.3	163.87	0.022 a
18	141.1	153.5	0.11
20	133.8	145	0.176
22	127.9	135.6	0.358
24	120.8	126.5	0.493
26	112.5	118.9	0.441
28	105.8	111	0.524
30	98.6	104.1	0.476
32	92.9	94.5	0.822
34	86.6	85.9	0.916
36	80.9	80.3	0.917
38	76	75	0.886
40	72.1	71	0.897
42	67.7	70.1	0.701
44	65.8	69.2	0.599
46	65.8	69	0.615
48	65.8	69	0.615
50	65.8	69	0.615

Simulated storm event 2			
Rotation	**NT**	**CT**	**p[1]**
2	209.8	213.5	0.162
4	205.4	207.4	0.397
6	197.4	198.6	0.609
8	191.8	193.6	0.548
10	186.3	191	0.236
12	180.6	185.1	0.387
14	176.7	178.4	0.77
16	170.8	170.5	0.966
18	165.2	160	0.499
20	158.7	148.3	0.208
22	151.1	137.2	0.103
24	144	125.8	0.036 a
26	135.9	114	0.011 a
28	129.7	105.4	0.005 a
30	122	97.9	0.004 a
32	114.6	92.1	0.006 a
34	108.4	85.6	0.004 a
36	101.2	79.4	0.006 a
38	94.8	76.9	0.02 a
40	89.6	73.6	0.035 a
42	83.2	71	0.105
44	81.1	69.9	0.134
46	80.1	69.9	0.172
48	80.1	69.9	0.172
50	80.1	69.9	0.172

The probability denoted by an "a" are significantly different.

[1] p = probability value

Fig. 4.8 (storm 1) shows a gradual decrease in the rate of infiltration over time for both soils. The rate of decrease is lower for the NT soils. The first 16 rotations were significantly higher for the CT soil than the NT soils.

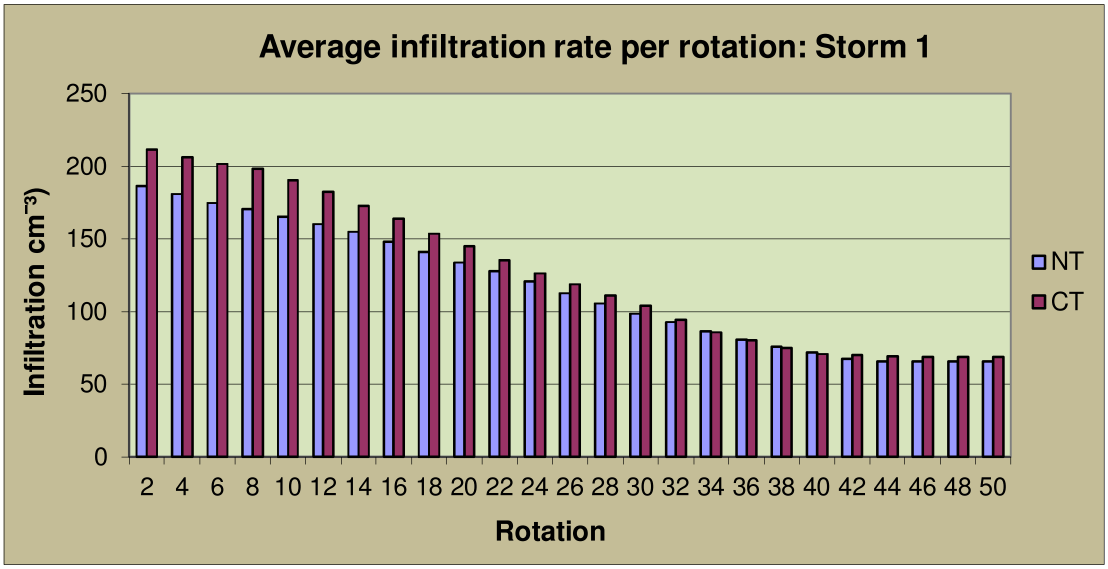

Figure 4.8 Infiltration means in the NT and CT for storm 1

The NT soils rate of infiltration for storm 2 is maintained at a higher rate for a longer period than the CT soils. . The difference is statistically significant for rotations 24 to 40.

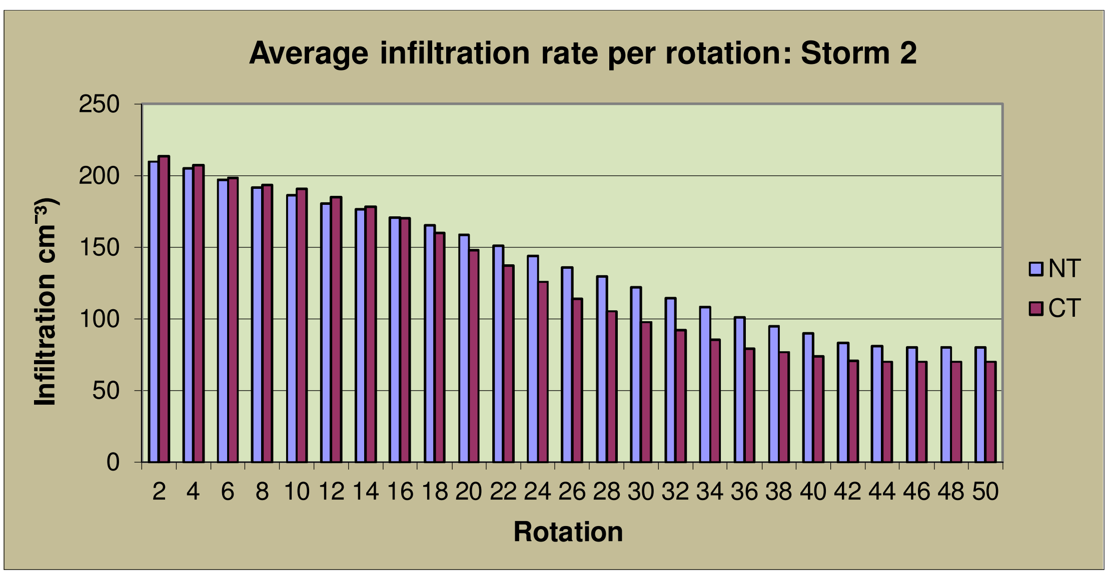

Figure 4.9 Infiltration means in the NT and CT soils for storm 2.

Figure 4.9 (storm 2) had a slightly lower initial infiltration rate, but decreased less than the CT soil. There was a significantly different higher infiltration rate for the NT soils compared to the CT soils for rotations 24 to 40.

Table 4.13 gives the average infiltration rates of the 72 samples measured in cm^3, for the NT and CT soils, per storm separately. The results show the initial infiltration rate (IIR) and final infiltration rate (FIR) to be higher for the second storm event compared to the first simulated storm event, for both the NT and CT farming systems.

Table 4.13 Average initial (IIR) (Rotation 2) and final infiltration rates (FIR) (Rotation 50) for the first and second simulated storms.

	NT		**Difference between IIR and FIR**	**CT**		**Difference between IIR and FIR**
	IIR cm^3	FIR cm^3		IIR cm^3	FIR cm^3	
First simulated storm event	185.7	64.3	121.4	212.9	70.7	142.2
Second simulated storm event	204.7	77.9	126.7	213.1	71.5	141.5
% Difference	10.23	21.15		0.16	1.13	

The average initial infiltration- and final infiltration rate for the NT and CT treatments, in Table 4.13, show there was a higher Initial Infiltration Rate (IIR) and Final Infiltration Rate (FIR) for the second simulated storm event for both the NT and CT soils. The difference of the IIR and FIR was higher for the NT soils at 10,23% and 21,15% respectively; compared to 0.16% and 1.13% for the CT soils. The NT soils settled with the first storm event and remained more stable. The difference between the IIR and FIR is lower for the NT treatment compared to the CT treatment, for both simulated storm events. The difference between the IIR and FIR is higher for the second storm than the first for the NT soil, compared to the

CT soil. This indicates that the CT soils slake more than the NT soils during the simulated storm event.

Stern (1990) indicated that crust formation is a common phenomenon in arid and semi-arid regions of the world, including South Africa. Seal formation was the dominant factor in promoting water runoff and soil loss. If the crust is permanently formed, then it would be expected that the initial infiltration rate for the second simulated storm would be lower. From the results it would appear that if a crust was formed, it broke down as the soils dried out. The soils in Mpumalanga are inherently stable due to the high iron and aluminium and low smectite content. This could be the reason for the similar initial infiltration rates. The first storm settled the soil resulting in the soils having a lower second storm initial infiltration rate (personal communication Christal Bühmann, 2008). Literature cited showed results for one simulated storm event only. This comparison for two simulated storm events has not been reported in literature. The higher infiltration rate for the NT soils for the second simulated storm event demonstrates the stability of the soils due to them not being worked, and the benefits of the stabilising action of micro-organisms and fungi on aggregate formation and stability.

4.3.4.2 Statistical Analysis – part 2

For the second part of the statistical analysis the farming systems (NT and CT) were combined. The data was analysed as a split-plot design with the treatment, farming systems (NT and CT) as main plots and the storm and rotations as sub-plots. Table 4.14 shows the ANOVA for the combined farming systems (treatments). This dataset was analysed using SAS 9.2.

Table 4.14 - ANOVA for the farming systems NT and CT (combined).

Source	DF[1]	MS[2]	p[3]
Farm	17	264549.0	
Tmt	1	86.8	0.9732
Error 1	17	74745.0	
Storm	1	207880.2	**<.0001**
Rotation	24	648713.2	**<.0001**
TmtxRotation	24	6831.9	**0.0016**
TmtxStorm	1	179310.3	**<.0001**
StormxRotation	24	394.7	1.0000
TmtxStormxRotation	24	477.8	1.0000
Error 2	1666	3273.9	
Total	7174		

[1]Where DF = Degrees of freedom, [2]MS = Means Square and [3]p= Significant level of F-Ratio. Tmt = treatment (NT and CT). A significant level less than 0.05 is considered as a significant effect and indicated in bold.

Table 4.15 Average infiltration means for the NT and CT soils and different rotations.

Rotation	Tmt	N	Mean (cm^3)	T grouping[A]
2	NT	144	198	bcd
2	CT	143	212.52	a
4	NT	144	193.13	cdef
4	CT	143	206.85	ab
6	NT	144	185.94	defg
6	CT	143	200.14	abc
8	NT	144	181.13	fgh
8	CT	143	195.94	bcde
10	NT	144	175.81	ghi
10	CT	143	190.7	cdef
12	NT	144	170.43	hij
12	CT	143	183.8	efg
14	NT	144	165.69	ijkl
14	CT	143	175.48	ghi
16	NT	144	159.56	jklm
16	CT	143	167.17	ijk
18	NT	144	153.14	lmn
18	CT	143	156.78	klmn
20	NT	144	146.25	no
20	CT	143	146.67	mno
22	NT	144	139.51	op
22	CT	143	136.43	opq
24	NT	144	132.43	pq

Table 4.15 Average infiltration means for the NT and CT soils and different rotations (continued)

Rotation	Tmt	N	Mean (cm^3)	T-grouping[A]
24	CT	143	126.17	qr
26	NT	144	124.22	qr
26	CT	143	116.43	rst
28	NT	144	117.74	rs
28	CT	143	108.18	stu
30	NT	144	110.31	stu
30	CT	143	101.02	uv
32	NT	144	103.76	tuv
32	CT	143	93.29	vwx
34	NT	144	97.5	uvw
34	CT	143	85.71	wxyz
36	NT	144	91.06	vwxy
36	CT	143	79.86	AByz
38	NT	144	85.4	Awxyz
38	CT	143	76.01	ABz
40	NT	144	80.83	ABxyz
40	CT	143	72.45	AB
42	NT	144	75.46	ABz
42	CT	143	70.56	B
44	NT	144	73.47	ABz
44	CT	143	69.51	B
46	NT	144	72.99	ABz
46	CT	143	69.44	B
48	NT	144	72.99	ABz
48	CT	143	69.44	B
50	NT	144	72.99	ABz
50	CT	143	69.44	B
LSD(p=0.05) = 13.249				

Means within each column with the same letter or letters do not differ significantly at the 5% significant level.

[A] T-grouping where capital letters might occur, it is different to lower case letters

Table 4.15 and figure 4.10 give the means for each treatment (NT and CT), rotation interaction. Looking at it, it can be seen that the treatment CT for rotations 2 to 12, for both storms, differs statistically (better infiltration) for the same rotations, from the NT at a 5% significance level. At later rotations (22 to 50), the NT treatment performs better (better infiltration) - although not statistically different.

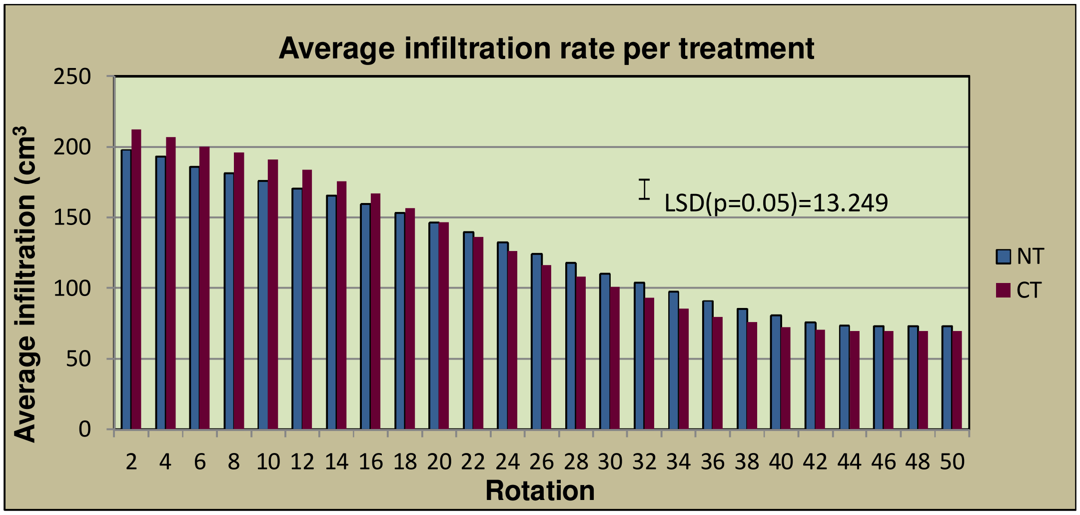

Figure 4.10 Average infiltration rate for the 2 storms for each rotation.

Table 4.16 and figure 4.11 show the means for the combined rotations for each treatment-(NT, CT) and storm interactions. Within storm 1 the treatment CT did statistically better than the CT treatment over all the rotations. Within storm 2 the pattern changed; the NT treatment performed statistically better. The infiltration for the treatment CT did not change over the 2 storms. As expected partly due to the loosening of the soil by the ploughing action, the infiltration rate for the first storm was significantly higher. The NT soil had an improved infiltration rate for the second storm, due to the settling effect of the first storm. This would be attributed to the soil maintaining its' structure for a longer period of time.

Table 4.16 Average infiltration rate for the 2 storms combined as per treatment (NT and CT).

Storm	Tmt	N	Mean (cm^3)	T-grouping
1	NT	1800	116.82	c
1	CT	1775	127.01	b
2	NT	1800	137.55	a
2	CT	1800	127.39	b
LSD(p=0.05)	=3.7475			

Means within each column with the same letter or letters do not differ significantly at the 5% significant level

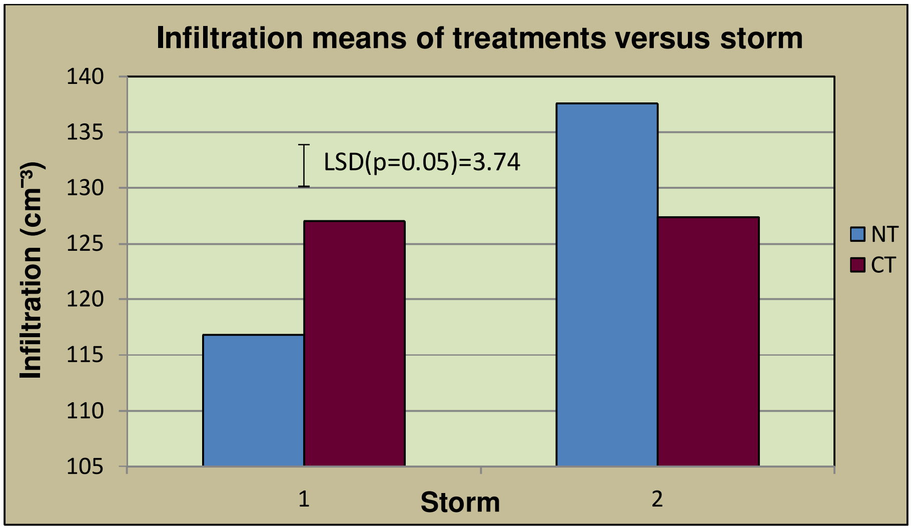

Figure 4.11 Average infiltration means as per treatment (NT and CT).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

LandCare is a community-based programme with the overall goal of optimizing productivity through the sustainable use of natural resources, resulting in greater food security, job creation and better quality of life for all. A community-driven approach was followed with the core principles being the training and empowerment of land users and community members in the principles of conservation agriculture technologies. Training was in the form of farmer managed research demonstrations and farmer demonstration trials were the thrust with the Mlondozi project. Eighteen farmers initially joined the programme.

Mlondozi is a low income area which is also far from the main centres, thus making farming difficult and costly. The LandCare approach was a successful programme in that yields increased with reduced labour. With the farmers planting the NT alongside the CT plot, they were able to compare the two production systems. This resulted in the farmers taking ownership of the experimentation on their respective farms. The enthusiasm was such that the conventional production plots, which were meant to be cultivated following the conventional practices for the duration of the study period, for the farms and researchers to monitor and compare the differences were, over the study period, converted to NT.

Due to the granitic parent material, the soils are inherently acidic, which is the second largest limiting factor in maize production after rainfall, in Mlondozi. With an increase in soil acidity there was a decrease in Ca and Mg and an increase in Al. The recommended 5 ton of lime ha^{-1} proved to be beneficial as the soils' pH and nutrient status gradually improved for the basic elements during the study period. The fertility levels for Ca, Mg and P of the top soil for the NT farming system gradually increased over the years, and the pH also had an upward trend over the study period (Table 4.3).

The aim of the project was to optimise the production of maize by introducing an improved farming system (NT) by planting hybrid seed, applying lime to correct the pH, correct fertilizer type and quantity applied, earlier planting and weed control by the use of herbicides. The yield of the NT system was higher than the CT systems over the study period. The 2001-2002 season was a below average rainfall year, accompanied by hail, resulting in reduced yield, compared to the previous years. The improved yields meant the farmers were able to grow sufficient maize for their own consumption and sell the excess to buy inputs, thus improving their standard of living. The improved farming system led to higher yields and improved drought tolerance, thus ensuring food security.

A higher root density is required for optimum nutrient and water uptake as 80% of the feeder roots occur in the top 100 mm of the soil. The root density for NT in the top- and sub-soil increased from 1999 to 2001 but decreased in 2002 due to a lower than normal rainfall season. By keeping the soil covered a more favourable condition is created with regard to temperature and soil water content, for root growth.

The FAO (2001, 2007) definition of NT includes keeping the soil covered by a mulch or cover crop. Retaining the crop residue aids in maintaining soil water content by reducing evaporation and improving infiltration. Rain drop impact was adsorbed by the mulch, thus reducing surface crusting. A more conducive condition was created for earthworm activity. Mulch cover increased from 30% to 60% for 2000 and 55 % for the remaining years (2001 and 2002). An observation the farmers repeatedly made for themselves was the way the NT maize plants continued to grow unhindered between rain fall events, while the conventionally cultivated maize would be wilting within a few days to a week after a storm.

Mlondozi is a high rainfall area, which could result in soil erosion taking place on the conventionally cultivated soils (CT). At the end of the project four undisturbed soil samples were taken from both the CT and NT fields of the eighteen farmers who initially joined the training programme. The samples were placed in a laboratory rainfall simulator for two successive storm events where the run-off, infiltration and soil loss was measured. From the results above, the implementation of the NT farming system resulted in a reduced run-off, improved infiltration and reduced soil erosion. Following the conventional cultivation practice the fields were ploughed yearly for weed control and seed bed preparation. In so doing aggregates were broken along with the fungal hyphae and organic gels, which would otherwise have maintained the soil's stability.

The CT soils disturbance by the regular cultivation resulted in a reduction in the infiltration rate compared to the NT soils. The NT soils improved stability resulted in a lower reduction in infiltration rate that could be attributed to the fungal hyphae which were not damaged by regular cultivation, adding to aggregate stability. The Conventional tillage soils had a lower soil loss for the first storm. The soil loss for both the NT and CT soils was the same for the second storm. The "No Till" soils showed reduced run-off for the two storm events and the infiltration increased. The CT soils had a similar infiltration rate for the two rainfall events.

From the above results it is recommended that NT be implemented for sustainable crop production.

The pan method:

Traditionally soil samples taken in the field were dried; clods pulverised then sieved thus breaking the aggregates. The pan method was as an improvement in that undisturbed soil samples were taken.

- The soil samples taken using the pan method showed consistent similarity of the results for the four replicates for each treatment. Further investigation could be undertaken, to take the soil samples using a perforated metal tray, which could be placed directly into the laboratory rainfall simulator, resulting in even less soil disturbance.

- Soil samples taken using the pan method gave results quicker than would have been the case with the other methods. Results could be obtained within 2 hours after returning to the laboratory, compared to months for in-field run-off plots.

Further study and recommendations

No Till is a modern day agricultural revolution. There is no other farming practice that has had such an impact on sustainable crop production. This study paves the way for further research on the effects of No Till versus Conventional agricultural practice:

- It is recommended that a planned trial be laid out (NT versus CT) with the following treatment applications:
    - Plough versus no-tillage,
    - Fertiliser,
    - Liming;
    - Weeding.

  These treatments could be tested against one another for soil erosion, run-off and infiltration.
- To further verify the stability of the NT soils it is recommended that samples be placed in the rainfall simulator for a third and possibly fourth storm event to further verify the stability of the "No-Till" soils.
- Further research needs to be conducted to investigate crusting, clay mineralogy and the effects of sodium and magnesium on the stability of aggregates for NT and CT soils under different rainfall conditions. The soils used in the study had a high kaolinite content (31% to 70%) which explains the high stability along with the fact

that they are highly weathered. Aggasi, Shainberg & Morin (1988) found that there was a partially formed crust with a short duration rain event or low intensity long duration storm event. It can be assumed that a partially formed crust formed would result in the infiltration rate being the same at the start of the second storm event, but this needs to be verified.

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