Conservation Agriculture and Commercial Farmers in the Eastern Free State

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PROMOTING CONSERVATION AGRICULTURE IN THE EASTERN FREE STATE OF SOUTH AFRICA

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DECLARATION

I declare that the thesis hereby submitted for the qualification *Philosophiae Doctor* at the University of the Free State is my own independent work and that I have not previously submitted the same work for a qualification at/in another university/faculty.

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CONSERVATION AGRICULTURE AND COMMERCIAL FARMERS IN THE EASTERN FREE STATE

Jakob Knot

Abstract of the thesis

Agriculture contributes to greenhouse gas emissions (GHG) through practices that reduce the amount of soil organic carbon. Examples of this are fallow and intensive tillage. Conventional ways of farming are not sustainable as soils are degraded, imbalanced, over-utilized, low in organic matter and without heavy inorganic fertilizer good yields are not possible. Sustainable crop production however is essential for South Africa's food security, employment and contribution to the national economy. The sustainability of agriculture needs therefore to address environmental, economical and sociological aspects.

Conservation Agriculture (CA) is world-wide found as an antipode against soil degradation, erosion and ineffective water conservation as a result of conventional tillage. The problem, however is that CA is a much developed product of No-till, which requires a gradual and timely process. No-tillage in itself is not the desired outcome, but a first step to CA. Ample technical research has been conducted on no-tillage and CA reflecting improved soil quality, yields and profits (see paper 1). This thesis will elaborate more on local technical issues e.g. soil quality (paper 4) and profitability (paper 3), as to contribute to the increased adoption of sustainable farming.

This thesis emphasized the urgency for transdisciplinary research and the role of sociology in innovation studies. The role of sociology is often overlooked, but this thesis advocates that sociology is an integral part of transdisciplinary research. Narratives are useful methods of explaining what NT and CA is (see paper 2). The Actor Network Theory is useful in that farmers possess "agency" as a result of networking, which enables the uptake of an innovation of NT and in addition to develop into context related or ecotype specific CA production system (see paper 5).

This thesis addressed conventional farmers barriers to adopting NT e.g. livestock integration, doubt concerning profitability and lack of knowhow. This thesis contributes to environmental awareness and promotes that CA can mitigate GHG emissions through sequestration of organic carbon in the soil (paper 4) and reflecting direct and indirect environmental costs in terms of GHG through the use of diesel, fertilizer, pesticides and other chemicals (see paper 3).

Keywords: *No-till, Conservation Agriculture, sociology, transdisciplinary, soil quality, water conservation, sustainability, cover crops*

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INTRODUCTION

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1. Conservation agriculture

Agriculture faces increased pressure from global environmental organizations to address sustainability issues. There is general scientific acceptance of the conclusion of the Intergovernmental Panel on Climate Change (IPCC) that increases in atmospheric concentration of carbon dioxide (CO_2) and other greenhouse gasses (GHGs) have contributed to increases in global temperatures and associated climate change (O'Dell et al, 2013). More and more people call for greener and more environmentally friendly production and processing cycles. Agriculture produces 13.5% of GHG world-wide (O'Dell et al. (2013) quoted from the U.S. Council for Agricultural Science and Technology Task Force Report). According to Denef et al. (2011) CO_2 emissions from agriculture result primarily from practices that reduce the amount of organic carbon in the soil: e.g. fallow or intensive tillage. Consideration should also be given to the direct and indirect costs to the environment in terms of GHG as a result of the agricultural use of diesel, fertilizer, pesticides and herbicides.

These two elements of fallow and intensive tillage are common features of the eastern Free State's conventional farming practices. The growing of crops and rearing of livestock are combined on most EFS farms, and that this reduces the organic matter of the soils. South Africa's soils in general are degraded, imbalanced and over-utilized; have high weed pressure, and are low in organic matter (Mills and Fey, 2003; Burger, 2010) and nutrients (P, K, Mg and Ca). Without heavy chemical fertilizer applications good crops yields are generally not possible (Govaerts et al. 2009, p. 117 and Reeves, 1997, p. 132). Sustainable crop production in South Africa, however, is essential for its long-term food security, employment and contribution the national economy. SA is a water-scarce country. It is also characterized by a scarcity of productive agricultural land. The nonagricultural demand for both these resources is increasing. It is imperative for agriculture to utilize these two resources to ensure the sustainable production of agricultural products (DAFF, 1995).

Sustainability and sustainable agriculture were put on global policy agendas in the 1970s and 1980s, and discussions have continued since then. "Sustainable agriculture is not a clearly defined production model, but rather a set of complementary approaches that seeks to minimize negative environmental impacts from agriculture, by increasing efficiency of input use and by making greater use of biological and ecological factors in production processes"

(Bruinsma, 2003). No-till (NT) started as a corrective against the soil erosion and degradation associated with conventional ways of farming.

A range of new technologies, management strategies, and analytical tools relevant to sustainable agricultural intensification has emerged in recent years. These include integrated pest management (IPM), conservation farming (CF), low external input and sustainable agriculture (LEISA), organic agriculture, precision agriculture (World Bank, 2004), regenerative agriculture (du Toit, 2007) and diversification. The latter is an adjustment of the farm enterprise pattern in order to increase farm income or reduce income variability by reducing risk, by exploiting new market opportunities and existing market niches, diversifying not only production, but also on-farm processing and other farm-based, income-generating activity (Dixon et al. 2001).

This study explored the concept of ‘sustainability’. The different papers refer to ecological (environmental), economic and social sustainability in order to define the sustainability of various production systems. This research shows that conventional ways of farming are not sustainable. No-till as well as fully-fledged Conservation Agriculture (CA) are explored in this study, as alternative farming philosophies. The study investigates no-till and CA within the Eastern Free State context, in terms of their impact on environmental and financial sustainability. It contrasts these systems with conventional ways of farming. A further question is the generally low levels of adoption of these farming systems within the Eastern Free State farming community. The study therefore seeks to understand the nature of farmer networks, as an explanatory variable.

CA refers to a farming system where the three principles – minimum disturbance of the soil, soil cover and sound crop rotations including legumes - are applied simultaneously. No-till is actually the first principle of minimal soil disturbance. No-till should therefore not be confused with CA. NT in itself is not the desirable final destination. Govaerts et al. (2009:113), Govaerts et al. (2006:172) and Zanatta et al. (2007:517) argued that NT without soil cover and or good rotations may score less on soil quality indicators as compared to CV. This paper reflects that CA is not the same as NT although often referred to as similar.

No-tillage (NT) is practiced world-wide to counter the soil degradation effect under CV. Conservation Agriculture (CA) is a more encompassing concept, and refers to the improvement of the initial NT production systems. CA is practiced with three guiding principles in mind, which act as stepping stones when converting from CV. CA is the implementation of the following three principles: minimum disturbance of the soil, year round soil cover and sound crop rotations by utilizing legumes. Kassam et al. (2009) recommended that crop rotations using less than three sequential crops should not be called CA. CA also encourages the promotion of plant diversity, increased biological regulation functions, and risk minimization. CA encourages a production system that is not only ecological sustainable but also economic feasible and socially acceptable.

NT in this paper is defined as the adherence to the first principle of disturbing the soil as little as possible. NT refers to soil disturbance up to 20%-25% (Govaerts et al., 2009, p. 98) by using tine- or combination tine and disc planters. NT is not the desired final outcome for CA proponents (Govaerts et al. 2009:113). Govaerts et al. (2006:172) and Zanatta et al. (2007:517) argued that NT without soil cover and good rotations may score lower on soil quality indicators as compared to CV. This paper argues that CA is not the same as NT, although they are often regarded as identical. Moyer (2011) refers to NT without cover as "conventional NT", which should be distinguished from proper NT or advanced NT.

Farming and land-use systems could be viewed as social-ecological systems (SESs). Many scientists are concerned that contemporary SESs may collapse by the end of the 21st century (Ostrom, 2007, p1). Social-ecological systems research deals with complexity because there are no blueprints nor panaceas for the sustainable use of natural resources (Berkes, 2007 quoted in Ostrom 2007). This paper addresses the issues of context and ecotype specific approaches to NT.

CA research requires a transdisciplinary approach (Miller et.al. 2008, Gallopin et al. 2001 Lubchenco, 1997 Roux et al. 2006, Eigenbrode et al. 2007). This research is a contribution to transdisciplinary research by bridging the disciplines of sociology, economy and ecology. Mixed farming, in addition, is the dominant farming system in the EFS and sustainable farming alternatives should cater for both cropping and livestock components.

This research has elements of a comparative assessment between conventional cropping practices (CV) and CA. Technical and economical findings of CA studies are overwhelmingly in favour of CA as compared to CV (Gassen and Gassen, 1996; Thierfelder and Wall, 2010; Scopel et al., 2005; Nangia et al., 2010; Blanco-Canqui, 2010; Fowler, 2004; Nangia et al., 2010; Calegari, Darolt and Ferro, 1998; Derpsch 2003; Derpsch et al., 2010; Scopel et al., 2005; West and Post, 2002; West and Marland, 2002; Silici et al. , 2007; Dowuona and Adjetey , 2010; Woomer et al., 2004, quoted in Perez et al., 2005; Kosgei et al., 2007). The social aspects regarding NT and CA remain poorly understood. Social sustainability can be correlated to increased adoption figures. Global adoption figures of CA reflect the increased interest of land-users in CA world-wide. CA adoption is growing globally. A total of approximately 105-110 million hectares are currently being cultivated globally according to the principles of CA (Derpsch, 2008 and Derpsch et al., 2010). The highest adoption rates are in North and South America, and Australia. North America constitutes 46.8% of the world's adoption rate, while South America and Australia reflected 37.8% and 11.5% respectively. The Eastern Free State adoption rates of NT are however not so rosy. The NT adoption rate in the Zastron area is around 11.62% whilst it is only 2.54% in the Ficksburg-Ladybrand-Tweespruit area (source: own analysis, based on committee's assessment of farmer lists. See paper Five of this thesis).

The real challenge remains *social* sustainability. Environmental problems are, ultimately, social problems and are related to social issues, processes, networks, knowledge and power. Two of the five papers in this thesis are sociological. The adoption of sustainable agricultural production systems, as depicted in this research, needs to be oriented to sociological insights. This paper elaborates on the different sociological theories underlying this research. This serves as an introduction prior to each paper's brief theoretical layout. Each paper reflects in detail the methodology used for that paper.

The structure of this thesis is based on a "5-paper-route". This thesis therefore consists out of five papers. The five papers are: 1) Is Conservation Agriculture a sustainable alternative for Eastern Free State Agriculture? A literature based review of the world-wide status quo of NT and CA; 2) From Conventional farming to Conservation Agriculture in the Eastern Free State with No-Till practices as an intermediate – a narrative approach; 3) Economic and Environmental Sustainability of different Crop Production systems in the Eastern Free State; 4) Improved Soil Quality under No-Till cover cropping in the Eastern Free State and 5) Conventional farming reveals conventional networking. The Actor Network Theory explains stunted and hybrid networks. The five papers in this thesis are aimed at addressing the gap of knowledge, knowhow and research on NT and CA in the Eastern Free State.

This thesis also highlights the essence of transdisciplinary research and approaches to counter the gradual "artificialisation" of agriculture as described by Dore et al. (2011). Social, economic and environmental issues will therefore be addressed. This thesis, finally intends to start an agenda for action to promote realistic, profitable and environmentally sustainable alternatives to current conventional ways of farming. The thesis does this by means of a study of the international literature on NT/CA, an in-depth analysis of the concepts of NT and CA, and through multiple comparative assessments, comparing farming systems and crop rotations on technical and financial aspects.

2. Researcher's role

Researcher bias and subjectivity are commonly understood as inevitable by most qualitative researchers (Mehra, 2002). Meaningful knowledge can be constructed in a way that provides room for personal and subjective ways of looking at the world despite the acknowledgement of the positivist traditions of knowledge construction where objectivity and value-neutrality are considered important criteria for evaluating research (Mehra, 2002).

The researcher of this thesis is practising NT, promotes NT, and is also teaching NT at a training organization in Lesotho. The researcher's interest in NT, led to this research in the first place. "A researcher's personal beliefs and values are reflected not only in the choice of methodology and interpretation of findings, but also in the choice of a research topic. In other words, what we believe in determines what we want to study. Traditional positivist research paradigm has taught us to believe that what we are studying often has no personal significance. Or, that the only reason driving our research is intellectual curiosity (which is a valid reason on its own). However, more often than not, we have our personal beliefs and views about a topic, either in support of one side of the argument, or on the social, cultural, political sub-texts that seem to guide the development of the argument." (Mehra, 2002).

The issue of researcher bias in this case needs to be assessed. Qualitative research is not value-neutral (Mehra, 2002). A systematic and reflective analysis shows that this risk of bias can be minimized during a research. The researcher questioned his own subjectivity in this research. "How does someone keep personal values aside when conducting research on a topic that is of personal significance to him/her"? A researcher cannot entirely achieve this degree of separation, as some degree of bias is nearly always present in research (Mehra, 2000; Pannucci and Wilkins, 2010).

The researcher chose the role of facilitator when it came to the group discussions. Furthermore, the researcher chose the role of active participant in the interviews, case-study research, and dialogue, which does open the process to potential bias. "Qualitative research paradigm believes that the researcher is an important part of the process. The researcher cannot separate himself or herself from the topic/people he or she is studying. It is via the interaction between researcher and researched that the knowledge is created. Thus a certain amount of researcher bias enters into the picture even if the researcher tries to stay out of it." (Mehra, 2002). It was a challenge to interpret interviewees' narratives in such a way as not to change and distort their narratives to suit the researcher's own bias.

One aspect, as can be seen in one of the sub-headings of the narratives (paper Two), was added by the researcher. This is the issue of the three key CA principles. Farmers did not previously speak about "CA", but "NT". The concept "three CA principles[1]", derived from the extensive literature research (paper One from this thesis). The interviewed NT and CV farmers talked about "level of soil cover associated with NT" and "no-tillage", whilst "crop rotation" was not explicitly mentioned. The interviewed NT farmers, however, did assess their own crop rotations. The researcher did ask leading questions in that regard e.g. "Do you plant legumes on your farm"? The two case study farmers were practising NT for a significant period of time (around 2003 and 2004), before this research started in 2010. That is documented in this paper. The researcher is aware of the inevitable, that the interaction post 2010, between the NT farmers and the researcher might have influenced their thinking about NT and CA. The researcher acted and still acts in the position of a change-agent (Burgess, 2009).

There is a bias-potential right from the beginning of the research to the end. The research topics, proposal and design can all be biased and even the way the final thesis is written (Pannucci and Wilkins, 2010). A guiding question in this regard is to understand the purpose of the research. This understanding can help the reader to frame the results of this thesis.

The purpose of the study was to gain insight in the reasons for adoption of NT, and the barriers of not adopting NT. It became evident from a very early stage of the research that CV farmers could not reconcile NT with their current grazing strategies. More reasons were mentioned as summarized in paper Five i.e. clustered under financial, risk and knowledge.

[1] CA is founded on the simultaneous adherence to three principles: minimum disturbance of the soil, permanent soil cover and sound crop rotations.

The most mentioned barrier to the adoption of NT was linked to livestock, the associated compaction of the soil by animal hooves, and financial risk. The researcher is pragmatic and is driven by applied-science. Paper Three and Four were developed with the intention of contributing to local technical knowledge and to counter the barriers to the adoption of NT.

This research has elements of quantitative and qualitative data collection. The quantitative research included crop trials, soil sampling, final water infiltration rates, soil cover assessments and weed counts. The trials had four treatments with four repetitions each. All abovementioned components were done randomly among the repetitions, but with systematic modus operandi, e.g. middle rows of a plot were harvested. The plot design was co-developed by a soil science student from the University of Tennessee.

The on farm trials did not include conventional tillage (CV). The NT-farmer was not prepared to plough and rip part of his fields. Additional research has been conducted in addition to the trials in the form of off-site water infiltration assessment linked to measuring soil carbon levels. Ten pairs of treated sites and untreated reference sites were compared in 2011 and 2013. CV farmers' data was included whilst doing the final water infiltrations. This component was added in order to give a fair representation of technical data collected under CV.

The potential researcher bias was reduced in the qualitative research sampling part of this thesis. Firstly, the selection of the NT-pioneers. All seven NT-pioneers that started to practice NT prior to 2010 in the Ladybrand, Clocolan, Ficksburg, Westminister and Tweespruit areas, as far as the co-op staff and NT-farmers knew, were part of the research. The Zastron area had a slightly higher NT adoption rate and consequently more NT farmers. Not all the NT farmers from the Zastron area were included in the research. Three farmers were selected, whereas two were on the NT tour to Australia (see papers Two and Five). A third NT-farmer was selected from this area because he adopted NT as a result of repeated interaction with the farmer that started NT in the area. There were fewer NT-farmers from the Zastron area in the sample due to distance. Five from the ten NT-pioneers were selected from the 400-600mm and five from the 600-800mm ecological zones. The two NT-farmers, from the different two ecological zones, that started NT in their respective areas, were selected for the narrative case study.

The initial assumption was that NT farmers are smart educated farmers with high management standards. In order to counter that perception the researcher identified the CV farmers with the biggest turnover. It was assumed that high turnover positively reflects farmers with high management skills. The 'biggest' CV farmers were therefore visited and interviewed as to provide a realistic view on CV. The focus group discussion with CV farmers, based on an open invitation, did include less well-known CV farmers. All interviewees were male, which might pose a gender bias. There were simply no female NT farmers and the researcher is not aware of any female CV farmers in the research area.

The questions that were asked during face-to-face as well as telephonic interviews and group discussions might have had a degree of bias. Measures were, however, taken in order to reduce the bias. The questions on the questionnaire were open-ended and were asked in Afrikaans or English, based on the farmers' home language. This reduced any language barriers. The researcher started the group discussions by asking positive and open questions. The researcher tried to reflect all respondents' views in an unbiased manner. The researcher often asked respondents to listen to the researcher's formulation of what he had heard. The respondents were able to correct the researcher if the answer was reflected incorrectly. The NT-pioneers were asked to write their own narratives. This was done to minimize the researcher bias. Both the case study farmers (farmer A and B, paper Two) read and edited the researcher's compiled narratives concerning them.

The researcher worked with farmers in order to quantify the local eastern Free State NT-adoption rates. These data sheets were sent to the local co-op to be verified and adjusted if necessary, which they did. To conclude on this matter of bias, the researcher had invited numerous University researchers (i.e. from various disciplines) and private sector experts to read parts of the papers in this thesis. This shows a spirit of inviting other experts to comment on this research and to be peer reviewed. Their critical thinking, comments and inputs have reduced some bias in this research in terms of design and reporting.

3. Methodology

This thesis comprises of five separate, but interlinked papers. This paper serves as the theoretical paper to identify the theoretical underpinnings of the argument, and the theoretical linkages between the papers.

- Introduction and overview

- Paper 1: Is Conservation Agriculture a sustainable alternative for Free State Agriculture? A literature based review of the world-wide status quo of NT and CA.
- Paper 2: From No-till to Conservation Agriculture in the Eastern Free State: A narrative approach
- Paper 3: Economic and environmental Sustainability of different crop production systems in the Eastern Free State
- Paper 4: Improved soil quality under NT cover cropping in the Eastern Free State
- Paper 5: Conventional farming reveals conventional networking: The Actor Network Theory (ANT) explains stunted and hybrid networks.

The first paper reflects a world-wide literature research on NT and CA. It provided an overview of land degradation, erosion statistics, silting up of dams, and the cost of land degradation as a result of conventional ways of farming. Different tillage systems were conceptualized. The sustainability of tillage systems is assessed from economical, ecological and social perspectives. The social sustainability remains poorly understood, which paves the way for more sociological research.

The second paper is sociological in nature by using a narrative approach. This paper highlights the increased awareness of the role of sociology in defining "sustainable agriculture". The two founding NT-pioneers, from two different agro-ecological zones in the EFS, were interviewed over a four year period. Their in-depth case studies are documented. The narratives give insight on "what NT is on their farms", and how initial challenges, after converting to NT, were overcome. The results of this paper reflect short-term gains of NT, and the role of cover crops. This paper also reflects the profitability and environmental costs of different production systems.

The third paper provides financial figures related to NT. It shows savings of NT as compared to CV. A detailed model reflects the increased gross margins per hectare after incorporation of different crop rotations including legumes and cover crops. The financial assessment of production systems and modeling are crucial. The most mentioned reason for adopting NT in the EFS was economics. In addition, one of the barriers for adopting NT is the perceived initial financial dip farmers assumed to have after converting to NT.

The fourth paper refers to the soil quality under different production systems. On-farm cover crop trials were conducted at Ladybrand from 2010-2013. Additional comparative final water infiltration and soil quality assessments were undertaken in 2011 and 2013 at various sites comparing readings under veld, CV and CA. This paper made use of a comparative assessment approach comparing soil quality indicators under different crop production systems. A minimum data set was adopted with two indicators: soil organic carbon and plant available water capacity. The latter has several sub indicators. These are final water infiltration rates, soil water levels, and crop water productivity.

The fifth paper is also sociological in nature by using an Actor Network approach. This theory, also called the 'sociology of technology' or 'sociology of translation', is tremendously useful in studying innovations and their adoption. It helps in understanding the relationships between people and technology. The Actor Network Theory (ANT) is used by applying a 'translation' process with four stages. These are problematization, interessement, enrolment and mobilization. A fifth stage is dissidence. The concept of 'translation' is this thesis refers to two parallel running processes. These are the process of conversion from conventional ways of farming to NT, and the process of NT-pioneers developing their NT-systems into Conservation Agriculture. The eighteen barriers to the adoption of NT are mentioned. The ANT reveals a failed and successful translation. The limited conversion of CV farmers to NT reflects a failed translation. NT-pioneers, on the other hand, were able to gradually improve their NT systems over a period of ten years.

4. The geographic focus

The research area is the Eastern Free State of South Africa and includes towns like Ficksburg, Tweespruit, Westminster, Ladybrand, and Zastron. Maphutseng, which falls within Lesotho's borders is also included in the research area. It is located 50km east of Zastron and 10km from the South African border. The research area falls within the semi-arid zone and annual rainfall figures are between 500-600mm per year for Zastron, Wepener, Tweespruit and Westminster. The other three towns, Ladybrand, Clocolan and Ficksburg, have annual rainfall figures of 600-800mm per year. The case studies and locations will refer to area specific rainfall figures.

The mean annual precipitation (MAP) for the Free State ranges from 400-600 mm in central, western and south-eastern Free State to 600-800 mm for Eastern Free State. The Free State province falls within the 20-30% range of deviation from mean annual rainfall. The mean annual evaporation in the Free State is 1600-1800 mm/year. Its climatic region is semi-arid which can be characterized against an aridity index of 0.2-0.5, which reflects the proportion between annual rainfall and the potential evaporation. If annual rainfall is 700mm and the mean annual evaporation is 1600mm than the aridity index is $\frac{700}{1600}$ = 0.44

The Free State's farms typically involve mixed farming enterprises. It is in the dry semi-arid areas (for example Zastron) that crops are either planted as feed or livestock feeds on cash crop residues.

Thirty-six percent of South Africa's total arable land is located in the Free State. The Free State's agricultural sector is important for the country's food security. The Free State produces significant proportions of the nation's sorghum (53%), sunflower (45%), wheat (37%), and maize (34%). The province has approximately 1,590,900 arable hectares. Approximately 40% and 7% of those hectares were under minimum- and NT respectively in 2003 (Hittersay (2004) in Fowler (2004)).

South-eastern Free State farmers primarily grow crops for fodder due to lower precipitation and lower scores on the aridity index and shallow, clayey soils. Central- and north-eastern Free State farmers grow more cash crops on deeper sandy soils (Hensley et al. 2006). Typical central-eastern Free State farms consist of cash crops, pastures, green forage and veld. Beef and sheep are reared in the area. The main cash crops grown in the area are maize, sunflower, wheat and, to a lesser extent, soya and sorghum. The grain prices have fluctuated over the years, and together with rising input prices, crop farming has become a risky enterprise. The beef and mutton market has been more reliable. Conventional farming practice includes summer veld and pasture grazing combined with winter grazing on forage (green feed) and crop residues. The commercial farming context in the Free State is characterized by fallow periods between cash cropping.

Within this region, there are vast differences between rainfall, soil types and climatic conditions, which affect the suitability of CA in the research area. Other variables include sun hours and heat units, percentage deviation from mean annual rainfall, and possibility of frost, farming systems and farm objectives. Research should therefore be ecotype specific.

5. The sociological dimension

The sustainability of agriculture needs to address environmental, economical and sociological aspects. These three aspects of sustainability is discussed in detail and explained in the first paper (chapter two) of this thesis. Social sustainability is discussed in the second (chapter three) and fifth paper (chapter six). Economical sustainability is discussed in the third paper (chapter four). Environmental- or ecological sustainability is discussed in the fourth paper (chapter 5) Social-ecological systems are discussed below and can be regarded as the fourth leg of the sustainability assessment. This chapter reflects only introductory notes on social-ecological systems.

“Normal science” has become less capable of addressing complex social–ecological interactions (Gallopin et al. 2001 stated in Miller et.al. 2008), and less resilient to dramatic changes in the societal demand for knowledge (Lubchenco, 1997 stated in Miller et al. 2008). Complex social-ecological interactions and research go beyond different disciplines. Although individual disciplines are well positioned to examine certain areas of concern, many inflexible and entrenched epistemological cultures have generated narrowly parochial inquiries of expansive, complex systems (Miller et al. 2008).

One example of such complex systems is social-ecological systems (SES). Understanding SES require acknowledgement of multiple, potentially equally valid ways of knowing. Miller et al. (2008) refer to epistemological pluralism. Multi- and interdisciplinary research is useful, but is not sufficient. New transdisciplinary theoretical studies should be promoted. Multidisciplinary research arises when multiple researchers investigate a single problem, but do so as if each were working within their own disciplinary setting. In this situation, research is conducted within disciplinary boundaries. Miller et al. (2008) calls this “epistemological silos”. Interdisciplinary research incorporates a greater degree of integration than either disciplinary or multidisciplinary research. It often has an applied orientation. However, most interdisciplinary research ends up entitling a single discipline or epistemology, incorporating others in a support or service role—we can refer to this as “epistemological sovereignty” (Healy 2003 stated in Miller et all. 2008). In contrast, transdisciplinary research transcends entrenched categories to formulate problems in new ways. Collaborators may accept an epistemological perspective unique to the effort, redrawing the boundaries between disciplinary knowledges (Roux et al. 2006, Eigenbrode et al. 2007 both stated in Miller et all. 2008).

Transdisciplinary research is often, although not always, characterized by an explicit engagement with society (Miller et al, 2008). Transdisciplinary research naturally calls for a narrative approach as used in paper Two, which is cross-disciplinary and based on different epistemologies, theories and methods. A narrative approach enables us to gain an in-depth understanding in farmers' lives and opens up creative collaborative research taking different opinions into account. Farmers' self-narratives are crucial for the move to more sustainable agriculture.

Agriculture and land-use systems should be understood from a perspective of socio-ecological complexity. Globalization has impacted most if not all social societies. Societies are changing rapidly. What sociological theory can best describe and explain "change" and the sustainability of natural resources? Many scientists are concerned that many of the social-ecological systems existing today may collapse by the end of the 21st century (Ostrom, 2007, p1). The sustainability of the environment, including large-scale human and biophysical processes - carbon emissions, overharvesting and pollution - are increasingly questioned by researchers and analysts. There are no panaceas or ready-made solutions for solving the diversity of problems facing linked social-ecological systems (Berkes, 2007 quoted in Ostrom 2007). Environmental problems are complex and seldom reveal themselves in similar ways.

Social-environmental studies recognize the increased "complexity" of relations, networks and connectedness. The different disciplines - social ecology, human ecology and environmental sociology - all refer to societal-environmental interactions. The concept of social-ecology recognizes that ecological problems are rooted in deep-seated social problems. The focus of environmental sociology is on social factors that cause environmental problems, the societal impacts of those problems, and efforts to solve the problems. In addition, environmental sociologists pay considerable attention to the social processes by which certain environmental conditions become socially defined as problems. Human ecology focuses on humans and is an interdisciplinary and transdisciplinary study of the relationship between humans and their natural, social, and built environments.

Social-ecological systems assume an increased connectivity between actors as they become entrenched in “mutually reinforcing relationships” (Walker and Salt, 2006 stated in Miller et al. 2008). Understanding any system’s internal connections and the collective ability of these connections to respond to external forces or shocks is a challenge that faces all students of human behavior and environmental processes. Network-based approaches are useful in revealing interactions, relationships, and increased connectivity.

Environmental problems are profoundly social problems. Social theories need to be assessed on their usefulness and adequacy by explaining the adoption of Conservation Agriculture as a social-ecological problem. The increasing complexity of social-ecological problems calls for trans-disciplinary research and assumes an increased connectivity between actors as they become entrenched in “mutually reinforcing relationships” (Walker and Salt, 2006 stated in Miller et al. 2008). This would suggest the use of social networks (Coughenour, 2003). What sociological theory can best be used in future work related to social-ecological problems?

Paper Two elaborates in detail on narratives and different ways of knowledge formation. It involves a conversational approach to social research. This particular paper and this thesis advocate a postmodern constructive understanding of NT/CA as a social ecological system. This paper does not want to derogate the merits of classic sociology with its bivalent schools of thought: of action/ actors/ knowledge and structure/ networks/ systems and Giddens’ structuration theory bridging the two. Farmers possess “agency” as a result of networking. Post-structuralist social theory suggests that agency is located neither in individuals nor in social structures, but rather is an emergent property of networks or collectives (Goodman, 1999 cited in Trauger, 2008). The ANT proposes new possibilities for understanding structure as a network and agency as the outcome of networking (Trauger, 2009, p. 117).

The notion of “human agency” is central to the concept of a social actor. The concept of an actor is distinct from that of a stakeholder. In general terms, the notion of agency attributes to the individual actor the capacity to process social experience and to devise ways of coping with life. Social actors are ‘knowledgeable’ and ‘capable (Long 1992). Ostrom (1995) refers to “human capital” in similar terms: “Human capital is the knowledge and skill that individuals bring to the solution of any problem.” Social actors seek to solve problems, learn how to intervene in social events, and continuously monitor their own actions (Giddens 1984). Learning, however, requires a minimum of human capital. The concept of “social actor” is at the heart of the actor-oriented approach. The second school of thought in classic sociology is that social action is produced by structures: religion, families, and institutions. According to these theorists, agency in itself fails to explain patterned interactions that exist or emerge in everyday life (Van den Berg, 2010). Giddens argued that although actors posses agency, they are constrained by structures. Giddens's notion of structure basically refers to cultural or institutional frameworks to which others comply (Van den Berg, 2010).

The structuration theory bridges the bivalent schools in sociology as mentioned above (knowledge/actor and the school of structure & systems). The structuration theory gives appropriate emphasis on the acting abilities of farmers. This research makes use of the actor-oriented approach. The structuration theory draws attention to the structures & systems (networks) in which individuals operate. This thesis (in paper Five) takes it further by using the Actor Network Theory and concepts from other network-related approaches such as policy networks. Giddens, but also Layder, Bourdieu, Bhaskar (Munters et al., 1993) stressed the theory of practical action where there is room for the human intensity but also for structural characteristics.

Conservation Agriculture (CA) relates to a universal set of principles, but needs to be unfolded, tried, experienced and practiced locally (Landers, 2009). In this view, the farmer is important as an actor. This actor-concept is borrowed from the actor-oriented approach. The actor is regarded as a motivated individual (Lewis, 1993) or knowledgeable human rationality (Long, 1989). Actors are also regarded as social agencies that have the ability or capacity to act, to have influence or to transform (Trauger, 2008) and to choose and even 'resist' (Lewis, 1993). The actors have often different backgrounds, perceptions, views, and cultural and religious convictions resulting in differences in opinion.

Networks have been identified as a key and fundamental concept when it comes to adoption of technology studies. De Souza Filho et al. (1999) argued that there will be a higher adoption of the technology if farmers are more integrated with farmer organizations. With reference to Australia, Gianatti and Carmody (2007) stressed the importance of networks as complexity increases in existing partnerships between the broad acre grain and livestock farmers. An organized entity that is designed to work in such a complexity is the network. Shared understanding or collective action is used to achieve outcomes where there are no clear-cut answers. Colliver (2011) argued that the one thing that will produce faster evolution of sustainable farming systems is a better flow of ideas and information. Networks are important when it comes to the adoption of a technology (Fowler and Röckstrom, 2007; Valente (1996) cited in Läpple and Van Rensburg, 2011 and Guerin, 2000). Training aimed at a few opinion leaders is much more effective than training provided for a whole group of leaders (Burgess, 2009). This reinforces the findings of this thesis.

It is good to have an eye for the role sociology plays with defining “sustainable agriculture” and in dealing with complex SESs. This thesis, advocating for transdisciplinary research, also draws upon disciplinary knowledge of ecology (paper Four), and environmental and agricultural economics (paper Three).

The First paper of this thesis conceptualized the different crop production systems and defined “sustainability”. Paper Three elaborated deeper into the crop productions systems by describing it as a process of increased sustainability. This is a process of moving from one crop production system to another. This process starts with conventional ways of farming (CV), which is associated with tillage operations. Many Eastern Free State farmers are trying to eliminate tillage to some extent due to increased prices of diesel. This is referred to as minimum tillage (MT) or reduced tillage (RT). Strip tillage i.e. tilling only part of the soil (strips) can be categorized under MT. Farmers have adopted increased use of chemicals for weed control under Minimum tillage.

There are farmers, referred to in thesis as the NT-pioneers that converted from CV to no-tillage (NT). They minimized tillage by purchasing a NT-planter (i.e. direct seeder). This initial stage of NT, which is associated with low levels of soil cover and limited crop rotations, is called conventional no-tillage (CNT).

Sustainability is measured and quantified by assessing multiple objectives, from the disciplines of ecology, economy and sociology at the same time. This findings of the First paper concluded that fully fledged Conservation Agriculture (CA), globally, is environmentally and economically more sustainable than CNT.

The Fourth paper of this thesis reflects results on how the CNT system can be improved. The success of NT is globally contributed to the use of cover crops. The four year cover crops trials reflected that cover crops can grow alongside a main cash crop resulting in higher crop water productivity. The trial results found higher soil quality (i.e. measured in soil cover and plant available water capacity) under NT cover cropping than CNT. The findings in this Fourth paper are in line with international reports, as summarized in the First paper of this thesis. The findings of paper Four regarding the improved water characteristics of the soil under NT cover cropping/ CA is of utmost importance in the light of climate change and changed rainfall distribution patterns. Paper four's result did not found CNT statistically better than CV. The findings of this paper emphasizes that NT cover cropping (comparable to CA) is ecologically more sustainable than CNT and CV.

These findings laid the foundations for the economic modeling. Different crop rotations were compared under different crop production systems with and without grazing. The results, partially based on the local trial results as well as global studies, provide answers for the inclusion of livestock combined with NT-cropping. One of the reasons of this research was to obtain more insight in the social dynamics of adoption and non-adoption of NT. CV farmers did not adopt NT due the presumption that livestock cannot be integrated with NT. The NT-pioneers adopted NT for economic reasons. This particular paper contributed to more technical knowledge and information, which hopefully leads to increased adoption of CA.

Any crop production system needs to be profitable in order to be practiced. The research elements as described in paper Three and Four contribute to reducing the barrier of non-adoption of NT by providing economic data (i.e. profitability of NT); by providing more practical and technical information regarding livestock and grazing alternatives; and by reflecting the environmental impact of different crop production systems. The greenhouse gas emissions were modeled lowest under NT cover cropping and organic CA. This reflects the need to elaborate the high levels of external inputs that are used under the different production systems.

6. Conclusions

Agriculture contributes to greenhouse gas emissions through practices that reduce the amount of soil organic carbon. Examples of this are fallow and intensive tillage. Conventional ways of farming are not sustainable as soils are degraded, imbalanced, over-utilized, low in organic matter and without heavy inorganic fertilizer good yields are not possible. Sustainable crop production, however, is essential for South Africa's food security, employment and contribution to the national economy. The sustainability of agriculture needs therefore to address environmental, economical and sociological aspects.

Conservation Agriculture (CA) is increasingly recognized worldwide as a countermeasure to soil degradation, erosion and ineffective water conservation as a result of conventional tillage. The problem, however, is that CA is a further stage of agricultural technology, which transcends no-till. Changing from no-till to CA is a gradual and extended process. No-tillage in itself is not the desired outcome, but a first step to CA. Ample technical research has been conducted on no-tillage and CA reflecting improved soil quality, yields and profits. This thesis will elaborate more on local technical issues e.g. soil quality and profitability, as to contribute to the increased adoption of sustainable farming.

This thesis emphasized the urgency for transdisciplinary research and the role of sociology in innovation studies. The role of sociology is often overlooked, but this thesis advocates that sociology is an integral part of transdisciplinary research. The subjective narratives of farmers are useful methods of explaining what NT and CA is. The Actor Network Theory is useful in that farmers possess “agency” as a result of networking, which enables the uptake of an innovation of NT and in addition to develop into context related or ecotype specific CA production system.

This thesis addressed conventional farmers’ barriers to adopting NT e.g. livestock integration, doubt about profitability and lack of technical knowledge. This thesis contributes to environmental awareness and promotes that CA can mitigate GHG emissions through sequestration of organic carbon in the soil and reflecting direct and indirect environmental costs in terms of GHG through the use of diesel, fertilizer, pesticides and other chemicals.

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PAPER 1:

CONSERVATION AGRICULTURE AS A SUSTAINABLE ALTERNATIVE FOR EASTERN FREE STATE AGRICULTURE

Abstract

Current conventional farming practices (CV) in South Africa and more specifically the eastern Free State are not sustainable. The soil quality is low due to land degradation and erosion resulting in loss of productivity. The degradation of land continuous to worsen as a result of current intensive tillage practices. Topics related to land degradation are loss of (top)soil, loss of soil productivity, erosion rates, silting up of water ways and dams, and loss of soil organic matter. No-till and its ameliorated version Conservation Agriculture proofed to be more sustainable than conventional forms of tillage. Conservation Agriculture is environmentally more sustainable which can be measured in reduced erosion and run-off; increased water infiltration and water-holding capacity of the soil, and rainfall use efficiency; reduced leaching of nitrogen and improved nutrient recycling; and increased soil organic matter and carbon build-up in the soils. Conservation Agriculture is economically more sustainable which can be measured in increased yields; reduced input costs and savings on fertilizer, diesel and lubricants; consequently higher gross margins and highest long term total farm income potential and scores lowest on environmental costs - with savings on high carbon-output cost lines. Social sustainability can be measured in the adoption of CA global and locally or in other words the acceptance of the technology. Other related social sustainability indicators are knowhow, knowledge, perceptions, and knowledge information flows. Environmental- and economic sustainability are well documented in this paper, but more research is needed on the social sustainability and adoption-related question of CA. Publications reflect increased global CA adoption rates. The success of CA is contributed to the role of cover crops. Some cover crop facts are therefore incorporated under economic sustainability. Locally adapted crops can be used as cover crops overcoming lack of cover and complement the quest for sound crop rotations and incorporating livestock in a mixed farming context. Cover crops can provide alternative sources of fodder moderating pressure on crop residue grazing. CA, from a whole-farm perspective offers sustainability for the eastern Free State farming community. Conservation Agriculture is more sustainable then conventional ways of farming.

Keywords: Sustainability, Conservation Agriculture, land degradation, cover crops

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1. Introduction

The agricultural sector is important for South Africa's economy: food production for the cities and towns, labour absorption, inputs for manufacturing, earner of foreign exchange and only feasible industry in rural areas. Therefore it is important to assess whether current tillage practices are sustainable. Conventional ways of crop farming are financially and environmentally not sustainable. The real costs of agricultural production are not being fully calculated in the cost of production (DAFF, 1995).

One of the causes of land degradation is intensive tillage (O'Dell et al., 2013). Tillage is often highlighted as the main cause of soil organic matter decline (Decker et al., 2011; Mills & Fey, 2003; Le Roux et al., 2007; Compton et al., 2010; and Derpsch et al., 2006). The factors leading to the loss of soil organic matter and related decline in soil quality can probably be attributed to erosion and vegetation removal (Mills and Fey, 2003; Compton et al., 2010; Allen et al., 2011). Conventional tillage is contributing to increased erosion (Laker, 2004; Mills and Fey, 2004) and therefore, indirectly, to the decline of soil organic matter.

Land degradation is one of the major challenges to sustainable agriculture in South Africa. This paper presents a literature review from the standpoint of the concept of "sustainable agriculture" and assesses the sustainability of the different tillage practices as we find them in the eastern Free State of South Africa: no-till (NT), Conservation Agriculture (CA), and conventional ways of farming (CV). Cover crops play a crucial role in the success and sustainability of CA globally. A section of this paper will therefore concentrate on cover crops referring to locally adapted and suitable cover crops.

This paper assesses and compares the ecological (environmental) and financial (economic) aspects of different tillage systems. Social sustainability is introduced in this paper, but forthcoming papers in this thesis will deal with it in detail. Ecological sustainability indicators suggest various factors, such as carbon sequestration rates (Mills and Fey, 2004), excess nutrient losses and nutrients leaching rates (acidification), and soil quality measured in terms of water infiltration rates (Moroke et al., 2008) and soil organic carbon levels (Reeves, 1997; Gregorich et al., 1994; Rantoa, 2009). Economic sustainability is measured in long-term profitability (total farm gross margins) and reduced environmental costs. The production of fuel, fertilizer and chemicals contribute to environmental costs (Zanatta et al., 2007). Social sustainability is measured in acceptance (adoption rates) and in agriculturalists knowledge, perceptions, fears, and aspirations.

The agro-ecosystems in the Highveld region of South Africa (Free State, North-West, Mpumalanga and Gauteng provinces) produce 70% of South Africa's commercially grown cereal crops, with 90% of its maize being cultivated there (Walker and Schulze, 2008). South Africa's agriculture is primarily driven by the commercial sector, but there are many small subsistence farmers in the rural areas. Farmers manage 80-82% of the land in South Africa (Department of Agriculture, Forestry & Fisheries, 2012). Therefore their management of South Africa's natural resources is of the utmost importance. Although agriculture is important, there are numerous challenges facing the sector, such as land degradation, intensive tillage, mono-cropping, overgrazing, inadequate water supplies, scarcity of high potential agricultural land and social challenges.

No-till is practiced in South Africa and more and more farmers in the Highveld, Kwazulu-Natal, Swartland and Western Cape are adopting the technology. Global and local adoption figures reflect the increasing trend of Conservation Agriculture (CA) (Derpsch, 2008; Derpsch et al., 2010). CA is an approach to farming that can address current agricultural challenges in the Eastern Free State. This paper provides a clear description of CA. It compares CA with conventional farming (CV) and reflects both agricultural practices against a sustainability index assessing whether CA is a more sustainable practice. The two farming systems are analyzed by means of a comparative assessment. This paper reports on the level and nature of land degradation before comparing CV and CA.

2. Land degradation

A global assessment of soil degradation estimated that 38% of all agricultural land has undergone anthropogenic soil degradation (Reeves, 1997). About 20% is moderately degraded, i.e., farming is still possible but soil productivity is greatly reduced to the extent that major inputs are required to restore the soil to full productivity (Reeves, 1997, p. 132)

Land degradation is one of the major challenges to sustainable agriculture in South Africa. Land degradation reflects a diminution, destruction or deterioration of the condition, quality or biological potential of the land (Botha and Fouche, 2000). In other words, land degradation signifies a loss of land productivity (Bojo, 1991; Reeves, 1997). An important process in soil degradation is the burning of crop residues and continuous tillage, which have led to excessive soil erosion (Laker, 2004; Mills and Fey, 2004). Burger (2010) argues that soil degradation is largely related to the decline in soil organic matter. Monoculture cereal production, intensive tillage, short-to-no fallow periods and limited crop rotation have contributed to this in the commercial sector. Different authors stated the effects of soil erosion and land degradation is a result of tillage (Decker et al., 2011; Mills and Fey, 2003; Le Roux et al., 2007; Compton et al., 2010; and Derpsch et al., 2006).

The socio-economic system and lack of skills of subsistence farmers force them into excessive fuel-wood collection, inappropriate land use, population density and overgrazing (Smith et al. 2009) which are the main causes of soil degradation in communal areas (Burger, 2010; Jafari et al., 2008). Some researchers limit their definition of land degradation to desertification (Botha and Fouche, 2000). Desertification is one specific form of environmental degradation like soil erosion, distinguished only by the fact that the end state tends toward desert-like conditions because it occurs in marginal and semi-arid regions (Botha and Fouche, 2000). As topsoil becomes shallow, due to erosion, so greater inputs are needed to maintain or increase yields. The high use of nitrogen-based synthetic fertilizer contributes to soil acidity. It is estimated that about 60% of the cropland area in South Africa is moderately to severely acidic in the topsoil and 15% of cropland affected by subsoil acidity (Burger, 2010).

South Africa's arable land is low in organic matter (Rantoa, 2009; Du Preez et al., 2011) and prone to erosion (Laker and Smith, 2006), soil compaction and soil crusting (Laker, 2004). Laker and Smith (2006) and Scotney and McPhee (1990), argued that 60% of SA has topsoils with low organic matter contents (<0.5% organic carbon). Thirty-two percent of SA comprises soils of high erosion hazard (Scotney and McPhee, 1990). Soil erosion consists of two principal sequential events: the detachment of soil particles from the soil mass as a result of rain drop impact and the transport of these soil particles (Young and Wiersma, 1973; Faulkner, 1945). Annual soil loss in South Africa to water erosion is approximately 300 million tons (Scotney and McPhee, 1990) resulting in soil loss of 2.48 tons ha^{-1} yr^{-1}. Garland et al. (2000) found that soil loss in South Africa is around 3 tons ha^{-1} yr^{-1}. A major effect of water erosion is the silting up of South Africa's dams (Garland et al., 2000; Laker and Smith, 2006).

Scotney and McPhee (1990) argued that soil loss occurring from wind erosion could be even higher than that caused by water. Wind erosion has been observed in many areas of South Africa, and in total about 2.2 million ha of land is subject to erosion by wind (Garland et al., 2000).

Van der Westhuizen (1986) cited in (Garland et al., 2000) estimated that soil loss through wind action could be as high as 60 t ha^{-1} yr^{-1} in some areas under CV. Most wind-induced soil loss takes place when soil moisture is low and winds are at their highest, between July and October. Soil is lost at higher rates than the rates at which soils are generated from parent material. Scotney and McPhee (1990) found soils under CA being formed from parent material at a rate of 0,31 – 0,38 t ha^{-1} yr^{-1}. Russell (1993) found similar rates at 0.5 t ha^{-1} yr^{-1}.

Land degradation comes at a cost. Annually South Africa loses approximately 400 million tons of soil through water erosion. The cost of replacing the nutrients lost in this process is approximately R 1 billion. In ploughed areas, this could result in a nutrient loss of R 165 to R 543 ha^{-1} yr^{-1} (KZN-No-till-Club, 2008, p. 2). These losses pose additional risks to the viability and profitability of farming systems.

South Africa is a country lacking water supplies. It is also characterized by a scarcity of productive agricultural land. The nonagricultural demand for both these resources is increasing. It is imperative for agriculture to utilize these two resources to ensure the sustainable production of agricultural products (DAFF, 1995). As South Africa moves towards larger and more intensive farms, the real costs of agricultural production are not being fully calculated in the cost of production. The negative impacts of intensive farming methods on the environment are not being reflected in the input costs (WWF, 2010). These impacts include pollution of ground- and surface water, loss of biodiversity, spread of genetically modified organisms, loss of soil fertility, erosion, transport costs and climate change, to name a few.

3. Conceptualizing farming systems

Conservation Agriculture (CA) is an approach to farming, classified under 'sustainable agriculture', which advocates the use of agricultural practices which conserve water and soil and are environmentally non-degrading, technically appropriately, economically viable and socially acceptable (Du Toit, 2007). CA is based on three principles: Minimum soil disturbance, permanent soil cover and practicing sound crop rotations. Benefits from CA are the most evident when all three principles are implemented simultaneously. CA can therefore be defined as crop production systems in which the soil is mechanically disturbed as little as possible; crop and other plant residues are retained on all or much of the soil surface at all times; and two and preferably more types of crop are planted on the same land as cover crops or in defined rotation (Fowler, 2004).

Conventional farming (CV) allows primary cultivation – action happening first - by means of moldboard ploughing or deep ripping actions. Once the soil has been worked deeply, secondary cultivation is done.

Minimum or reduced tillage refers to a tillage system that allows only secondary cultivation i.e. chisels, discs, cultivators, and sweeps (Du Toit, 2007). Secondary tillage is done at a more shallow level and more often than primary cultivation. Farmers practicing minimum tillage replaced some mechanical weed control passes with chemical weed control.

In contrast, No-Till (NT) or zero tillage reflects a system with no primary and secondary cultivation. Planting (direct seeding) is the only disturbance to the soil. Many publications refer to Conservation Tillage (CT) or Conservation Farming (CF), but in this paper these concept are not used, as CA is a more comprehensive concept. Programs in the 1990s which promoted conservation tillage in southern Africa amongst smallholders to address land degradation failed (Fowler, 1999) due to the lack of soil cover and diversified crop rotations (Derpsch, 2003).

In this paper, CA refers to a farming system where the three principles – minimum disturbance of the soil, soil cover and sound crop rotations including legumes - are applied simultaneously. Some publications refer to direct seeding with mulch or direct seeding with crop residue retention. Affholder et al. (2010) referred to this practice as direct-seeding mulch-based cropping system. Neto et al. (2010) referred to CA as no-tillage mulch-based cropping systems. Crop rotations, as reference to the third CA principle, need to be described explicitly. Kassam et al. (2009) argued that a crop rotation using less than three crops should not be called CA. NT is not the same as CA. The latter is based on three principles and NT is only one of them.

4. Sustainability of farming systems

This paper assesses the sustainability of different tillage systems and is therefore based on the concept of “sustainable agriculture”. From the 1970’s, environmental issues were increasingly understood in a global context. This induced sustainability debates in the 1980’s which were extended in the 1990’s (Brundtland, 1987). As a consequence, concepts as “sustainable development” and “sustainable agriculture” evolved. NT, and later CA, are approaches to farming which are classified under "sustainable agriculture", ensuring the use of agricultural practices which conserve water and soil and which are environmentally non-degrading, technically appropriate, economic viable and socially acceptable (Du Toit, 2007).

Sustainability involves simultaneously environmental, economic and social dimensions (Assefa and Frostell, 2007). The text below differentiates between environmental, financial and social sustainability.

4.1 Environmental sustainability

Ample literature is available comparing no-till and Conservation Agriculture with conventional ways of farming. Most publications from all over the globe reflect more environmental sustainable results favoring NT and CA. These advantages include the control of erosion and run-off, increased water infiltration, water-holding capacity of soil and rainfall use efficiency (RUE), increased soil organic matter and carbon build-up in the soils, and higher yields and gross margins.

The water holding capacity of soils is higher under CA than CV (Gassen and Gassen, 1996; Thierfelder and Wall, 2010). In two separate studies in China, erosion was reduced by means of CA by 93% (Nangia et al., 2010) and by 96% (Derpsch et al., 2010) compared to CV. Erosion was reduced by 50-90% in semi-arid areas in Western Mexico (La Tinaja in the state of Jalisco) during 1994-1998 (Scopel et al., 2005).

Soil loss is less under CA then CV due to soil cover (Derpsch, 2008). Run-off is lower with CA (Scopel et al., 2005; Nangia et al., 2010; Thierfelder and Wall, 2010; Blanco-Canqui, et al., 2010; and Fowler, 2004). Water infiltration rates and crop water productivity (rainfall use efficiency) is higher under CA (Nangia et al., 2010; Calegari et al., 1998; Derpsch, 2003; and Thierfelder and Wall, 2010).

Soil build-up from parent material is found to be higher under CA than CV (Scotney and McPhee, 1990, Russell, 1993). Parent material is the material from which a soil forms. It consists of unconsolidated and more or less chemically weathered mineral or organic material. It suffices in this paper to refer to parent material as the organic deposits from plant residues. Soil organic carbon (SOC) buildup and carbon sequestration rates are higher under CA (Scopel et al., 2005; So et al., 1999; Silici et al., 2007; Perez et al., 2007). Soil temperature fluctuates less under CA soils and makes it cooler, thereby avoiding exposure to extreme heat of >50º C (Scopel et al., 2005).

CA has been promoted by conservation professionals who gave technical backstopping to farmers through primarily farmer associations (Dumanski et al., 2006). CA has been promoted as a soil-building and environmental friendly practice, outscoring CV by far. However, it is crucial to apply all three CA principles simultaneously to reach the optimal level of environmental sustainability. NT, for example, without significant cover and crop rotations might score less on soil quality parameters than CV (Govaerts et al., 2006, p. 172; Zanatta et al., 2007, p. 517). It remains a challenge in the Free State's semi-arid regions to increase biomass production and the build-up of adequate levels of soil cover. Other papers (3 and 4) in the thesis will reflect CA research in the Free State with reference to soil carbon levels, water infiltration rates; yields, and variable input costs.

From the literature, it can be concluded that CA is more environmentally sustainable than CV. Cover crops have been identified as being probably the main reason for the success of CA (Derpsch et al., 2010; Steiner et al., 2001; and Pieri et al., 2002. Cover crops are grown to protect and improve the soil, not to harvest *per se* unless for own seed production. "Sustainable soil management practices will not be adopted unless economically viable. "With few exceptions, the need for crop rotation becomes more critical with conservation tillage than with conventional tillage" (Reeves, 1997, p. 158). Examples of potentially good cover crops are: wheat (*Triticum aestivum L*), cowpeas (*vigna sinensis*), grazing vetch (*Vicia dasycarpa)*, Pink Seradella (*Ornithopus sativus*), oats (*avena sativa*), stooling rye (*Secale cereale*), and fodder radish (*Raphinus sativus*). These crops already grow in the Free State and are adapted to the local conditions. Cover crops can be planted as a single crop but they are more often found in mixes (Tonitto et al., 2006).

When cover crops are used with CA, a decline in herbicide use is observed. CA-farmers in Brazil reduced the use of residual herbicides and with cover crops reduced the number of Roundup sprays per season (Hebblewaith, 2010). Herbicides use is reduced due to the weed suppression effect of increased soil cover. Kelly et al. (1996) suggested using an environmental hazard index that can be used to determine tradeoffs between herbicide & pesticide use and other environmental considerations. Another concern is the buildup of glyphosate weed resistance. Cover crops have the ability to build up cover and consequently suppress weeds, resulting in reduced use of herbicides. Research is conducted on the possibility of organic NT (Bilalis et al., 2011; Altieri et al., 2011). In organic NT, weeds cannot be controlled chemically as inorganic products like herbicides, pesticides and chemical fertilizer are not used under the label “organic”. Weeds can neither be controlled mechanically, which is regarded as secondary cultivation. Mowing of weeds is organic but is neither practical on commercial scale nor during a crop stand.

4.2 Economic sustainability

Several studies has showed higher gross margins and consequently lower variable input costs under CA. This includes Llewellyn and D’Emden (2009) in their Australian adoption studies amongst 1172 farmers, as well as Du Toit (2007) with his adoption study in the North West province of South Africa amongst 30 farmers. This can be explained in two ways: first, there were higher yields, as a result of increased soil quality under CA and improved water use efficiency. Secondly, economic sustainability improved due to a decline in production costs. Examples of such economic benefits include reduced fertilizer rates, reduced diesel use and less maintenance and repairs. Because there is less tillage under CA, there is consequently less wear and tear on tractors and equipment. This resulted in reduced costs for maintenance and repairs.

Higher yields are recorded under CA. Kosgei et al. (2007) concluded that maize yields in SA increased under CA due to better soil water retention. Scopel et al. (2005) found that maize yields in Mexico increased by 170-190% under CA due to improved water and nutrient use efficiency. Nangia et al. (2010) found in their research in China that CA increased grain yield by up to 36%. Derpsch (2008) stated that in Brazil, over a 17-year period, maize and soybean yields increased by 86% and 56%, respectively.

CA farmers were able to reduce input or production costs. SA COOP (2009, p. 22) and Du Toit, (2007) concluded that the variable input costs dropped with 39% and 12% under NT in South Africa. This trend is confirmed by (Derpsch, 2008; Bilalis et al., 2011; and Llewellyn and D’Emden, 2009). Fertilizer inputs for maize and soya fell by 30 and 50 percent, respectively (Derpsch, 2008).

Cover crops have been identified as being probably the main reason for the success of CA. There are several advantages of cover crops: increased soil carbon buildup (Metay et al., 2007; Bayer et al., 2000; and Metay et al., 2007a); suppressing weeds (Eash et al., 2011; Uchino et al., 2009; Ngouajio and Mennan, 2005; Czapar et al., 2002; and Pieri., 2002); addition of N through biological nitrogen fixation (Tonitto et al., 2006); reduction of N-losses (nitrate leaching) (Tonitto et al., 2006; Ritter et al., 1998) and reduction of P losses (Kelly et al., 1996; Tonitto et al., 2006, p. 58) illustrated that leguminous and non-leguminous cover crops can be successfully incorporated into cropping systems to maintain cash crop yields while reducing leaching of inorganic fertilizer by up to 50%.

Other recorded advantages of cover crops are: reduced stalk borer attacks (Chabi-Olaye et al., 2005) and reduced erosion (Kelly et al., 1996; Czapar et al., 2002, p. 507; Ritter et al., 1998, p. 2; and Ngouajio and Mennan, 2005, p. 522). Soil types need to be taken into account when analyzing nutrient leaching. Better weed suppression and pest control and vigorous growth as a result of organic N will consequently result in increased yields. Increased N supplies by cover crops and reduction in fertilizer losses can result in lower fertilizer rates for following crops. Cover crops feature strongly in organic Conservation Agriculture (OCA) farming systems (Uchino et al., 2009). Pieri et al. (2002) stated that successful NT users in Paraguay and USA report a decrease in herbicide use as up to 30% after the initial 3-5 years transition phase due to improved skills and knowledge.

The literature review shows that cover crops are important. Sixty percent of South Africa’s soils have been classified as low in soil organic matter (SOM). Reeves (1997) stated that soil organic carbon, which is strongly linked to SOM, can increase when it is coupled with intensive cropping systems. The cropping intensity can increase through the selection of cover crops. There is a need for sound crop rotations in order to maintain agricultural productivity and economic sustainability (Reeves, 1997). Zanatta et al. (2007, p. 517) underlined the importance of high residue addition cropping systems and emphasized that NT *per se* is not enough to increase or maintain SOC stocks.

The success of CA is contributed to the role of cover crops and it is deemed therefore to be necessary to further the discussion of cover crops and fallow from the point of view of economic sustainability. Firstly, the role of fallow in a crop rotation, and secondly, the replacement of bare fallow with cover crops, needs to be examined in more detail. Incorporating cover crops in eastern Free State crop rotations can result is various long-term savings due to improved soil quality. The cover crop discussion evokes, however, the question about its technical feasibility in semi-arid regions (Pieri et al., 2002) as another by-crop alongside a main crop utilizes an already scarce resource - rain- and ground water.

Fallow, as part of the crop rotation, is common in the eastern Highveld area for storing pre-plant water quantities and breaking pest cycles. Increasing the length of the fallow period before planting increases the amount of pre-plant stored water in the soil, thereby reducing the risk of drought damage to the crops (Bennie and Hensley, 2001). Soil water levels can be measured by the precipitation utilization of different production or management practices for dry land crop production or rangeland utilization. This is expressed or measured as a precipitation use efficiency (PUE) value (Bennie and Hensley, 2001), rain-use efficiency (RUE) (Snyman, 2004), also known as crop water productivity (CWP). The CWP is a concept adapted from Helleger et al. (2009). The crux of the matter is that if PUE can be improved, then smaller areas are needed for the same production quantities. The PUE will improve by reducing runoff and evaporation and increasing soil water storage, e.g. with various mulch practices (Bennie and Hensley, 2001). Cover crops during the pre-plant water storage period will utilize soil water and precipitation, but so do weeds. Poor control of weeds during the fallow period will almost always result in reduced yields (Bennie and Hensley, 2001). Soil structure improves with a decrease in tillage intensity resulting in higher rainfall use efficiency, which in turn reduces the need for fallow. Reeves (1997, p. 158) stated: “In semi-arid regions, tillage system interactions with rotations on productivity are often the result of improved harmonies or synergisms in water use efficiency”. In Texas, USA, “soil water storage generally increased with decreasing tillage intensity”.

Can cover crops replace bare fallow? Reeves (1997) refers to the concept of agronomic productivity (AP), which is sometimes referred to by others as land-use efficiency. This paper refers to AP as cropping intensity (CI); a concept used by (McNee et al., 2008). The CI reflects months with an actual standing crop divided by 36, 48 or 60 for a three, four and five year crop rotation respectively. In other words the CI will increase by reducing fallow. Cover crop propagandists question and challenge the benefits and need for fallow periods. Different studies have demonstrated that soil moisture depletion is slightly higher under a cover crop used under CA than under (stubble) fallow (Sooby et al., 1997; McNee et al., 2008). However, the same authors question whether there are actually any benefits gained by storing soil moisture by fallowing. It is generally assumed that after fallowing, timely rainfall is required to establish a successive crop. The limiting feature in the environment is good spring rains. Both no-till, Conservation Agriculture and conventional ways of farming systems require good spring rains before planting (McNee et al., 2008). Seif and Pederson (1978) reported, based on 37 trials in the Wellington district in Australia that 86% of the variability in yield in their trials could be accounted for by variability in spring rainfall. Where stored soil moisture is not a major production driver and timely rainfall is more critical, it may be possible to grow cover crops without seriously compromising yields in following crops (McNee et al., 2008).

The lack of understanding the role of livestock jeopardizes CA. It is common to graze crop residues in current mixed farming practices in the eastern Free State. The practice of using crop residue as a mulch to control runoff is seldom economically feasible, when compared with utilizing it as animal feed under low rainfall situations (Bennie and Hensley, 2001). Practicing no-till, disturbing the soil as little as possible, is not financially sustainable on its own. Soils need to be covered and sound crop rotations need to be practiced. Crop residues are crucial in annual livestock dietary cycles and therefore alternative strategies are required. It increases the need for cover crop research, soil cover strategies and increased cropping intensity. It requires us to look beyond cover crops during the 'fallow' period. Standing cash crops, i.e., maize and sunflower can be over-seeded with a cover crop. This can be done by means of aerial seeding or direct seeding by elevated self propelled machines ('high boys'). These details are however beyond the scope of this paper. The timing of seeding is crucial, but further local research need to provide answers to what extent cover crop uses in this regard contribute to additional feed sources and soil cover at the same time. One paper in this thesis (paper 3) will deal explicitly with economic aspects of cover crops and animal feed in common crop rotations in the eastern Free State. Commercial farmers rely heavily on income derived from the livestock sector. The adoption to CA will remain low unless solutions are found to overcome the dilemma of choosing between soil cover and animal feed. This topic will be partially discussed under social sustainability, but another forthcoming paper in the thesis deals with farmer perceptions regarding livestock and no-till.

4.3 Social sustainability

South Africa is referred to as the Sleeping Giant in NT (Derpsch, 2003; Fowler, 2004). CA adoption is growing globally. A total of approximately 105-110 million hectares are currently being cultivated globally according to the principles of CA (Derpsch, 2008 and Derpsch et al., 2010). The highest adoption rates are in North and South America, and Australia and reflected as a percentage of world totals of 46.8%, 37.8% and 11.5% respectively. Africa has the lowest adoption rate of approximately 0.3% of the world total CA statistics. African countries constitute up to 368.000 hectares under CA (Derpsch, 2008).

Table 1: Global NT adoption rates over time

Year:	1973/74	1983/84	1999/2000	2004/5	2008
Continent	Hectares No-till (NT)				
South America	1,000	400,000	23,870,000	44,904,000	49,579,000
North America	2,200,000	4,800,000	23,830,000	37,826,000	40,074,000
Australia & New Zealand	100,000	400,000	8,640,000	9,000,000	12,162,000
Asia	0	0	0	2,000,000	2,530,000
Europe	0	50,000	50,000	450,000	1,150,000
Africa	0	0	0	300,000	368,000
Others	477,000	605,000	650,000	1,000,000	
World Total	2,778,000	6,255,000	57,040,000	95,480,000	105,863,000

Source: (Derpsch, 2008 and Derpsch et al., 2010)

Both the environmental and economic sustainability of CA has been discussed. The technical aspects of CA have been highlighted in detail, but the question remains unanswered: “if it is technically so good, why is the uptake locally so relatively low?” This question should be elaborated in much detail. Possible factors include the importance of social networks; perceived risks; a better understanding of the different drivers of adoption; resistance to change; cultural land-use practices, dissemination of information; and level and quality of extension. All these factors all require additional research. Equally important are other questions that require answering: availability of NT equipment, current agricultural paradigms and farmer perceptions. Effective transition to alternative and sustainable farming systems is more than substitution of inputs. Effective transition requires a fundamental change in the way soil is viewed (Palaniappan et al., 2010).

Derpsch et al. (2010) argued that in order for the sustained adoption of CA to grow, the main barriers for CA adoption need to be overcome. These include the issues of mindset (tradition, prejudice); technical knowledge (know-how); availability of adequate machines; availability of adequate herbicides; and adequate policies to promote adoption. Derpsch et al. (2010) further argued that with adequate policies to promote NT and CA, it is possible to obtain the "triple bottom line" of economic, social and environmental sustainability, and while at the same time improving soil health and increasing production.

CA adoption rates are growing locally and globally, reflecting acceptance of it amongst land users. Humans are at the centre of agro-ecosystems and their well-being is a key issue for the sustainability of agro-ecosystems Walker and Schulze (2008). Rogers (1983) stated that farmers prefer that change comes 'from inside' through farmers' recommending it. They may modify and diversify prescribed Conservation Agriculture recommendations to fit their own farms' different situations. Spread of a favored technique is seldom because farmers have evaluated it on the basis of scientific studies of its consequences. Rather, most people depend mainly on a subjective evaluation of an innovation that has been made by their neighbors/friends who have previously adopted it (Rogers, 1983 and Ekboir et al., 2001). Forthcoming papers will deal with the social problems related to the current adoption of CA in the eastern Free State. Future social-oriented topics for research are: knowledge and information systems; farmer agency and the role of networks in the adoption and increased acceptance of CA; and perceptions related to the role of livestock in mixed farming enterprises.

5. Conclusion

CA should not be confused with no-till, which is actually only one of the three CA principles. CA is only a potential alternative to conventional agriculture if all three principles of CA are applied simultaneously - disturb the soil as little as possible, maintain year round adequate cover and practice sound crop rotations including legumes. Cover crops are crucial in successfully implementing CA. CA requires whole farm planning including integrating livestock management with the CA system. CA with cover crops can address soil quality decline on fields with cash-, green- and fodder crops. Conversion strategies to CA should include incorporating cover crops into the rotation in order to build up soil organic matter, increase soil quality and reduce the use of herbicides. CA is a sustainable alternative addressing current land degradation as a result of conventional ways of farming.

CA is environmentally and economically more sustainable than CV. The sustainability of any agricultural system should be measured in terms of long-term financial profitability, ecological and environmental quality and socially acceptability. Comparative assessment is a valuable tool in defining and measuring sustainability. The social acceptability of CA locally requires more research. The acceptability to farmers' question will lay the groundwork for future articles in this thesis.

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PAPER 2:

FROM CONVENTIONAL FARMING TO CONSERVATION AGRICULTURE IN THE EASTERN FREE STATE, WITH NO-TILL PRACTICES AS AN INTERMEDIATE OPTION: A NARRATIVE APPROACH

Abstract

Conservation Agriculture (CA) is an approach to farming that conserves resources like water and soil. It is based on three principles: disturb the soil as little as possible, which is synonym to no-tillage (NT). The other two principles are applying permanent soil cover and have good crop rotations that include legumes. CA is regarded as 'sustainable agriculture'. There is an increased world-wide awareness of the role of sociology to designing: "sustainable agriculture" and "agroecology". Farmers practice NT in the eastern Free State of South Africa, but it is not merely a 'technology transfer'. The initial converts to no-till faced challenges like lack of equipment and technical knowledge. However, they overcame those challenges. Farmers, through innovative thinking, by trial and error and by obtaining information through different networks, made no-till work on their farms. Farmers posses 'agency' and they are able to 'unfold' and develop no-till to higher standards, which in this paper is called CA. This paper draws upon concepts and discourse of the Narrative Study Method. This theory is tremendously useful in studying innovations and their adoption of NT by assessing a few in-depth cases.

Keywords: Narrative Study method, CA, actor, problem solving ability, sociology, know-how

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1. A *Lyrical* No-till anecdote

South-eastern Free State farmers primarily grow crops for fodder because of lower precipitation, lower scores on the aridity index and shallower, more clayey soils. The central- and north-eastern parts, where more cash crop farming is found, have deeper, sandier soils (Hensley et al., 2006). Total farm area of typical central-eastern Free State farms consists of cash crops, pastures, green forage and natural veld. Beef cattle and sheep are reared in this area. The main cash crops are maize, sunflower, wheat and, to a lesser extent, soya and sorghum.

Prices for crops in the Eastern Free State derived from SAFEX prices. SAFEX, in turn, can be considered to be a price discovery mechanism. The grain prices have fluctuated over the years, so with rising input prices, crop farming has become a risky enterprise. The beef and mutton market has been more reliable than the grain market, so conventional farming practice includes summer veld and pasture grazing combined with winter grazing on forage and crop residues i.e. maize, sunflower, soya and wheat. The commercial farming context in the Free State is characterized by fallow periods between cash cropping.

The tale below is a rendition of the author's experience based on the numerous in depth interviews conducted with 20 farmers, both NT and conventional, over the last five years. This tale is written in a personal context, but depicts a fictive farmer that converted to NT. The concepts of NT and CA (Conservation Agriculture) are used interchangeably in this paper. Farmers refer to NT and don't make reference to the academic division of the two concepts. CA is seen as a fully fledged farming system based on three principles. NT is seen only as one of those three CA principles of 1) disturbing the soil as little as possible; 2) maintain year round soil cover; and 3) implement sound crop rotations including legumes with least three or more crops in the rotation.

Many elements, quotations and issues in the tale are based on the different interviewees' experiences. The author also tried to create the setting of the tale as based on its interpretation of the current state of agriculture in the EFS. Most of the pressing issues regarding the adoption of No-till and Conservation Agriculture against the eastern Free State context have been mentioned.

The tale presented in this paper shows that the adoption of NT or CA is not a simple or straightforward matter. The sociological relationship between fathers and sons (and sometimes, daughters), on family farms, is a complex relationship of authority, individuality and innovation. Sometimes, the older generation is more open to change, and sometimes the younger generation. Typically, the atmosphere on family farms is non-confrontational, with farmers behaving in a reserved manner, but simultaneously very critical of their own performance in comparison with other farmers. Farmers tend to measure their own management style according to factors such as tight fences, well-managed livestock, mowed lawns, large tractor, neat and tidy farmyards, and clean vehicles. This is the “work aesthetic” on a typical Eastern Free State farm. Farmers tend to meet each other at a range of social events, including sport and church, where their values are confirmed and entrenched.

The tale shows that the NT adopters tend to be self-critical, and do a lot of self-analysis about the potential impact of changing their tried and tested technologies. A change to NT makes farmers deeply uncomfortable with their operating style. While they undertake the change, they constantly question the wisdom of their decisions. Furthermore, the lack of a support system is a disincentive. Nevertheless, the fact that some farmers are adopting changed technologies illustrates the growing pressure and need to change, often for financial reasons to survive on their farms. It also shows the strength of character of the NT pioneers.

2. A tale of a conscientious farmer

I always wanted to be a farmer. I always farmed with my father. I often tried to sound him on about the ‘why’ we did certain things. The answers were normally short, but once he said, “I am 64 now. We don’t have to make changes to our farming style. We can still farm like this for another 100 years”.

Now I hold the reins of the farm. When I drive to town, I observe other farms, curiously judging whether my own farming standards match up to those of my neighbours. Are their fences straight and tight, what is the height and stand of the crops, condition of their veld, and even whether their lawns are mowed? Driving in the old Toyota bakkie, I can still hear my granddad mumble as he criticizes about every single thing and person he passed by. I am very much like him. What are people going to say about me, as a farmer? This is a question that all of a sudden hit me between the eyes. I can't blame my father if things are not going well. I need to critically assess my own farming practices.

I turned for advice to the 'good' farmers - I later figured out that they ironically had also the biggest co-op debts. I often heard: this is the way we do things here. This is how we farm here. I want to be respected by all the other farmers that drive up and down the several farm roads adjacent to my farm. Sometimes I wonder if they are looking for me although everybody can see my *bakkie* and faithful dog at the back. What are they looking for? Maybe just going home via a different route? Are they looking at my fields?

Occasionally I would turn up for a farmer meeting in the nearby farmers' association hall. When joining some of the informal after-meeting chats, I picked up that some farmers are the talk of town. I learned a new term "ag, shame". By the way I don't want anyone to comment on the standard of my fields or on a crop stand as "ag, shame!" That would suggest that I don't know what I am doing. I want to avoid that by all means. I don't want to hear that at the tennis club, the weekend *braai*[2] and even in church on Sundays. Yes, that gossip might prevent me from trying something new or alternative.

I am confused. I hear other farmers speak about no till. My neighbor used to say "no till no crop". He seems to think that proper farming needs a lot of tillage. Granddad used to send me out with the disc when I was young. How often did he make me pee on the soil as urine pebbles reflects soil compaction? Put the disc into it! Get rid of the weeds at the same time too. Man, what a dust! But grand-dad would not know what it costs to let the tractors go up-and-down the fields nowadays, in terms of the diesel bill.

I wondered many times whether anyone could tell me a bit more about this idea of no-till. All the 'official' guys visiting my farm, selling their products, seem to be unaware of no-till. If I have the courage to mention no-till, it makes them shrug their shoulders or even laugh at the idea. But to me it is no laughing matter. Who pays my bills? Maybe I should ask those 'big cannons' that supplied my dad with the annual loans. They should definitely know. My hopes were disappointed and I felt deceived. Most of what I know about no-till was reading the *Farmer's Weekly* over and over again. I could do that undisturbed. Some of the articles made me think. Since we got wireless internet on the farm, I have been getting answers on my many

[2] Barbecue.

questions from Google. My friends, I will still call them that although they think differently about farming than me, just shake their heads - pityingly or disapprovingly?

Now I am one of those “ag, shame” farmers although my bank managers never used that phrase. I remember the echoes of a few farmers hanging over the fence: “You will be bankrupt soon” and “One day I am going to farm on your land”. I guess they were wrong, because I am still here!?[3] Of course, how can hundreds of thousands of farmers world-wide be wrong? Derpsch, known world-wide for his knowledge on NT stated in two articles (2008, 2010) a total of approximately 105-110 million hectares are currently being cultivated globally according to the principles of CA .The highest adoption rates are in North and South America, and Australia and are reflected as a percentage of world totals of 46.8%, 37.8% and 11.5% respectively. South Africa is referred to as the Sleeping Giant in no-till by Derpsch (2003) and Fowler (2004).

It is not easy. Sometimes, when I just started no-till, I saw everybody cruising through their fields, with discs, tine-implements and even ploughs. It drove me insane. “What if I was wrong?” I had lots of questions. By the way, I realized that I am not the only one researching on the internet looking for information on cover crops, organics, carbon sequestration, planting equipment and lots more. It seems that the most-cited articles and highest topic-hits on specific academic sites are also the articles I was looking for. Lichtfouse et al. (2010) made a nice summary about that, and it was worth reading it. I also learned recently that a few farmers in the district are starting to experiment with the same ideas. I wonder how they are getting on. Do I really want to visit them? I have more time at hand – so it is an option. Let me come back to the issue regarding my bank manager. We are not that close yet. I did not take a (slight) initial knock in my annual income as some-one predicted. I started to buy different off-the-beaten track equipment - in the middle of the season, believe it or not. Quite contrary to the end-of-the-year tax-related ‘transactions’ we would normally do.

It is as if I walk into a wall. I get tired of defending myself, explaining time and again why I adopted no-till. I am excited about it; it works; I want to share my experiences, but there is no point in sharing my enthusiasm with others or trying to convince them. I am going to focus on

[3] The financial modeling of conventional farming (CV), No-till (NT) and Conservation Agriculture (CA) is done in paper three of this thesis. Farmer A is still farming after many years of NT although a slight drop in yields initially on maize and sunflower, but not on wheat. The drop in yields (p24) did not affect the in-year cash flow significantly. The financial modeling did not include the conversion affect from CV to NT, but reflects NT and CA after the initial conversion period.

making it work even better on my farm. After all, if I want to convince others, they will only believe me if they see real results. “Seeing is believing”. I wish there were good examples when I started. It would have saved me some ’learning-fees’. I helped a few farmers in the past six years to ‘demo’ NT, but it was a disaster from onset as they did not select the best fields for it. We started our demo’s on soils with no cover, as hard as concrete after the winter grazing. Soils were not corrected nor the compaction layer broken. The planter ‘jockeys’ complained that their teeth were rattling out after trying NT with a conventional planter. I learned: If you want to do it well you need to be convinced that it works.

Another pressing question is whether livestock can be combined with no-till. We need to find the balance between the apparent problem of building up soil cover and using the biomass for animal feed. If granddad sees all this ‘feed’ he will definitely chase the cows into the paddock. Others are not as lucky as I having complete control of the reins. I don’t find my fellow farmers narrow-minded, to the contrary. I learned to have more empathy by listening to their stories. We all want to minimize risk, maintain steady incomes and farm, because that’s what we love. That’s where we are good at. If there were only more local applicable data and examples!

Some of the neighboring farmers copied some of ‘my’ ideas, but got it the wrong side of the stick: something they call strip tillage. I have seen strip till planters at work. The soil billowed making the tractor roar like an enormous beast. I guess we all understand “minimum disturbance of the soil” differently. Whom is to blame for this? Who persuaded them to do this, and where did they get the information from? I guess there are still those ruled by the hard-to-get-rid-of perceptions: farmers need ‘big toys’, whether green, red or blue, and we just need to work the soil a ‘little bit’. Cattle causes compaction and I have learned that nothing compacts the soil more than sheep hooves. Maybe strip-tillage soothes the mind, calming down the worried voices, and is it an attempt to find a compromise between conventional farming and no-till.

I am now for solutions on how to get more soil cover, proper crop rotations and how to get the different cover crops integrated into the system. Do you think I need to explain the ins-and-outs of no-till to all my laborers? Off course, but let’s wait and see how many are still there next season. I am also still learning. Although the workers might not be aware of all the technical stuff they definitely realized that NT operations are far more pleasurable. All the workers stated that “we don’t work in the dust anymore”. If the majority of farmers adopted no-till then that will be the end of the red dust-clouds, which are so typical in August and September.

From narrative to analysis

This personal story, drawn from different in-depth narratives of farmers in the area, highlights key issues in the process of adoption of new, simpler, and ecologically sound technologies. Two farmers were interviewed in depth. Eight other NT pioneers' stories were also drawn into the analysis. Their experiences are reflected later in the chapter.

3.3 The role of Sociology in understanding Sustainable Agriculture

Weis (2010) stated that the productivity of industrial capitalist agriculture is central to dominant development narratives. According to Weis (2010) rethinking agriculture's place in concepts of development and modernity requires sociological narrative studies. Van der Ploeg (2008) in Weis (2010) gives evidence of how some farmers (in the North) are increasingly opposing industrial capitalist imperatives and practicing alternatives. Farmers' narratives about their own experiences are crucial for the move towards more sustainable agriculture (i.e. organic food movements, the slow food movement, the permaculture movement, fair trade networks, public concern over climate change, the farm animal welfare movement, vegetarianism, also the movement to low food miles) and moving away from industrial capitalist agriculture.

Lichtfouse et al (2010) reflected three data sets in the journal Agronomy for Sustainable Development with most-cited articles from 1999-2009, most frequently mentioned topics in article text from 1999-2009, and most downloaded articles in 2009. Most-cited articles show that soil carbon and climate change are the major mainstream topics over the last 10 years. According to Lichtfouse et al. (2010) the 10 most emerging topics over the period 1999-2009 are: biofuels, "genetically modified", conservation agriculture, urban agriculture, sociology, organic farming, carbon sequestration, phytoremediation, mulch and biodiversity. Most of these topics are found in this thesis. The fact that sociology is also mentioned by Lichthouse et al, confirms the importance of sociological dimensions of topics such as climate change, despite the negative evaluation of 'sociology' (McNall, 2008).

Lichtfouse et al (2010) have written and oft-cited passage: “Unprecedented changes call for unprecedented adaptation. Unprecedented adaptation calls for unprecedented thinking. For instance, a major issue is that agricultural research has been for too long driven solely by the need for higher yields using monoculture, whatever the adverse ecological effects, such as food and drinking water pollution, biodiversity loss, and pest resistance. Mainstream goals such as higher yields should be challenged and rethought to take into account other factors. Those factors should not be solely defined by classical agro-sciences, e.g. plant and soil sciences, but should also include all other sciences that really rule agriculture; for instance, ecological, economic, social and political sciences” Lichtfouse et al (2010, p. 2). In sympathy with this approach, this thesis deals with the adoption of Conservation Agriculture based on ecological (paper 3), economic (paper 4), and social sciences (paper 2 and 5).

There is an increased world-wide awareness of the relevance of sociology to the concepts of “sustainable agriculture” and “agroecology” (Lichtfouse et al., 2010, p. 5). According to Lichtfouse et al (2010, p5) “We find that sociology is clearly bringing novel and unexpected findings to designing sustainable agriculture”. Sociology takes into account opinions of all stakeholders; it also analyses farmer discourse and farming systems (Abrol and Sangar, 2006) Sociology is found to be useful in defining sustainable agriculture. Abrol and Sangar (2006) emphasized the need to bring all the involved stakeholders to create a common set of principles for strategic planning.

Two papers in this thesis are sociological in nature. One forthcoming paper (5) is based on the actor network theory, while this paper deals with the adoption of Conservation Agriculture using a narrative study methodology. The researcher visited the two Eastern Free State farms repeatedly over a period of four years. Eight other examples of NT pioneers are included in the text, but not discussed in detail, which would have made the paper too lengthy. Narrative inquiry is a way of understanding people’s lived experience, over a significant phase of their lives. It requires collaboration between researcher and participants, often over a fairly lengthy period, in a place or series of places, and in social interaction with local milieus (Giovannoli, undated).

This paper has three main goals. The first purpose of this paper is to explore the Narrative Study Method as a valuable approach by analyzing different local CA case studies. The narrative study method helps in answering the question of why some Eastern Free State farmers implement CA whilst other farmers remained hesitant to implement such changes.

The third and last purpose of this paper is to illustrate the link between the narrative study method and the Actor Network Theory for further research.

4. Theoretical perspectives

The term ‘narrative’ carries many meanings and is used in a variety of ways by different disciplines, but often it is regarded as synonymous with ‘story’ (Larsson and Sjöblom, 2010; Riessman and Quinney, 2005; and Abbott, 2007). Narrative analysis typically takes the perspective of the teller.

Kvale (1996) in his book InterViews describes two classifications of interviewers metaphorically as “miners” and “travelers”. The interviewer as miner is seeking to unearth some knowledge buried within the subject of the interview. The traveler, on the other hand, is journeying through the other’s landscape, gathering stories to retell when he or she arrives back home. The two metaphors—of the interviewer as a miner or as a traveler—represent different concepts of knowledge formation. Each metaphor stands for alternative genres and has different rules of the game. In a broad sense, the miner metaphor pictures a common understanding in modern social sciences of knowledge as “given.” The traveler metaphor refers to a postmodern constructive understanding that involves a conversational approach to social research. The miner metaphor brings interviews into the vicinity of human engineering; the traveler metaphor into the vicinity of the humanities and art.

Narratives differ from qualitative interviews. Most of the talk in interviews is not narrative but question-and-answer exchanges, argument and other forms of discourses (Larsson and Sjöblom, 2010). Semi-structured interviews promote that narrative aspect. Narrative research is a very promising approach for gaining an in-depth understanding of people’s lives and the subjective meaning which people give to things and experiences (Larsson and Sjöblom, 2010).

Larsson and Sjöblom (2010) stated that narrative methods can be used in social work research. They indicated two major theoretical and methodological positions in narrative research: a psychology-based and sociology-based approach. This paper represents a sociology-based approach, grounded in social constructivism (Larsson and Sjöblom, 2010;

Riessman and Quinney 2005, p. 393) and postmodernism (Giovannoli, undated; Larsson and Sjöblom, 2010).

The narrative allows for the inclusion of actors' reasons for their acts, as well as the causes of events (Giovannoli, undated). Franzosi (2010) stated that the structural features of a narrative are based on a triplet: actor-action-actor. This thinking fits within the actor-oriented approach where an actor possesses 'agency'. The unfolding of the three CA principles at farm level is an example of such human agency. Narrative texts thus seem to be characterized by processes of action (Franzosi, 2010).

It is essential for the researcher to provide a facilitating context to encourage the interviewees to tell complete stories about important moments in their lives (Giovannoli, undated). Conducting narrative research is not without challenges. There are theoretical, methodological and practical considerations. What is a good narrative? Riessman and Quinney (2005, p. 393) stated that the term 'narrative' has come to mean anything and everything. A narrative needs to be organized and the script needs to be structured and or organized even though such structure is only implicit in the actual verbal narrative (Riessman, 2002 stated in Larsson and Sjöblom, 2010). Sequence and consequence distinguish narrative from other forms of discourse (Riessman and Quinney, 2005, p. 394). The authors argue, furthermore, that events are selected, organized, connected, and evaluated as meaningful for a particular audience. Analysis in narrative studies interrogates language – 'how' and 'why' events are storied, not simply the content to which language refers (Riessman and Quinney, 2005). Four criteria for the evaluation of narrative studies have been offered by Lieblich et al. (1998, p. 173) as summarized by Giovannoli (undated):

1. Width: the comprehensiveness of evidence. This refers to the amount of evidence that is provided to allow the reader to make an informed judgment on the evidence and its interpretation.

2. Coherence: the way different parts of the interpretation create a complete and meaningful picture. Lieblich et al. (1998) distinguished between internal coherence (how the parts fit together) and external coherence (how the research compares to existing theories and previous research).

3. Insightfulness: the sense of innovation or originality in the presentation of the story and its analysis. Does this research move the reader to greater insight into his or her own life?

4. Parsimony: the ability to provide an analysis based on a small number of concepts, and elegance or aesthetic appeal. This refers to the literary merits of oral or written presentation of the story.

These four dimensions are applied to the two narratives. Firstly, is there enough evidence to say that NT works on farmer A and farmer B's farm? How would they measure success? Success is measured by the fact that the NT pioneers were able to implement NT profitably on their farms and that they gradually move towards CA? Evidence should address the current barriers of adoption as mentioned by the interviewed conventional farmers: the mixed farming context of the Eastern Free State so that adequate care is given to the incorporation of livestock. Evidence should also address NT implements, the economics of CA, technical knowledge, risk reduction strategies, and weed management.

Secondly, the coherence of the narratives could include the following parts that will give a complete overview of the NT adoption and implementation aspects: the reasons for adoption, basic farm economics, labor issues, gained know-how and information networks, adherence to the three CA principles, weed control, crop rotation and cropping details, and accommodating livestock.

Thirdly, do the narratives move other farmers to greater insight in the alternatives CA has to offer? The cover crop discussion is probably an eye-opener for most readers as the worldwide success of CA is largely attributed to the role of cover crops (Steiner et al. (2001), Pieri et al. (2002), and Derpsch et al. (2010). Farmer A's narrative includes significant attention to the issue of cover crops.

Finally, the two narratives will do justice to the concept of 'parsimony'. The narratives reflect on the conversion of CV to NT in mixed farming contexts in the Zastron and Ladybrand areas in the Eastern Free State. This research becomes the basis of future research.

What is good about the narrative approach? Its main contribution is that it provides in-depth understanding of people's lives (Larsson and Sjöblom, 2010, p. 272). Narrative inquiry is cross-disciplinary and based on different epistemologies, theories and methods. It opens up creative collaborative research (Larsson and Sjöblom, 2010, p. 273). Other papers in this thesis highlight the urgency of transdisciplinary collaboration. According to Mishler (1986, p. 81) quoted in (Larsson and Sjöblom, 2010) the most important aspect of the narrative is that it helps to understand 'the quality of the mind'. In other words quality of mind, not plot, is the soul of the narrative. Narrators can position themselves in many different ways, giving themselves, for example, active or passive roles in their stories (Larsson and Sjöblom, 2010, p. 276). An active role adopted by the narrator or interviewee helps to reduce any possible bias held by the researcher. The narrative approach can be well combined with other qualitative and quantitative research approaches. Narratives are practice-oriented (Riessman and Quinney, 2005, p. 407) and can contribute therefore to the establishment of eco-type specific and area-bound (site-specific) CA guidelines. Farmers as narrators have the ability to compose their own CA stories on how they did things, how they managed change and how they successfully implemented CA on their farms.

Narratives are used in several disciplines: social work (Riessman and Quinney, 2005; Larsson and Sjöblom, 2010); Sociology (McNall, 2008); Agriculture (Weis, 2010); Education (school counseling) (Bekerman and Tatar, 2005) and emphasis on learning by doing and experience (Hansen, 2008).

Bekerman and Tatar (2005) found in their study that counselors' own adolescence influenced their current views on adolescence and counseling. In the context of our study, this implies that farmers' own experiences influence their current views of agriculture and mixed farming. Farmer narratives and their cultural constructs are equally helpful in understanding farmer identity and farming practices. The farmers' narratives are important to document their journey from conventional ways of farming to NT and CA. This will assist other NT adopters in the area by establishing local adapted conversion strategies and local ecotype-specific mixed farming approach based on NT.

5. Methodology

The NT-pioneers were easily identified because there were only few by the time the research started. An NT-pioneer in this thesis refers to those farmers that started NT in their area despite lack of data, technical knowledge and support networks. All visits were informally conducted, and included dinnertable discussions, field observations, and traveling on the farm together. This created plenty of opportunity to listen, ask and participate as suggested by Brown (2008). Ten NT farms were visited and general observations made. These farmers participated in a general NT dialogue. After the initial visits, it became apparent that there was a need for more research. The initial informal data was assessed and a data-base was developed. The main themes were coded and the available data was entered into the data-base.

Because of the initial informal conversation-type of interviewing, it became evident that not all farmers were asked all the questions, resulting in some data gaps. A questionnaire with 12 questions was send to the NT pioneers by email and their replies were, in addition to the initial obtained data, thematically plotted on the data base.

The 12 questions were: (1) reasons for adopting CA, (2) how did you get to know about CA, (3) what the challenges were and (4) how they were overcome? (5) Who promotes CA in the area and (6) why, (7) who is against CA and (8) why? (9) How success in CA is measured, (10) who are potential converters (adopters) of CA, (11) what advice would you give them and lastly (12) what need to be in place for an increased CA adoption.

Five people, four of the largest conventional commercial farmers in the Ladybrand research area and one retired extension officer, were interviewed. The researcher requested names of conventional farmers, with good reputation and, one would assume, high management skills. The names of the farmers with the largest farms were provided by the local co-operative. Large farmers are those with the highest turnover, but possibly the highest co-op debt. The reason for the interviews were to assess potential barriers to the adoption of NT. Farmers were asked what they thought of NT and whether it could be a good alternative for the wider area. They were also asked whether they considered switching over to NT. The style of the interviews was in the form of conversational dialogue.

The NT farmers were visited occasionally, during a two year period (2009-2010), whilst the researcher conducted additional literature research. The foundation of the interview process was conducted on an informal basis. The ‘dialogues’ continued over several months. A more structured sociological foundation emerged from the literature, and this added insights to the ongoing dialogues. Findings of the literature research pointed to the importance of multi- or transdisciplinary research. Cover crop trials were set up with initially three of the NT-pioneers, but were reduced to one scientific research trial. Trial results will be reported on in a forthcoming paper (4) in this thesis. Multiple farm visits were conducted and dialogues continued as a result of the planning and implementation of the crop trials. Two of the NT pioneers' narratives are documented in this research.

The interviews were conversations between the researcher and the farmers. This dialogical interviewing made the farmers and the researcher egalitarian partners in a close mutually beneficial personal relationship. The dialogues were open-ended and often resulted in discussions of the pros and cons of many CA-related issue and topics. The information was transcribed and assessed, and their insights were sifted to uncover questions for future discussions.

It became evident that the NT-pioneers were all able to successfully convert to NT despite the initial challenges. In order to find out why other commercial farmers were not switching over to NT, the researcher decided to conduct farmer forums or group discussions. Two farmer group discussions were held. Here only the conventional farmers were invited. Farmer forums can be a powerful sociological tool, but the researcher found it difficult to get few farmers together. Five people attended these two sessions. Two follow-up visits were done with two of the attendants. Therefore other individual conventional farmers were visited to obtain insight in the barriers of adoption to NT, sustainability perceptions and stakeholder assessments.

Two case narratives were selected. Other NT pioneers also deserve consideration, but farmer A and farmer B were selected because they were both the founders of NT in their areas, both have mixed farming and both reflect two divergent mixed farming contexts under two different and divergent set of conditions. The researcher posed deliberative questions to these farmers. These questions were related to the barriers to NT adoption mentioned by CV farmers. These questions were: Did you have a decline in income after converting to NT? Are you able to integrate livestock into your NT farming system? How did you gain knowledge about NT and how did you manage to obtain the right equipment?

The narratives are structured into specific narrative modes and re-cast into new stories by the researcher. In order to enlarge the readability of the text, headings and sub-headings were added. The headings were selected by the researcher, who is a NT promoter and has a preference for NT. The researcher became part of the NT farmers' new network, which will be elaborated upon in paper 5 of this thesis. The issue of researcher bias is discussed below.

Six of the ten NT-pioneers were asked to write their own self narrative. Many questions were posed to the NT-pioneers during 2010-2012, but two questions were added for six of the NT pioneers of who were visited most regularly. Each of the six farmers was asked to write the answers down. This reflects the NT-pioneers self-narratives where they were free to (re-)tell their own stories. The narratives are then analyzed according to the main themes and topics, and compared with the framework of topics as described by Lichtfouse et al (2010).

The two questions for self-narratives were: (a) Describe your NT journey from the beginning till now, and (b) describe your dream for sustainable agriculture. No instructions or directions were given. This written self-narrative is included for two reasons: to minimize any biased effect of the researcher and to capture the NT-pioneers' meaning and motives as they reflect on what is important to them. This methodology conforms to the guidelines offered by Bekerman and Tatar (2005). Only two farmers replied with their self narratives. The content of the narratives was analyzed and coded according to major themes. The two narrators, farmer A and farmer B have read and re-worked their narratives as documented in this paper. This accounts for being self-narratives.

Narrators can position themselves in many different ways, giving themselves, for example, active or passive roles in their stories. The narrators create 'fluid semantic spaces for themselves and narrators use particular grammatical resources to construct who they are' (Riessman (2002, p. 702), cited in Larsson and Sjöblom (2010). The researcher's role is that of an active participant in the dialogue, which does open the process to potential bias.

It was a challenge to interpret interviewees' narratives in such a way that not to change and distort their narratives to suit my own bias. One aspect, as can be seen in one of the sub-headings, was added by the researcher. This is the issue of the three key CA principles. Farmers did not use to speak about "CA", but "NT". The concept "three CA principles[4]", derived from the extensive literature research (paper 1 from this thesis). The interviewed NT and CV farmers talked about "level of soil cover associated with NT" and "no-tillage", whilst "crop rotation" was not explicitly mentioned. The interviewed NT farmers, however, did asses their own crop rotations. The researcher did ask leading questions in that regard e.g. "Do you plant legumes on your farm"? The two case study farmers were practicing NT for a significant period of time (around 2003 and 2004), before this research started in 2010. That is

[4] CA is founded on the simultaneous adherence to three principles: minimum disturbance of the soil, permanent soil cover and sound crop rotations

documented in this paper. The researcher is aware of the inevitable, that the interaction post 2010, between the NT farmers and the researcher had influenced their mutual thinking about NT and CA.

Different authors stated that narratives need to be organized Giovannoli (undated), Riessman (2002) stated in Larsson and Sjöblom (2010); Riessman and Quinney (2005); and Lieblich et al (1998). The layout or structure of the narratives is on the basis of the following points: (a) farm background and farm enterprise details [area, farm segments (i.e. pasture, crop land, veld etc), current crop rotation, stock details, annual rainfall, reason and motivation for adoption]; (b) NT equipment; (c) adherence to the 3 CA principles and a description of what is CA in the case of this particular NT-pioneer; (d) livestock integration; (e) weed control and (f) what is currently different from his previous conventional practices and other farmers?

This paper limits itself to two case studies, although all interviewed farmers deserve consideration. The leading theme is whether CA can be developed by the farmers to such an extent that each farmer's methods can be used as ecotype-specific. The case studies proves the farmers' ability to adopt and adapt to new, more intensive management practices, stating the usefulness of an actor-oriented approach by making use of the narrative study method. This paper describes the case studies of farmer A and farmer B as the 'founders' of NT in the Ladybrand and Zastron areas respectively. The two in-depth case studies describe the process of developing NT.

6. Narratives

6.1. An in-depth study of the Ladybrand no-till founder: Farmer A

6.1.1 Farm background and farm enterprise details

Being the first Ladybrand NT farmer did not go unnoticed. Many neighboring farmers were skeptical about the potential success of NT. Farmer A has been ridiculed, and farmers watched his performance closely. During 2008/9, some local farmers tried NT on some of their fields. These informal trials often failed because the selected fields were far from home and consisted of less productive land. That left Farmer A still alone, whilst battling to find the right solutions for his set of conditions: soil types, monthly rainfall, slopes and location. On the other hand, Farmer A was also a source of inspiration and advice. Numerous farmers have come to see his operations since 2006, but especially after 2010. Farmer A was operating in a predominantly neutral environment, in the sense that many farmers, co-op workers, and seed and fertilizer representatives did not express either skepticism or support. Farmer A had to rely on his own resources to make the new technology work.

The farm ‘Waterfall’ is situated 15km outside of Ladybrand, close to the Maseru Bridge border gate. This mixed farm consists of 600 ha arable land, 300 ha Eragrostis pastures, 200 ha of natural veld and 100 ha of waste land (slopes, marshes). An additional 200 ha is leased for the production of maize, sunflower and wheat. Approximately 80ha of the arable land is under irrigation.

The 35-year old farmer A manages the family farm. His father is the main shareholder and his mother is responsible for administration and management of farm accounts. Livestock includes 250 head of cattle, mainly Santa Gertruida, and 200 head of sheep.

In 2006, a few farmers from Zastron and Wepener went to Australia on a NT tour/excursion. Farmer B, a NT pioneer from Zastron, had organized the trip. Farmer B’s case will be discussed below. Farmer A joined the group as well. The group was exposed to NT farms in Australia across different agro-ecological zones. The group members were impressed by the successes achieved by the Australian farmers in both summer- and winter rainfall semi-arid areas. Australian farmers practiced traffic control on their fields, implying that all equipment (planters, sprayers, harvesters) were using the same tracks, which contributed to reduced compaction. Both tine and disc planters were demonstrated. The group’s time in Australia was a good opportunity for the Free State farmers to network together, to learn, to encourage one another and to explore ideas that they would take home.

Farmer A used to practice summer-maize-winter-wheat rotation with a ten month fallow period in between. Soya was planted rarely and only on small plots. Farmer A occasionally planted sunflowers. Farmer A’s preference is to plant maize between the middle of October and the middle of November, providing that soil water levels are adequate. Maize is not planted beyond the middle of December due to increased risks of sub-optimal yields. Sunflowers can be planted slightly later in the year compared to maize.

The mean annual rainfall for the past 30 years is 760mm. It appears that the annual total rainfall is on the increase. However, rainfall is characterized by high variance and high intensity thunder showers. The long-term rainfall figures are reflected below. Average long term yields for maize, wheat and sunflower are 3.8; 1.5; and 1.5 tons/ha respectively. The main challenges of crop production include the following: fluctuating and uncertain crop prices; lack of spring and early summer rains jeopardizing winter wheat crops and crippling summer crop planting operations; mid-summer dry spells; rainfall use efficiency; lack of skilled workers and declining profitability.

6.1.2 Reason and motivation for adoption

The farm was converted to no-till in the season of 2004. The main reason for conversion was to reduce input costs against an annual fluctuating SAFEX price for crops. The idea of conversion was born after Farmer A came back from a working period in America in 1999. Farmer A was exposed to NT, for the first time, in the USA, and, initially, he thought the farmers were mad. Having an open mind, he inquired: “What are you doing by planting right after harvesting”? That was his first exposure to NT. As he watched the American farmers, he conducted his own research. Once back home, he needed to convince his father, who was still farming alone at that stage. It was a process of persuasion. Being the first farmer in the Ladybrand area to think about NT was unusual, but he had to face several challenges: stigma and ridicule, lack of NT planting equipment, finding the correct types of nozzles, herbicide rates, not readily available glyphosate products and lack of dealers; and a lack of know-how regarding when to spray glyphosate determining optimal spraying conditions.

6.1.3 NT equipment

Farmer A was determined to conduct his own research on NT planters and direct seeders. Being a handy mechanic, he travelled all the way to Kwazulu-Natal, where NT had already been practiced for a few years. He observed how different models of NT planters operated, and he inquired about various options: importing equipment from USA/Brazil; buying secondhand planters from farmers from KZN or Western Cape; buying new planters from KZN or Western Cape; or adjusting and making his own planter(s). After calculating the cost, he decided with the help of a NT engineering workshop to modify his own conventional John Deere planters. He was restricted by a tight budget. He reinforced his own planter and initially bought six manufactured planter units (i.e. to put together a 6-row direct seeder). Planter parts were put together, and the planter was calibrated, ready for use. Currently he has two John

Deere NT-planters which are easy to operate. He replaces the planting tines annually, due to wear and tear.

6.1.4 Adherence to the 3 CA principles and a description of what is CA

When starting NT, Farmer A was not able to implement the three CA principles of minimum disturbance, soil cover and sound crop rotations simultaneously. As a matter of fact, he and other farmers spoke and referred to NT rather than to Conservation Agriculture. Farmer A started to talk about CA rather than NT around 2010. Initially, the advantages of NT were measured in terms of cost savings. The main cost-saving item was fuel and tractor maintenance. Annual diesel-use in liters dropped from 45,000 liters per annum to 10,000 liters per annum after converting to NT - a saving of 78%. Over time, farmer A learnt, through his own research and networks, that NT is not the same as CA.

When using the three main criteria of CA, Farmer A's persistence can be clearly measured. The first CA principle is to disturb the soil as little as possible, which, as practiced by Farmer A, is seen in his John Deere NT tine planter. The tine or cultivator behind the front discs disturbs the soil very little. The tine is important for opening the soil, which creates a small optimal seedbed and ensures good seed-to-soil contact.

The second CA principle is to maintain adequate soil cover throughout the season. Good soil cover is >60-70%; the higher the better. Farmer A has found that building up adequate soil cover is difficult. Crop residues are grazed after harvesting, especially maize and sunflower. Wheat stubble with weeds is grazed by cows as well as sheep. Farmer A initially aimed to maintain a 30-40% residue cover on the fields, which he managed to do, but it was difficult to maintain due to the practice of livestock grazing the crop residues. Another factor inhibiting this principle is the relatively long period during which the land is left fallow[5] after livestock is removed from the fields. Fallow is practiced by Farmer A to harvest and store rainwater and to break pest cycles between crops. Fallow is almost a logical consequence of his summer-

[5] Fallow refers to farm land not being used for planting crops. Crops refer to beneficial biomass. Fallow does not mean that all passes on the land in terms of weed control (i.e. disking or spraying) is omitted. The main reason for fallow in conventional farming systems in the eastern Free State is for water harvesting and breaking pest cycles. The planting of winter crops followed by summer crops on the same land actually result naturally in fallow as for e.g. the summer crop maize's planting window period is gone when the winter wheat is harvested.

maize-winter-wheat rotation, as wheat is harvested after the optimal planting window of October-November.

The third principle is to apply good crop rotations that include legumes (Fowler, 2004) and preferably a minimum of three crops (Kassam et al., 2009). The main crop rotation that Farmer A practiced as mentioned above is maize-fallow-wheat-fallow with additional sunflower resulting in a sunflower-fallow-wheat-fallow-maize-fallow-wheat-fallow rotation. This crop rotation lacked legumes. Soya and cowpeas are summer legumes that are grown in the area. Farmer A did not plant excessive hectares of soya because of the limited market opportunities for soya before 2010; initially, lack of Roundup-Ready soya seed varieties also discouraged him from planting. Cowpeas can be planted, and local varieties are well selected, but it is a local fodder crop with no commercial value.

6.1.5 Livestock integration

Cattle and sheep graze on pastures, veld and wasteland during summer months. The grazing capacity of pastures, veld and wasteland is expressed in animal units (AU) per hectare (ha). Grazing capacity is 1:4; 1:5; and 1:6 for pastures, veld and wasteland respectively. Excess grass is baled and stored in case it is needed to feed livestock during the winter and spring months when feed shortages usually occur. Bales are sometimes sold to predominantly Basotho farmers at R200-R400 per bale, depending on quality. Beef cattle feed on maize crop residues after harvesting in June till September. The ratio for grazing maize residue is equivalent to 1 AU: 1 ha. Sheep graze green feed like oats and, to a far lesser extent, rye or fodder radish during winter and spring months. Oats is normally planted between late February and April each year. Bull calves are sold to feedlots at approximately 260 kg live weight, normally during September or October each year, depending on meat prices. The main challenges regarding the rearing of livestock are predators, fire and theft.

Farmer A hasn't changed his stocking rates before and after conversion to NT. He has decided not to graze wheat stubble any more, but has not built up adequate feed alternatives for all the livestock to take them completely off the maize residue. He started looking into cover crops as a means to increase his soil organic matter contend. His cover crop trials can potentially provide additional feed. He considers expanding feed sources by his three identified cover crop strategies: over-seeding a standing maize crop in Jan-Feb utilizing excess rainfall water, but not jeopardizing the cash crop yield itself. A second option is to direct-seed a cover feed crop like oats after harvesting soya. A third alternative is to replace the bare fallow after wheat with a cover-crop fallow, where the crop might be grazed, but significant levels of organic matter needs to be left behind for feeding the soil.

6.1.6 Weed control

The fields are kept clean from weeds at an average of two Round-up applications of 2-3liter/ha each. Fields are sprayed at an average of 3-4 times annually, depending on the season. Decomposition rates of residues are high in the eastern Free State due to relatively high rainfall and evaporation rates. Farmer A sprays Roundup or a generic glyphosate product just before or while planting Roundup-ready maize. Roundup is normally sprayed twice during the growing season before the height of the maize prevents him from entering the fields with his tractor-sprayers. In order to avoid Roundup resistance, he uses another chemical called 2-4D in the later winter/early spring application. This broadleaf herbicide contains a growth stimulant, which makes the weeds more susceptible to taking up the herbicide, especially in late winter and spring when weed growth is not yet vigorous.

Weed control is important and Farmer A did not see weeds as a contributing strategy to build up soil cover. Weeds can provide a diversity of crops with some subsoil biomass i.e. tap roots of broadleaf weeds as well as root biomass of grass species. Weed control is easiest when weeds are small. The green material decomposes quickly providing no lasting residue. Leaving weeds to grow bigger will increase the chances for weed to flower and potentially set to seed.

Weeds in a wheat crop are also chemically controlled by using Climax.

6.1.7 What is currently different from his previous conventional practices and other farmers?

Farmer A started to think differently about the role of fallow in his crop rotation. He decided to plant fewer hectares to wheat. He started to incorporate more legumes into his crop rotation and moving to a summer maize-soya rotation. His cropping intensity (CI) or agronomic productivity (AP) (Reeves, 1997) increased. The latter is sometimes referred to as land-use efficiency. The CI reflects months with an actual standing crop divided by 36, 48 or 60 for a three, four or five year crop rotation respectively. Farmer A increased the CI from 50% under Wheat-Fallow-Maize rotation to 66% when the bare fallow is replaced with a cover crop fallow.

A maize-soya rotation's CI is approximately 70% and maize-soya and a CI of 83-87% if both maize and soya is followed by cover crops.

Farmer A planted sunflower straight after harvesting wheat in January 2010 – a very unusual practice which is locally referred to as "bankrupt farming". He also started to take out the contour banks. The banks are synonymous with conservation practices from the 1960s until today. Farmer A reckons his water infiltration is so good and run-off so little that he doesn't need contour banks anymore. It is evident that Farmer A did cut down dramatically on all tillage done on the farm. He replied that the staff likes the NT as their working conditions improved: "We no longer work in the dust, and there is less dust on the tractors, and there are reduced costs from repairs and maintenance". He only uses the disc (offset) and ploughs to level down the contour banks. Farmer A is leasing land from neighbouring farmers and always rips these conventional tilled fields deep before starting NT i.e. to remove potential plough plan or hard layers of soil as a result of frequent tillage. Leasing is not ideal as the landlord wants to graze the cash crops residues. This is a sub-optimal situation for good CA practice.

Staff numbers have declined over the years. Lack of skilled workers is a general trend in the region and cannot be attributed to the increase in NT. Reduced tillage requires fewer drivers and Farmer A farms a 1000ha farm with 4-5 assistants. The number of staff declined from about eight to twelve, to about five.

Weed control in conventional farming saw an increased use of herbicides, especially the use of pre-emergent herbicides at planting. In that sense, there is no difference between CV and Farmer A's practice. Farmer A regards himself as a 'beef farmer', but doesn't use the cattle and sheep for cleaning up weeds during fallow. Weeds prior to planting, including fallow, are chemically controlled. He uses livestock occasionally prior to planting to clean up the weeds. This is typically in the case of late spring rains. The reason for grazing is to boost re-growth of weeds through grazing in order to get better glyphosate uptake thereafter.

Farmer A made a switch from NT to CA with an even higher emphasis on maintaining and building up soil cover. His conventional and initial NT crop rotation consists of 2 crops and not ≥3 as the suggested minimum amount of crops made by Kassam, et al. (2009). He adjusted his combine harvesters by adding a spreader at the back so that it spreads the residue cover evenly on the field.

Farmer A deliberately started to build-up soil cover. He is experimenting currently with grass mulch and cover crops. Contrary to conventional and his initial NT practice, he did not allow any grazing after the Dec 2010 wheat harvest.

Although still in an experimenting phase, the cover crops have contributed to increased soil cover as well as weed suppression and added N through biological nitrogen fixation. The soil cover on 31/8/2011 at the end of the fallow period and before the main summer cash crop planting period was 40%, 71%, 57%, 80% and 78% for bare fallow, mix of eight cover crops, cowpeas, grazing vetch and pink seradella respectively. Farmer A is still in the research stage experimenting on relatively small plots, but intends increasing the test plots to ≥ 1 ha.

His rainfall-use efficiency increased. Consequently, he was the only farmer in the region being able to plant in 2011/12 season before good spring rains. Spring 2011 was very dry, and good spring rains only came in December 2011. The winter rains consisted of 11mm, 4mm and 0mm for July, August and September 2011. Farmer A was able to plant maize in October on those fields that were under bare fallow, but not those fields where the cover crops were planted. This confirms the need for timely and sufficient spring rainfall (Sooby et al., 1997; McNee et al. 2008; and Seif and Pederson, 1978). October, November and December 2011 rainfall figures were 17, 18 and 110mm. All the fields, both under bare fallow and cover crops had wet soils at 50cm depth, but the topsoil was drier under cover crops. Farmer A is still testing optimal termination strategies of cover crops.

In the middle of March 2012, Farmer A planted different winter crops into his standing maize that had been planted in December 2011. Farmer A's research is still ongoing, but it indicates his ability to unfold the three CA principles on his farm. This time, Farmer A selected the best performing cover crops that were most suitable for the cold winters: grazing vetch, stooling rye, oats, and fodder radish. Fodder radish does not seem to do well when planted later than April. Farmer A planted initially single cover crops. As time went on he has devised two mixtures: (1) grazing vetch/ oats/ stooling rye/ fodder radish and (2) grazing vetch and fodder radish. This process shows how farmer A developed his own knowledge base, drawn from his observations during the previous season. Farmer A also covered part of his fields with grass. The grass mulch is spread in between the maize at a rate of 2-3 tons ha^{-1}. He is simulating a grass bale chopper that will enable him to chop bales at a faster rate. He considers buying a bale chopper that will cut up grass bales into hay if mulching proves to be successful and economically viable.

Farmer A improved his cropping system from NT to CA. He realized that putting cover crops into his rotation can provide not only fodder for grazing but also extra organic material for increased soil cover. In six years, the initial NT system has improved and he is getting closer to a viable CA system. Initially, the challenges were to obtain good direct seeders and spray-equipment and to obtain information and advice on how to implement NT/CA. These challenges were overcome. Since then, the focus was continually on the question of how to keep on improving the NT system.

Farmer A did experience an initial drop in production of maize and sunflower, whilst wheat remained the same after adopting NT! The slight drop in production did not significantly impact his in-year cash flow. "I was convinced NT worked when I started NT. All my equipment was in place. I had good sprayers and a NT planter. You can't blame NT for the drop in my production. I learned the hard way and I paid my own learning- or "school fees", yes I did, because initially I simply did not have the technical knowledge and the hands-on management. Initially the weed control was bad as I had to determine optimal spraying conditions and timing and application rates".

He had other financial setbacks, but he attributes that to the struggle of producing high yielding wheat crops: "It appears that the spring- and early summer rainfall is too unreliable to finish off a good wheat crop". Currently, he plants less wheat and uses a summer-summer crop rotation of maize-soya. Farmer A has maintained the same acreage and stocking rates from before and after converting to NT. He stated: I consider buying more cattle utilizing, the feed sources better".

Lastly, Farmer A started to view soil differently. He started to compare soil organic levels and is determined to increase the soil cover and consequently the soil carbon. He started to send soil samples to the USA to see the results as per the Albrecht method. This method differs from conventional local sampling techniques as it focuses on soil health, soil mineral correction and soil nutrient balancing. In short, his view on farming has slowly changed from "feeding the plant" to "feeding the soil". Farmer A adopted NT for economic reasons, and although productivity and efficiency are still key words, he became increasingly aware of biological farming principles. Farmer A realized that when farming in a semi-arid region: “water is the key thing to everything”. Farmer A has noticed increased soil life, such as earthworms.

6.2. An in-depth study of the Zastron no-till founder: Farmer B

6.2.1 Farm background and farm enterprise details

Farmer B, living approximately 25km north-east from Zastron. The farms in the area are generally mixed-farming enterprises. This is typical in the dry semi-arid areas, where crops are either planted as feed or livestock feeds on cash crop residues. The farm falls in a semi-arid region with a mean annual rainfall figure of 500-600mm.

Farmer B’s farm is a conglomeration of different farms. The totals farm size is 7,800 ha with an typical stocking rate of 800 head of cattle and 2,500 sheep. Crops are grown as standing feed. The farm consists of 600ha arable land with 250 ha under a summer crop of either maize/ fodder sorghum/ soya/ sunflower and 350 ha under winter feed oats/fodder radish. 400ha is pastures and the 6800 ha is natural veld. Seventy five percent of the natural grass in his area is sour. Farmer B is not in favour of cowpeas because of danger of bloat among sheep. Maize kernels are harvested for being the main ingredient of farm-made pellets. Farmer B intends to start establishing 40% of the arable land under Lucerne as a perennial crop for sheep, from the 2013 season onwards.

6.2.2 Reason and motivation for adoption

Farmer B was confronted with NT by his son Alwyn who has worked in Australia since 2003. Alwyn left South Africa to start working for a Conservation Agriculture (CA) equipment manufacturer. Alwyn became convinced that CA had potential on his own father’s farm. Alwyn was raised on a farm where conventional tillage (CV) was practiced. Farmer B was 64 years old, and was looking for a successor amongst his children on the farm. Alwyn was not interested in conventional ways of farming and insisted that his father review his tillage practices. Eight years later, farmer B has no regrets. Alwyn invited his father and other eastern Free State farmers in 2007 to go on a NT study tour in Australia in 2008. It shows how important global networks are; and it shows how important individual intellectual pioneers are.

Farmer B converted to NT for the following other reasons: cost saving and consequently increased profitability and he was convinced it works. He believed in the system after conducting his own research and saw it work in practice in Australia. His annual input costs reduced with 86% and 80% for diesel and maintenance and repairs respectively. The herbicide use is an additional cost as compared to conventional farming, but the total running and fixed costs, per hectare, have dropped with 68%.

Farmer B did not find the conversion to NT as risky as what others claimed. In fact, his gross margins increased. NT requires more intensive forms of management. An example of this is the management of soil under restoration. During the 2010/11 and 2011/12 season he observed that plant health and growth on fields where NT had been practiced for a 5-8 years were underperforming compared to fields that were no-tilled more recently. Both Farmer B and Alwyn suspected an imbalance between soil nutrients blocking effective uptake of fertilizer and soil nutrients.

Both father and son are open-minded and have conducted expensive soil testing outside South Africa in 2006. They are considering re-testing their soils according the Albrecht system. This is an important shift in thinking. Both father and son started to change from a *ad hoc* fertilizer applying "feed the plant" principles to a more sophisticated soil mineral balancing approach, focusing on "feeding the soil", which will then give the plant optimal nutrition.

6.2.3 NT equipment

Farmer B decided to convert to NT in 2003. He designed himself and manufactured his own NT planter. Another NT planter was put together by his business partner, who got the planter frame from dealers in Swellendam, Western Cape. Swartland and Western Cape are winter rainfall regions in the Cape with a relatively high adoption of NT. NT started in that region 20-years prior than the Eastern Free State. It was good to network and learn from planter manufacturers who already put their experience into practice. The planter's parts were imported from Australia via Alwyn.

It was not easy to convert to NT. His planters were ready to start planting in the summer of 2004. With all the seed and fertilizer in the store he had spare time, whilst waiting for good spring rains. *"When I drove to town (Zastron) I saw all other farmers discing, ripping and ploughing; I thought this whole NT is a mistake… I became almost insane and almost had a* *mental breakdown; ready for psychiatrics…"* Change of mindset is not easy. The biggest challenge of conversion initially was "what to do with my spare time". Farmer B had time available, a luxury which he had never enjoyed before. Farmer B was the first farmer to convert to NT in the Zastron area. Many people queried his 'new' approach to farming. Most farmers were skeptical about NT because it was completely unknown to them and kept an eye on Farmer B' progress.

The first hurdle of equipment, obtaining the direct seeder, was partially overcome. Farmer B and his business partner initially wondered whether to choose a tine or a disc planter. They bought both. He settled for a tine planter, allowing a bit more soil disturbance. The other planter on the farm was a disc planter. Farmer B argued that the soil cover was not ready yet for a disc planter. The soils were always prone to compaction and inclined to crusting after trampling during winter grazing. He believed that a small tine would be adequate, and eight years later he still plants satisfactory with his NT tine planter, although he realized that the disc planter is actually better. Alwyn also recommended the disc planter: "You can hardly see where the disc planter planted" and "in Australia they would call planting with a tine planter conventional". There is more soil disturbance with the tine planter, to such an extent that soils in the plant furrow dry out much quicker after planting.

Farmer B's business partner left and he converted a second conventional John Deere tine-planter. Another second-hand disc planter was bought, which totals up to four working NT planters. Farmer B also assisted neighboring farmers with the conversion of their conventional planters.

6.2.4 Adherence to the 3 CA principles and a description of what is CA

Farmer B' crop rotation under conventional practices was Maize-Fallow-Oats-Fallow (M-F-O-F). He added fodder radish with oats resulting in Maize-Fallow-Oats/Fodder Radish-Fallow (M-F-O/R-F). His farm cropping intensity (CI) or agronomic productivity (Reeves, 1997) was 50-55% when practicing conventional agriculture prior to 2003. The CI improved over time. Farmer B almost completely eliminated fallow, unlike conventional (cash) crop farmers in other areas of the eastern Free State. His cropping intensity is currently at 78%. Farmer B reckons his soils improved extensively under NT. His soils have visually higher water infiltration and improved water-holding capacity. That allows him to plant summer crops consecutively each year. Farmer B improved his crop rotation to Maize-Soya-Oats/Fodder Radish-Maize-Soya-Oats (M-So-O-M-So-O).

Maize is interchanged with fodder or grain sorghum, because it has a better stem-leaf ratio than maize. Sheep prefer fodder sorghum to maize. Sorghum species are in general more drought tolerant than maize. Maize, on the other hand, gives cobs that are harvested and used for farm-made pellets. Oats was often planted in a mix with fodder radish, where the rows were intermixed: 1 row oats, 1 row radish etc. However, Farmer B realized that fodder radish should be planted in February/ March using a disc planter to reduce soil moisture losses. In contrast, oats could be planted with a tine planter in April, as soil water losses are then not an issue due to cooler autumn temperatures.

Farmer B is aware of cover crops, but hasn't over-seeded maize. It poses additional costs and risk against a relatively low annual rainfall figure. Oats can be planted after fodder- or grain sorghum. Farmer B considers harvesting the grain sorghum in March/April for the farm made pellets directly followed by double-row oats drilled into it. Applying glyphosate when the sorghum is 1/3 ripe will speed up the ripening process. A short intensive grazing session is permitted after harvesting the grain before drilling in the oats.

Farmer B's above-ground soil cover percentage before planting the main summer crop is roughly 40-50%. Farmer B always stresses the importance of sub-soil root biomass adding to increased soil quality. Farmer B thinks that he can build up his soil cover to ≥ 70%, but realizes that he needs to destock on animal numbers or find alternative grazing strategies. He is unable to destock at the moment due to unforeseen outstanding debt. Destocking slightly and wisely is something he considers doing after being financially secure again. Alwyn also mentioned that he loves to see all livestock off the NT fields and prefers to convert close to 40% of the arable fields to lucerne and 25% to winter feed (oats/ fodder radish).

Farmer B did not plant legumes as an integral part of any crop rotation before. He used to plant cowpeas occasionally, but concluded that marginal losses could be contributed to bloat on his sheep caused by cowpeas. He tried cowpeas, grazing vetch and seradella again in 2010/11. The cowpeas performed well, but he prefers roundup ready soya. The glyphosate application makes weed control the easier. In 2011/12 he bought local available legumes: velvet beans and Dolichos (lab-lab), to assess and analyze whether these legumes were suitable in complementing his crop rotations. These are two legumes known for vigorous growth in other areas. He wanted to see whether these legumes could diversify the rotation, but also to use the added legumes as potential soil builders, increasing soil cover, as well as testing it on palatability. Both legumes performed on average, but weed control posed a problem just like the cowpeas. Farmer B had planted soya before. He is satisfied with the soya as plant, but learned the hard way, as initially his herbicide program was not geared to accommodate legumes. The residual effect of the pre-emergent herbicide Atrazine used the previous season proofed detrimental for the soya that stunted severely after a good germination.

Farmer B managed to implement NT as one of the 3 leading CA principles, although both Farmer B and Alwyn realized that the disc planters are disturbing the soil to a lesser extent than their tine planters. Alwyn stated: “I haven’t seen good examples of NT in this area”. He believes that this is due to “ineffective weed control, no traffic control on the fields, lack of standing stalks and lack of high performing crops which I think is a result of imbalances of soil nutrients and minerals”. Farmer B is in the process of implementing CA by trying to adhere to all 3 CA principles. The second principle of maintaining permanent soil cover is challenging. Farmer B and Alwyn have started correcting their soils, which they hope would result in improved quality of crops which in turn lead to increased biomass, feed and soil cover. Farmer B’s crop rotation improved over time and the maize-soya-oats rotation is in line with Kassam’s (2009) benchmarking of ≥3 crops in a rotation including a legume.

6.2.5 Livestock integration

The area is known for its relatively low and unreliable annual rainfall (500-600mm) with high evaporation rates. It is common practice in the area is to plant feed crops as standing feed. Farmer B plants maize to harvest the kernels for making his own winter feed pellets. In the past, farmers were able to bring harvested maize to the silos in Zastron, but the latter closed down due to decreased acreage under maize for harvesting. Maize yields are averaging around 3 tons/ha. Maize cash crop production posed increased risks for farmers in the area as a result of increased input prices and low return (loss) on investment.

The area is known as a mixed farming area, but the backbone of income is livestock. Over the last four years, Farmer B stated repeatedly that: “I am a beef farmer”. Farmer B finds it a challenge building up adequate levels of soil cover. Eight years later, it proved to be an ongoing struggle and a constant trade-off. The trade-off is between grazing and limited or controlled grazing. Limited grazing and soil cover build-up is possible in excessive wet years, whilst in dry seasons is soil cover sacrificed to feed. NT requires a different management approach with more variables to create the right balance.

Farmer B is working on an improved whole farm management plan of phasing in newly established pastures of mono lucerne. Livestock can gradually and increasingly be taken off the NT fields as alternative lucerne pastures are established. They are moving to a 10-year crop cycle of 5-6 years of Lucerne followed by maize-soya-oats rotation; after 5 years of grain cropping the fields are planted to Lucerne again.

6.2.6 Weed control

Weeds were identified, by most NT pioneers, as one of the other ongoing challenges. Effective weed control was therefore of utmost importance. Farmer B used herbicides before converting to NT, but figuring out a good herbicide program took a few years. He cleans up fields before or at planting by using a generic glyphosate product. Farmer B applies high levels of glyphosate at 4-5 liters ha^{-1} per pass: "Initially when I started I tried to save costs by applying low rates of herbicides, but I encountered weed resistance to a certain extent. That is why I use a high rate now in order to hit the weeds hard". He applies Roundup or similar glyphosate products 3-4 times a season. He used Atrazine and 2-4D as well. With NT, he realized that he had better windows of opportunity of planting timely. That made him also flexible by planting certain crops at different stages during the summer months. He also learned that he was actually restricted by the choice of herbicides used in the past. The residual effect of Atrazine used in 2008/9 and 2009/10 was detrimental in the year 2010/11 that he planted soya. The germination of the soya crops was good, but had severe growth constraints; to such an extent that Farmer B was forced to re-plant (in this case, with sunflowers), in order to avoid a complete crop failure. Sunflowers were not susceptible to the Atrazine residual effect. Secondly, the planting window of opportunity was running out; it became late to plant. He noticed the stunting among Soya 2-3 weeks after planting.

Farmer B was able to develop a tailor-made herbicide program and he is aware of the danger of potential glyphosate weed resistance. Farmer B and Alwyn realized that their herbicide program is too heavily glyphosate-based. The weed control is linked to the seed varieties they used. When Farmer B started NT, he would 'burn down' a field with glyphosate before planting the summer crop of open-pollinated varieties of maize or sorghum. Alternative he would use 2-4D. This broadleaf herbicide contains a growth stimulant, which makes the weeds more susceptible to taking up the herbicide, especially in spring when weed growth is not yet vigorous. At planting he would apply Atrazine as a pre-emergent herbicide. A glyphosate-based herbicide is sometimes applied just after planting when small weeds appeared again. No weed control is done thereafter. The crop is allowed to mature, grain is harvested for the farm-made pellets, and livestock is brought in to graze the residues. In this system the weeds are not managed during crop growth. The Maize or sorghum had a significant head-start and weeds are not reducing the yield significantly, but are nevertheless allowed to mature and set seed. The weed bank in the soil is growing and is not reduced as required. Farmer B started to test roundup-ready- and BT (stalk borer-resistant) varieties in the 2012/13 season. Alwyn is exploring other selective non glyphosate-based chemicals that can be applied on open-pollinated varieties. Farmer B stated “die *gif-smouse* leer maar saam met ons soos ons aangaan” (the herbicide seller can’t teach us, but learns with us as we go along).

6.2.7 What is currently different from his previous conventional practices and other farmers?

Farmer B started to remove contour banks. He was able to cut out fallow gradually. He consequently was able to increase his farm’s cropping intensity or agronomic productivity with approximately 25%. It used to be 50-55% and it is currently 78%.

Farmer B was able to improve his initial NT system. He gradually moved from NT-CA. Farmer B became increasingly aware of the importance of simultaneously applying all 3 CA principles. He adheres to the principles of minimum soil disturbance and sound crop rotations with ≥ 3 crops, including legumes. He started to incorporate legumes systematically into the rotation since 2010.

Tillage reduced significantly on the farm resulting in huge savings on diesel and repairs and maintenance. Farmer B stated: “I can better utilize the (very) few planting windows of opportunity we get in spring and early summer”.

Alwyn stated “NT exposes your soil deficiencies. These deficiencies are not easily recognized when one is ploughing”. This statement was made after soil sample results came back. Alwyn and Farmer B observed that plant growth and general plant health had declined slowly over the years. All other management practices, such as plant density and plant dates, had remained constant. During the 2012-winter season the oats didn't look healthy at all. Father and son suspected soil mineral deficiencies and nutrient imbalances in the soil. They appointed a contractor to assist with soil sampling and soil mapping. Alwyn requested that all soil-related work should be based on biological farming principles. This thinking matured over the years as the first "alternative" or special soil sampling was done in 2006. Alwyn, who worked in Australia by then, assisted his father by sending the sample to an Australian soil lab. Increasingly, Farmer B and Alwyn began to understand soil as a living organism. They started to apply lime and gypsum in Oct 2012 in order to correct the imbalance and soil nutrient deficiencies. Farmer B started to observe the magnesium, calcium, boron, sulphur and zinc levels in their soils differently.

Staff numbers have declined on Farmer B's farm since 2006. There are currently only eleven workers just as in the past, but the acreage increased as from 2003. The acreage/worker ration increased, although Farmer B believes that this not correlated to NT.

7. Discussion

7.1 NT-pioneers and conventional farmers' views on progress on NT

CA requires a good planter or direct seeder with proper discs to cut through crop residue at planting. In addition, good boom sprayers are needed for weed control. Weed control and a herbicide program was the third biggest challenge mentioned by three out of ten CA farmers. Seven out of ten CA farmers confirmed that lack of NT equipment was the biggest challenge of NT. Equipment is expensive, but it is increasingly becoming more available. CA farmers in the Eastern Free State are also adjusting conventional planters into NT planters at a far lower price than purchasing them new.

Four out of ten CA respondents indicated that lack of know-how, information and support was a problem. Five out of the ten interviewed farmers were exposed to NT through travelling and working in countries with high CA-adoption rates. This is an indication a shift from local to global networks, which will be discussed and elaborated upon in a forthcoming paper in this thesis regarding actor networks. Lack of know-how and information was the second biggest challenge for NT farmers following lack of equipment, which was mentioned by seven out of ten farmers. Farmers were actually financially 'forced' to convert to CA in order to reduce their variable costs and continue farming. CA farmers all report huge savings in fuel use and machine maintenance costs. Farmers anticipated savings on fertilizer and chemicals after establishing legume-based crop rotations because of the biological nitrogen-fixing ability of the legumes and the weed-suppressing effect of the cover crops.

Challenges were overcome in several ways. Four out of ten farmers built their own equipment. Three out of ten farmers obtained their own information, conducted their own research, and learned by doing through trial and error. Two out of ten farmers sold old equipment. It appears that farmers could not afford to build up adequate levels of soil cover, getting ley crops established prior to converting to CA and were not able to reduce grazing pressure on crop residues in order to build up soil cover.

Nine out of the ten no-till farmers converted because of declining gross margins under CV.

The outcome of the interviews with the ten NT farmers reflects the fact that the farmers are knowledgeable actors. It reflects the farmer's abilities to implement no-till despite their initial lack of information, know-how, support and equipment. The interview results reflect the continuous process of knowledge-gathering by the farmers through trial and error as they moved from NT to CA. NT should not be confused with CA, as it is only one of the three CA principles. All farmers are still developing their CA farming systems so that they are suitable for each farmer's specific conditions.

There is no blueprint for CA. CA is ecotype-specific because each farm differs in climatic conditions, soil types, and number of livestock, crop rotations and livestock-grazing integration. Each farm is divided in different ratios of crop land, pastures and natural veld. Farms also differ in their level of financial capital. This research is conducted in a predominantly mixed farming area, in which each CA farmer reflects different strategies on how to incorporate livestock into his or her whole-farm CA approach.

Local conventional farmers' main concern, which they see as a barrier to NT adoption, was that the transition to NT is expensive, especially procuring suitable equipment. Some farmers ageing in the 60's, and close to a pensionable age, did not want to start the 'overhaul' on the farm and rather stuck to the current well-known management practices. Farmers indicated that livestock could not successfully be integrated or combined with NT. Farmers were worried about the anticipated drop in production for the first three years after conversion to NT. Farmers did their own internet-based NT research and were relatively well informed.

7.2 NT differs from conventional ways of farming

Both Farmer B and Farmer A started in isolation without a support network. They were both ridiculed, Farmer A probably more than Farmer B. Such ridicule may have been directed more at Farmer A, who is a relatively young man. Both farmers had alternative networks and ties to Australia and or the USA. Five out of the ten interviewed CA farmers (including Farmer B and Farmer A) learned about NT abroad.

Both case study farmers were able to convert to NT successfully. Neither Farmer B nor Farmer A experienced financial setbacks in the first three years after conversion to NT. Both experienced that yields were more or less the same than before, but that savings on inputs resulted in increased gross margins. Yield decreases were rather contributed to climatic variables and not to NT.

Both called themselves cattle farmers, even though Farmer A appears to be primarily a crop farmer. Both farmers still act in a mixed farming enterprise. Current livestock rates are equal to their conventional rates prior to converting to NT. This shows that livestock can be integrated into cropping despite conventional 'perceptions' that it cannot with NT. Both farmers started thinking of alternative grazing strategies when they reduced the need for crop residue grazing. Examples of alternative grazing strategies are the establishment of legume-based pastures (Lucerne), high impact grazing on and proper fertilization of existing grass pastures, and increasing agronomic productivity by combining cover and fodder crops into the crop rotations.

Both farmers expressed the view that NT requires a different management system with different management variables. Weed control mistakes can easier be corrected under CV i.e. an additional disc action if weed control is not satisfactory. Chemical weed control requires knowledge regarding optimal timing of spraying and spraying conditions i.e. application rates, chemical uptake rates (which differ per season and are weather dependent), residual effect of chemicals and the effect on crop rotation, seed varieties and preventing weed resistance. Both farmers believed that they were able to better utilize the few windows of opportunity as far as planting was concerned. They were both able to get the seeds into the soil more rapidly, whilst CV farmers were more restricted by mud and required pre-planting tillage. Both case farmers were able to improve their herbicide control programs, although it remains learning-in-action.

Over time, both farmers managed to increase their agronomic productivity. That means that there was an increase in standing and growing crops over a five year period. This is a result of assessing their conventional crop rotations. Both farmers reduced bare fallow in the intervals between (cash) crop planting. Both farmers assessed different rotations and both started to test legumes and up-scaling legumes in their rotation. Farmer A started experimenting with different cover crops. Both farmers were able to slowly increase their annual soil cover. Both feel that the soil cover levels are not satisfactory yet, but slow progress has been documented in that regard. Both farmers started to take out the contour banks in their fields which are a trademark for soil conservation measures. Two other NT-pioneers also removed their contour banks.

Both farmers were exposed to alternative soil testing, which reveals a mind shift change regarding the way soil is viewed. Both had soils tested via the Albrecht soil sampling method. Farmer B had soil tested way back in 2006 via his son in Australia and again in 2012. Farmer A also started with soil mineral balancing in 2012. None applied foliar spray or compost tea but both have the attitude of getting the basics of farming right, before experimenting with the finer points of NT.

The structured narratives revealed the farmers ability to adopt NT and to adapt it by finding tailor-made farm solutions. The narratives further reflect the gradual process of the farmers to not only assess but also to adhere simultaneously to the 3 CA principles.

7.3 Adherence to the 3 CA principles is a gradual process.

It became evident to all the NT pioneers that soil cover is probably the leading principle, but also the most difficult one to adhere to. As knowledge about NT grew, so did the NT discourse. Farmers are aware that the three key principles of CA need to be applied simultaneously. However, it needs to be remembered that soils were long exposed to conventional tillage. That backlog and decline in soil quality cannot be rectified with quick-fix solutions. Farmers might think of an initial external source of cover i.e. wood chips or grass mulch. The economics of this will be assessed in a forthcoming paper. The success of NT in other countries is attributed to the role of cover crops (Steiner et al. (2001), Pieri et al. (2002), and Derpsch et al. (2010). More research is needed on cover crops locally.

It needs to be stressed that both case study farmers were seriously trying, depending on their own resources, to start moving towards CA. We need to remember that nine out of 10 farmers adopted NT for financial reasons. All CV farmers stated that although they see the merits of NT they are restricted by cash flow and lack of proof of the profitability of NT. CV farmers cannot afford failure and the ‘NT school fees’ are also paid by the NT pioneers. It is therefore eminent and understandable that the quest for sustainable agriculture is a slow road to progress.

The case study farmers have realized that a shift in mindset also requires thinking differently about investment. Investing in your soil through NT, diverse crop rotations and soil cover have only returns after an unknown period of time. Cover crops pays dividends at a later stage in the form of increased soil organic carbon, higher successive yields and more available feed and soil cover.

7.4 Livestock and NT are hand and glove

Both case study farmers and seven out of the eight NT pioneers incorporated grazing of livestock into their NT-system. It is evident that cattle can be integrated into an NT system. Farmer B emphasized that this requires a different set of management skills with different management variables. It is, however, a constant trade-off between two priorities - feeding the cattle or feeding the soil. This is a difficult question, which can only be answered according to each season, farm and farmer. Seasons differ and accumulation of biomass or organic matter is very dependent on annual rainfall distribution. That makes the management a challenging task, but as Lichtfouse et al. (2010) stated, “Unprecedented changes call for unprecedented thinking”. Unprecedented thinking leads to practical action, which might seem odd or strange to others, although it makes complete sense. Both case farmers stated that they started to do things differently from other farmers. Farmer A planted sunflower immediately after harvesting wheat, which he had never done before. Instead of “bankruptcy”, he had additional cash and feed in the winter months. Flattening contour banks is also something which is “just not done!” In conventional schools of thought, to the contrary contours banks must be maintained and repaired annually. Both farmers' agronomic productivity increased significantly, resulting indirectly in more soil cover or more feed.

John revealed very innovative thinking by gradually lowering his stock. It may well be the case that his overall farm gross margins may even increase by lowering annual stocking numbers due to improved quality of livestock. Farmer A stated the he considered increasing his stocking rates. Anyhow, livestock can go hand-in-hand with NT as we have seen by the two practical narratives. Therefore NT can be promoted in the eastern Free State where mixed farming is the main farming system and livestock the most stable source of farm income.

7.5. The narrative approach shows how farmers ameliorated their "eco-type specific NT" to CA.

The narrative study method is useful. The two narratives, supplemented by views of eight other NT-pioneers, provide insights regarding farmers' ability to not only adopt NT, but also to 'grow' in the system making it more sophisticated. This is what we call the journey to the simultaneous application of all three CA principles: minimum disturbance of the soil, having adequate soil cover and implement sound crop rotations. The narratives are useful, to such an extent that the narratives could be used by other motivated individuals (farmers) (Riessman, 1993 and Lieblich et al., 1998). Both these authors argued that part of the validation of the narratives is that narratives need to be of pragmatic use. This research fulfils that criterion, in that it intends to contribute to the development of local ecotype-specific CA approaches. Giovannoli, (undated) stated that narrative methodology does not lend itself to a standard set of technical procedures. Messick (1987) stated there is some evidence that such reductionism is insufficient even for quantitative research. Consequently, the narratives illustrated how NT was practiced on different farms under a complete set of different variables i.e. annual rainfall, soil types, and farming systems. The narrative approach is useful as it provides practical insight about NT application at farm level.

Narrative-thinking can have a positive spin-off on policy formulation. It suggests educational rather than mandatory strategies. This corresponds with the conclusion of Alkon and Traugot (2008). South Africa does not have a Conservation Agricultural policy. Lessons from this paper can be taken into account regarding future policy are the ability of actors to find solutions site-specifically. The NT pioneers mentioned in this paper and other stakeholders need to be consulted and 'requested' to be part of that educational process of policy formulation.

7.6 Unsupportive networks and further research on Actor-Network Theory

It became evident that all NT-pioneers, including the 'narrative farmers', were able to start with NT and in most cases were even able to make it more sophisticated. They all adopted NT amidst a predominately neutral, but unsupportive network. Examples of this environment included factors such as the lack of agricultural extension and research; lack of local data, scientific trials and examples; the main finance-providing agencies and input suppliers provide no information on NT in their publications, flyers or websites; and neighboring farmers were often skeptical.

The NT-pioneers managed to overcome the lack of technical knowledge in different ways. Their avenues included internet research, engagement in alternative networks far beyond the local area, reading agricultural magazines and through mutual learning by initially visiting one-and-other.

This networking and flow of knowledge and information will be discussed in detail in a forthcoming paper, from the theoretical perspective of Actor-Network Theory (ANT). This approach, with its roots in sociology and technology, explains the update of NT from a network point of view where existing networks become redundant and new hybrid networks are formed.

8. Conclusion

The success of Conservation Agriculture is most evident when all CA three principles are applied simultaneously. This proved to be a process with building up soil cover the most challenging principle. Minimum disturbance of the soil is widely adhered to, although most of the NT planters in the area are tine planters. Farmer B's narrative showed that disc-planters actually have the least impact on the soil whilst conserving precious soil moisture levels more effectively. Both narratives showed a change in crop rotations with ≥ 3 crops including legumes.

The narratives, complemented by the interviews with the eight other NT-pioneers, reflected the farmers' journey from NT to CA. NT farmers can step up more speedily if more research, extension and services are made available to the farmers. The NT farmers started to farm differently as compared to their conventional peers. This might be viewed as unprecedented. Examples of this are cutting out bare fallow, removing contour banks, double cropping & crop intensification, planting large areas to cash crop legumes, reducing crop residue grazing, establishment of legume-based pastures, and paying for expensive alternative biological soil testing.

The CA farmers' experiences and innovative thinking proves that, despite the challenges of lack of technical knowledge, lack of implements, a lack of institutional support, stigma, critical and skeptical peers, different solutions were found. The NT-pioneers conducted their own research, made inquiries, obtained information, bolstered their own morale, and created new networks. In the process they got tired of convincing conventional farmers and stopped trying to justify their change in farming practices to them. NT-pioneers started to modify and adapt their own planters, fine-tuned chemical weed control programs and started to view soil differently. The current leading barriers to the adoption of NT, as mentioned by conventional farmers, were refuted. Both narratives addressed the barriers to adoption of NT. The transition to NT was not as expensive and risky as perceived. Costs are minimized when farmers adjusted and modified their own NT-planting equipment. The NT-pioneers had huge savings on diesel and related running costs. Livestock can successfully be integrated or combined with NT. Farmer B did not experience a decline in production for the first three years after conversion to NT, but Farmer A did, due to his need to figure out a new weed control programme. Soil compaction due to residue grazing did not seem to be an insurmountable problem. NT can be promoted as a sustainable alternative in the mixed farming context of the eastern Free State.

The two narratives contributed to finding eco-type specific CA strategies. The two narratives provided site-specific alternatives to conventional ways of farming. The documentation of the farmers' stories also proves the usefulness of sociology in designing agro-ecology and defining 'sustainable agriculture'. It proves that answers, opposing the adverse ecological effects of conventional agriculture, should include several related disciplines that rule agriculture. CA-trans disciplinary research should therefore include input from sociology, ecology, economy and political sciences beside the classical agro-sciences.

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PAPER 3:

ECONOMIC AND ENVIRONMENTAL SUSTAINABILITY OF DIFFERENT CROP PRODUCTION SYSTEMS IN THE EASTERN FREE STATE

Abstract

This paper reflects a comparative assessment measuring the economic and environmental sustainability of various production systems. This paper modeled four crop rotations under conventional farming (CV), No-tillage (NT), Conservation Agriculture with cover crops (CC) partially-(2-4 years out of 7) and fully (every year) incorporated and lastly Organic Conservation Agriculture (OCA) over a period of 7 years. The rotations modeled were: 1) M-W-M-W-M; 2) *M-S-M-S-M-S-M*; 3) S-M-SF-S-M-SF-S and 4) *M-S-W-S-M-S*. Twenty nine alternative rotations were also modeled referring to NT alternatives including ley crops and cover crops. The comparative assessment compared the tillage systems on multi objectives: profits and gross margins, adherence to 3 CA principles, cropping intensity (agronomic productivity), risk, herbicide resistance potential, soil cover build-up qualities, crop diversity. Direct and indirect environmental costs were assessed in terms of the use of diesel. In addition, indirect environmental costs are also assessed in terms of the use herbicides, pesticides, and fertilizer per hectare over the modeled 7 years. The profitability of the production systems increased as cropping intensity (CI) increased. The rotations with wheat had the lowest CI. The maize-wheat rotation is not a profitable crop rotation in the EFS of South Africa irrespective the tillage system used. CA with CC grazed (graze gain) has the highest GMASC ha^{-1} 7yrs. NT has the highest GMASC when CC graze gain was omitted from the CA rotations for all three other remaining crop rotations 2) *M-S-M-S-M-S-M*; 3) S-M-SF-S-M-SF-S and 4) *M-S-W-S-M-S* modeled. NT also has the highest indirect load to the environment in terms of greenhouse gases (GHG) by the use of fertilizer, pesticides and chemicals. Cover- and ley crops feature strongly in defining sustainable agriculture. The economic and environmental sustainability assessment was done on the 3) S-M-SF-S-M-SF-S rotation. Organic CA, CA with ley and CC rotations and CA_{LE} with 100% cover crops i.e. double cropping every year are economic and environmentally the most sustainable. CV is not sustainable because of continues tillage, lack of soil cover and high diesel use and consequently high load of direct and indirect GHG. Conventional NT is not sustainable due to scoring lowest on this sustainability assessment. NT had highest use of chemicals and consequently highest load of indirect GHG and increased risk of herbicide resistance followed by CV.

Keywords: environmental impact, gross margins, cover crops, ley crops, CA, sustainability

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1. Introduction

Agriculture can be a sustainable activity, but then the concept of 'sustainability' should transcend production systems (Dore et al., 2011). Cropping systems then need to be productive, profitable, gaining financial returns, environmentally friendly, efficient in its use of nutrients, socially acceptable and not compromise the ability of the ecological system to sustain productive capacity. Agriculture should have several objectives simultaneously. Omer et al. (2005) refers to this as the multifunctional nature of agriculture. Such agricultural systems can best be achieved by making better use of biological regulation mechanisms (Dore et al., 2011; Omer et al., 2005). Cropping system diversification could promote ecosystem services that could supplement, and eventually displace, synthetic external inputs used to maintain crop productivity (Davis et al., 2012). The ignoring of biological interactions is actually causing the artificialisation of agriculture (Dore et al., 2011).

An extensive literature shows that Conventional farming methods (CV) are not sustainable. Conventional crop production systems are characterized by low species and management diversity, high use of fossil energy and agrichemicals, and large negative impacts on the environment (Davis et al., 2012). South Africa's soils in general are degraded, poorly balanced in nutrients and over-utilized; have high weed pressure, are low in organic matter (Mills and Fey, 2003; Burger, 2010). Without heavy chemical fertilizer applications, good crops yields are generally not possible (Govaerts et al. 2009, p. 117 and Reeves, 1997, p. 132). Different authors state that the effects of soil erosion and land degradation are a result of tillage (Decker et al., 2011; Mills & Fey, 2003; Le Roux et al., 2007; Compton et al., 2010; Derpsch et al., 2006). Land degradation comes at a cost. Annually, South Africa loses approximately 400 million tons of soil through water erosion (Scotney and McPhee, 1990) not even to mention losses to wind erosion. These erosion losses pose additional risks to the viability and profitability of farming systems. South Africa is currently moving towards larger and more intensive farms (DAFF, 1995), but the real costs of agricultural production and the negative impacts of intensive farming methods on the environment are not being reflected in the input costs (WWF, 2010).

No-tillage (NT) is practiced world-wide to counter the soil degradation effect under CV. Conservation Agriculture (CA) is a more encompassing concept, and refers to the improvement of the initial NT production systems. CA is practiced with three guiding principles in mind, which act as stepping stones when converting from CV. CA is the implementation of the following three principles: minimum disturbance of the soil, year round soil cover and sound crop rotations by utilizing legumes. Kassam et al. (2009) recommended that crop rotations using less than three sequential crops should not be called CA. CA also encourages the promotion of plant diversity, increased biological regulation functions, and risk minimization. CA encourages a production system that is not only ecological sustainable but also economic feasible and socially acceptable.

NT in this paper is defined as the adherence to the first principle of disturbing the soil as little as possible. NT refers to soil disturbance up to 20%-25% (Govaerts et al., 2009, p. 98) by using tine- or combination tine and disc planters. NT is not the desired final outcome for CA proponents (Govaerts et al. 2009:113). Govaerts et al. (2006:172) and Zanatta et al. (2007:517) argued that NT without soil cover and good rotations may score lower on soil quality indicators as compared to CV. This paper argues that CA is not the same as NT, although they are often regarded as identical. Moyer (2011) refers to NT without cover as “conventional NT”, which should be distinguished from proper NT or advanced NT.

Conventional crop farming is labour-intensive and has become uneconomical due to rising diesel prices and increased minimum wage levels. CV relies heavily on tillage i.e. land preparation, planting and weed control. Many eastern Free State farmers have started to reduce tillage in their crop production systems. In contrast Minimum tillage (MT) or reduced tillage (RT) and NT involved less tillage but require an increased use of herbicides for weed control (Moyer, 2011). NT is therefore not regarded as an environmental friendly practice by Gattinger et al. (2011). Gattinger et al. (2011) pointed out some environmental side effects of NT: groundwater pollution due to increased herbicide use; herbicide resistance in weeds; adverse effects on terrestrial wildlife; direct toxicity effects on human health as a result of increased herbicide use, and the use of genetic modified food crops. Gattinger et al. (2011) also doubted NT’s ability to reduce carbon dioxide (CO_2) through carbon sequestration, nitrous oxide (N_2O) and ammonia (CH_4) emissions. An interesting issue is the role agriculture can play reducing that total of 440m tons of greenhouse gasses (GHG) emitted annually, given South Africa’s position as the worlds 13th biggest GHG polluter (Standford, 2013). There has, however, been a notable reduction in fossil fuel use in agriculture worldwide (Gattinger et al., 2011, Moyer, 2011).

Cover crops are arguably the main factor for the world-wide success of CA (Derpsch et al, 2010; Steiner et al., 2001, Pierie, 2002, Moyer, 2011, Uchino et al., 2009). Cover crops enhance soil protection, soil fertility, groundwater quality, pest management, soil organic carbon concentrations, soil structure and water stable aggregates (Govaerts et al, 2009). Cover crops are crops also grown for increased soil cover (see paper 1 and 4). Permanent soil cover with a thick layer of mulch has been a key factor for having success in NT in Latin America (Derpsch, 2001). With few exceptions, the need for crop rotation becomes more critical with CA than with CV (Reeves, 1997, p. 158). Cover crops can be planted as a single crop (Moyer, 2011) but they are more often found in mixes (Tonitto et al., 2006).

Cover crops do not refer to a standard or generic application. It entails a whole management system of (i.e. winter hardy) crops representing small grain, leguminous and Brassica families. Cover crops refer to inter-seeding or over-seeding of maize by small aero planes; direct seeding after soya and or sunflower; cover crops replacing bare fallow (applicable in M-W rotations); and cover crops replacing a cash crop (Sabbath year).

Double cropping under CV is not possible in the eastern Free State and is locally referred to as ‘bankrupt farming’. Double cropping is, however, possible with the increased soil water conservation associated with CA (Govaerts et al., 2009:111, Govaerts, 2007, Sommer, 2007 and paper 4 of this thesis). The most promoted cover crops, for divergent reasons, are: oats, (stooling) rye, grazing vetch (Eash et al., 2011, Murungu et al., 2010b), fodder radish and fodder sorghum (Kirchman and Marstop, 1992 and Wolfe, 1994, 1997) or mixes of oats/grazing vetch (Murungu et al., 2010a, Zanatta et al., 2007 and Bayer et al., 2000) or (stooling) rye/grazing vetch (Ritter et al., 1998, Sainju et al., 2002, Ding et al., 2006, Ngouajio and Mennan, 2005, Nyakatawa et al., 2001 and Sisti et al., 2004 (both mentioned in Govaerts et al., 2006)). Oats and (stooling) rye are included in the CC-mix for its ability to free phosphates and potassium, N-scavenging and provision of lasting residues. Grazing vetch is included in the mix for its potential ability to high N-fix values (Murunga et al., 2010b), aggressive growth and weed suppression traits (Eash et al., 2011). Fodder radish, although far less reported on, is included in the mix because of its deep pen root and sub-soiling qualities (Williams and Weil, 2004), its tendency to alleviate soil compaction (Williams and Weil, 2004), its ability to scavenge N (Kremen and Weil, 2006), to free phosphates and potassium, to suppress weeds (Haramoto and Gallandt, 2005) and to provide a good feed source.

This paper argues that there are several advantages of cover crops recorded from other sites i.e. sites not in South Africa: increased soil carbon buildup (Metay et al., 2007, Bayer et al., 2000, Metay et al., 2007a); suppressing weeds (Eash et al., 2011, Uchino et al., 2009, Ngouajio and Mennan, 2005, Czapar et al., 2002 and Pieri., 2002); addition of N through biological nitrogen fixation (Tonitto et al., 2006); reduction of N-losses (nitrate leaching) (Tonitto et al., 2006, Ritter et al., 1998) and reduction of P losses (Kelly et al., 1996). Tonitto et al. (2006, p. 58) illustrated that leguminous and non-leguminous cover crops can be successfully incorporated into cropping systems to maintain cash crop yields while reducing leaching of inorganic fertilizer by up to 50%. Other recorded advantages of cover crops are: reduced stalk borer attacks (Chabi-Olaye et al., 2005) and reduced erosion (Kelly et al., 1996, Czapar et al., 2002, p. 507, Ritter et al., 1998, p. 2, Ngouajio and Mennan, 2005, p. 522).

Ley crops refer to an area of land where grass is grown temporarily instead of crops during a short-term period. This paper also refers to land planted with a perennial legume, or mix of legumes, or mix of grass and legumes, fulfilling the same role (Fair, 2008, Donald, 1981 and Halse, 1989). Ley crops are a key component of sustainable farming (Heitschmidt, 1994) and contribute to ecological intensification in agronomy by making better use of biological regulation mechanisms (Dore et al., 2011). This illustrates that that biological mechanisms are able to replace chemical or physical inputs (Moyer, 2011), or to interact favorably with them, playing the same agronomic role without external costs, including environmental costs in particular (Dore et al., 2011).

The main reason for including a ley (grass) crop is the build-up of soil fertility (Reeves, 1987 and Donald, 1981), soil organic matter (and consequently soil organic carbon), improved water infiltration, water retention, soil restoration (Reeves, 1987), less tillage and tractor passes (Harris et al., 1966 and Heitschmidt, 1994, Ch.2) less herbicide use (less GHG emissions) and profitable inclusion of livestock (SAN, 1998). Ley crops can contribute to increased cropping diversity and at the same time balancing productivity, profitability, and environmental health (Jannasch et al., 2002). Cover and ley crops increase cropping diversity and contribute to weed and pest control reducing the need for herbicides and pesticides (Moyer, 2011). CA improves the soils water characteristics (Reeves, 1987), which reduces the vulnerability of this semi-arid region to erratic rainfall (O'Farrell et al., 2009) and consequently lack of available soil water.

Knowler and Bradshaw's (2007) concluded that CA should be tailored per specific area. CA is ecotype specific, context dependent, seasonally variable and a constant tradeoff of simultaneously balancing adherence to various divergent sustainability objectives. Govaerts et al. (2006:99) stated the conversion from CV to NT and or to CA as a gradual or step-wise process. If was to be reflected as a process, culminating in organic CA (OCA) or organic NT as the final destination (Moyer, 2011). Gattinger et al. (2001) argued that efforts should therefore be strengthened to combine sustainable production systems such as organic agriculture with no-till practices. Organic NT combines the best of NT and organic farming (Moyer, 2011 p109).

The wayside stations on this journey are then minimum tillage (MT), NT and $CA_{CHEMICAL+ (High External Inputs)}$ and $CA_{(Low External Inputs)}$. The MT station maybe skipped. Rising diesel prices, however, makes it more economical for farmers to cut out tillage and to incorporate herbicides, at least partially. Different reasons determine the length of the intermediate phases in the transition to CA. The availability of the length of stop-over is determined by availability of equipment and finances; level of know-how and -information and management; and the level of (network) support from various stakeholders.

The ultimate form of conservation agriculture is organic CA. In order to achieve this several milestones should be reached: the use of artificial inputs should decrease; biological farming principles should increasingly be adopted; and cover and ley crops should be included. The inclusion of legumes and cover crops (CC) into the crop rotation are beneficial for increased environmental quality, but also for increased net returns (Zentner et al., 1992; Neto et al., 2010; Kelly et al., 1996).

A decrease in the use of synthetic fertilizer is possible to such an extent, that it can eventually be totally eliminated (Davis et al., 2012). Sanford et al. (1995, p. 1441) concluded that nitrogen fixation (kg N ha^{-1}) was significantly correlated to legume dry matter yield (DM) (kg N ha^{-1}). Unkovich and Pate (2000) developed a regression between the nitrogen fixation (kg N ha^{-1}) rate of subterranean clover and its aboveground biomass yield (kg N ha^{-1}) as N-fix = 0.016. Basically it means that the dry matter content of the legume per ha is multiplied with 0.016. This implies that some legumes, whether as cash crop or as cover crop (soya, grazing vetch, clover, sainfoin etc), can have more or less nitrogen fixed than 30kg N ha^{-1}. Peoples et al. (2001) reported the N-fix ability of grazing vetch to be between 72-160 kg N ha^{-1}. This is correlated with the plant biomass ha^{-1}, which can differ from year to year. The N-fixing rate for soya, Lucerne and Sainfoin in this model are conservatively assumed to be 30, 64, and 54 kg N ha^{-1}, respectively. Just as synthetic fertilizer can be eliminated, so can pesticides and herbicides be reduced.

Ample literature is available comparing NT and CV and various variants of technical and agronomic aspects. Little research has been done about comparing tillage or production systems on environmental costs in terms of greenhouse gasses (GHG). What is more sustainable in that regard? What inputs i.e. diesel, fertilizers, pesticides or herbicides contribute most to direct and indirect GHG under different crop production systems? Is NT merely a substitution in inputs i.e. replacing the savings in diesel with increased use of chemicals and would their impact on GHG be similar? There is lack of local research data on sustainable agriculture. CA, in fact any crop production system, is ecotype specific. More research is also needed on the impacts of changing weather patterns on agricultural production i.e. unreliable and highly variable rainfall, early and late (freak) frost periods and 'delaying' of seasons. Apparently the seasons in the eastern Free State are not stable anymore. It seems that the rainfall which always used to fall in September/October is now delayed till November/December, which needs adaptation of farming systems to climate change. This poses a serious threat to food security and agric sustainability. This paper intends bridging several disciplines (see other papers in this thesis), increase data on the Eastern Free State and contribute practically to encouraging sustainable agriculture. A further purpose of this paper is to find answers addressing local barriers to the adoption of NT, by providing data of livestock incorporation with NT-systems and NT in mixed farming enterprises. This paper also intends to provide information which would reduce farmers' perceived risks when converting to NT. It will also provide profitable options regarding cover crops.

This paper reflects a comparative assessment measuring the economic and environmental sustainability of various crop rotations under different production systems. According to O'Farrell et al. (2009), farming strategies need to ensure better financial stability, by addressing the constraints. Farmers need to adopt agricultural systems that are economically and environmentally sustainable. The crop rotations used as on an experimental basis for this paper, were assessed on profits, adherence to the three CA principles, cropping intensity (agronomic productivity), risk, herbicide resistance potential, soil cover build-up qualities, and crop diversity (number of crops & legume ratio). Different seven-year crop rotations were modeled under CV, NT, NT cover crops (CA) and OCA/ONT, assessing both increased GMASC and decreased environmental costs. Direct and indirect environmental costs were assessed in terms of the GHG, as based on the use of diesel. In addition, indirect environmental costs were also assessed in terms of the use herbicides, pesticides, and fertilizer per hectare over the modeled 7 years.

2. Methodology and procedures

Economic modeling is based on the local crop rotations with local adapted crops. This modeling is done by constructing an Excel-based model with input costs and prices based on fixed 2012 costs. Different crop enterprise budgets are collated. Crop income is derived from Waterfall farm's crop yield history multiplied with 2012 SAFEX-related product prices that the Waterfall farmer received for the crops in 2012. This farm models the idealized situation. This farm was chosen as it is currently the only mixed farming enterprise in the research area that passed the NT stage with inclusion of cover crop testing. It can be representative for the area as the farm covers the main crops grown in the Eastern Free State (i.e. maize, sunflower and soya) as well as livestock (i.e. both sheep and beef cattle).

The fixed costs of seed, fertilizer, and transport are used and documented below. The variable input costs were obtained from different sources. Mechanization cost (diesel and repair costs) were based on the local co-op OVK's input model. Labor figures were derived from minimum wage requirements divided by the farm's 1600 ha to get a labor price per ha. Pesticide and herbicide figures were obtained from Waterfall's used rates and based on an average of 2012/13 prices from one local supplier.

2.1. On-farm figures

The application of the three CA principles is ecotype-specific and may vary significantly from one ecotype to another. There are no rigid prescriptions to implement is CA, but farmers are guided by the three key principles and apply it under their own set of unique conditions, management style and farming system. Figures in this paper are therefore used, modeled and applied from one farm: Waterfall. This is a mixed farming enterprise where farm income is derived from livestock and crops allowing cattle to graze cash crop residues. The grazing of cash crop residues did not receive a monetary value in this paper as other alternatives are offered reducing the need for crop residue grazing.

This paper projects figures assisting Waterfall with the growing of NT into CA, by focusing on the improvement of two of the CA principles: increased soil cover and sound crop rotations. No-till planting- and basic spraying equipment has been bought previously as well as a highboy self-propelled sprayer in 2011. No repayment costs are calculated into the model. Different 7-year-period crop rotations under NT and CA are depicted. It starts with Waterfall's conventional maize-fallow-wheat-fallow rotation and other crop rotations are projected. The majority of summer planting remains maize. This paper analyses whether no-tillage and CA as an innovation can be profitable and risk reducing. The different crop rotations are assessed on profitability, crop intensity (agronomic productivity), legume ratio, crop diversity, soil cover building ability, potential contribution to herbicide resistance, perceived riskiness, and environmental cost.

An Excel-based model is used to determine ~~highest~~ gross margins above specified costs over a period of seven years. Prices and costs are based on 2012 figures derived from the local co-op OVK input model (OVK, 2012) and seed suppliers. OVK 2012 input model has been partially used determining the different crop enterprise budgets (CEBs).

2.2 Mechanization rates and costs

The following CEBs are based on Waterfall's figures by using the OVK input model prices. Fuel cost and repair & maintenance (R&M) costs are based on selecting tractor size (Kilowatt) and type of mechanization action (passes). Repair and maintenance include both the actual maintenance as well as depreciation and replacement costs (i.e. variables such as life expectancy, annual usage, purchase price, salvage value, depreciation, license, insurance, and interest). The following rates were used in the model under NT and CV.

Table 2: Mechanization costs and maintenance and repair rates for NT and CV: Waterfall farm

NT			CV		
Technique	Liter ha^{-1}	M&R, R ha^{-1}	Technique	Liter ha^{-1}	M&R, R ha^{-1}
NT planting	5.61	R140.52	Mechanical weeding	3.57	R27.40
Spreader	1.78	R10.56	Plowing	13.73	R101.20
Spray action	0.88	R34.98	Deep rip	15.87	R95
Planting ley crop (compacting it with tractor wheels)	6.16	R73.90	Deep rip (chisel)	12.50	R58.20
Aerial seeding		R600[1]	Disking	5.46	R53.30
Trailer	0.10	R2.50	Chisel plough	7.55	R61.10
Harvester (wheat)	23.17	R122.30	Shallow tine	5.21	R40.80
Harvester (maize, soya, sunflower)	33.24	R166.40	plant	5.61	R140.50
			Trailer	0.10	R2.50
			Harvester (wheat)	23.17	R122.30
			Harvester (maize, soya, sunflower)	33.24	R166.40

Key: [1] Aerial seeding is assumed at 30 liter ha^{-1} which equals 48 liter of diesel ha^{-1}. A straight cost of R600 is used in the model for aerial seeding

(Source: OVK, 2012)

2.3 Fertilizer types and rates

Different crops require different fertilizer rates. The most appropriate or best fitting type of fertilizer for the N:P:K demand in kg ha^{-1} was used.

Table 3: Fertilizer costs as well as kilogram ha^{-1} is included in the individual CEBs and environmental cost assessments under both CV and NT

Crop	Type	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Price ha^{-1}	Total kg fertilizer ha^{-1}
Maize	6:2:1 (32)	70	14	7	R969	197
Sunflower	6:2:1 (32)	50	7	3	R484	98
Soya	2:3:4 (34)	7	10	14	R1,041	100
Wheat	4:1:1 (32)	30	8	8	R713	150
Eragrostis Teff and Smuts finger grass (yr 1-3)	LAN	50	-	-	R643	179
Lucerne and Crown Vetch	KCL/DAP	-	30	50	R2,316	248
Sainfoin	KCL/DAP	30	30	50	R2,354	259
Cover crops replacing bare fallow and main cash crop	6:2:1 (32)	20	6	6	R415	84

Note: other cover crops (i.e. over seeding maize or direct seeding after soya or sunflower) did not receive fertilizer. (Source: Waterfall farmer, personal communication)

The mix Sainfoin and Smuts finger grass was planted on the same day. The fertilizer, lime and Smuts fingergrass was spread and rolled by driving the tractor up and down. Sainfoin seed was drilled directly into the soil at 90cm width.

Cover crops mixtures (oats/grazing vetch and fodder radish) were directly seeded without fertilizer following soya and sunflower. Cover crops were cast (aerial seeded) into standing maize without adding any fertilizer.

This cover crop replacing a cash crop refers to the planting of fodder sorghum in October/November. The fodder sorghum was grazed at about 1.2 m allowing the winter cover crop mix to be directly drilled into the soil allowing the re-growth of fodder sorghum. Kirchman and Marstop (1992), and Wolfe (1994, 1997) reported that one cutting of sorghum stalks at 0.9-1.2 m resulted in an increased root mass of 5-8 times compared to unmowed stalks and forced the roots to penetrate deeper. The winter cover crop mix of oats/grazing vetch/ fodder radish was direct seeded into the standing crop in January/February. The fodder sorghum died off after first frost, whilst the winter cover crops continue growing.

2. 5 Herbicide & pesticide types, costs and rates

A pre-emergence herbicide was only used for planting maize and not for sunflower, wheat or other crops. A mixture of Gardomill and Dual was used as a pre-emergent herbicide at rates of 2.7l and 0.60 l ha^{-1} at R67.50 per liter and R190 per liter respectively. Karate as a pesticide for the control of stalk borer and cut worms was added at a rate of 0.8 l ha^{-1} at R250 per liter. This mixture of Gardomill/Dual and Karate was applied on row at planting, resulting in approximately 40% per hectare applied.

A mixture of 2-4D/glyphosate and herbiboost was applied when cleaning the fields pre-planting. 2-4D was omitted when applying post emergence glyphosate-based chemicals on the round-up ready soya and maize cultivars. This was done at a rate of 3l ha^{-1} at R42 per liter for glyphosate and 1l ha^{-1} at R25 per liter for herbiboost.

Colmax and Eurolightning are chemicals used for the post emergence weed control in wheat and sunflower respectively. Colmax mixed with 2-4D was applied at rates of 20gr and 250ml ha^{-1} at the cost of R240 (per 200 gram container) and R75 per liter, respectively. Eurolightning was applied at 1l ha^{-1} at a cost of R250 per liter. Cysure and Fusalate were chemicals applied with the planting of Lucerne. Both chemicals were applied at 1.2l ha^{-1} at R377.19 per liter and R225.27 per liter, respectively.

2.6. Labour rates

The non-allocable (overhead) labour costs are modeled under CV and NT, as equal on this farm. The direct allocable labor rates used in this model are based on the minimum wage of R2,275 per month. The model incorporates 10 workers under CV and 5 under NT/CA. The total labor cost (i.e. 13 months x R2,275 x #workers) is divided by 1500ha of total farm land. The annual cost of casual labor of R99 ha^{-1} and R197 ha^{-1} is modeled for CA and CV respectively. Conventional farming operations require significant levels of mechanization which explains the higher labour costs. Labour figures are projected annually and not debited per crop enterprise budget.

2.6. Crop Enterprise Budgets for the different crops used

All crop enterprise budgets (CEBs) reflect the same seed cultivars (except maize) and same fertilizer rates. Interest of 12% was calculated on the cost enterprise budget amounts such as seed and fertilizer. The cash crops maize, sunflower, soya and wheat have added alternative costs like insurance, transport and price hedging. The other variable costs like herbicides, pesticides, diesel, repair & maintenance and casual labour are not reflected per year per crop, but rather as a total over the 7-year projected periods. This is done in order to calculate one of the key variables proposed in this paper: decreased external inputs per crop. All costs used in the model are based on the 2012 figures.

The fuel price (l) in 2012 was R11.2 per liter.

2.6.1 Maize

The seed used for NT was a genetically modified variety or the so called Round-up Ready seed from Pioneer, whilst CV used a Pioneer BT-hybrid. The prices of the RR and hybrid variety are modeled as equal at R1092/ha^{-1}. Maize yield increased due to increased cover from cover crops and added nitrogen in the soil from following a legume.

Table 4: Modeled maize yields

Nr.	Maize yields (t ha^{-1})	Description of maize yield or maize following certain crop
1	3.5	Yield under conventional agriculture, long term average for Waterfall
2	2.6	Estimated yield (no references) under OCA
3	4.19	Yield of maize under NT
4	4.96	Maize following a cover crop after wheat (replacing bare fallow
5	5.89	Maize following a cover crop after soya
6	5.95	Maize following a cover crop after Lucerne
7	6.04	Maize following a cover crop after legume-based pasture
8	6.68	Maize following a cover crop after legume-based pasture and consecutive years of soya,
9	6.02	Maize following a cover crop after legume-based pasture and consecutive years of Sainfoin

(Source: own analysis)

The maize yields were modeled as seen in Table 3:are 4.19, 4.96, 5.89, 5.95, 6.04, 6.68 and 6.02 per hectare for NT maize, maize following a cover crop after wheat (replacing bare fallow), soya, Lucerne, legume-based pasture, legume-based pasture and consecutive years of soya and Sainfoin, respectively. Maize yields under OCA were 3.08 and 4.50 t ha^{-1} following a cover crop and soya respectively. The price per ton was R1,780 for NT, CV and OCA. The price per ton of organically produced maize remained the same due to lack of current organic markets in the area. Maize seed, fertilizer, insurance, transport and hedging cost under NT and CV were R1,092, R969, R320, R340 and R280 per hectare respectively. Maize seed, insurance and transport under OCA was R368, R400 and R270 per hectare respectively.

Table 5: Production costs of NT, CV and OCA respectively, for maize production

Item	NT	CV	OCA
Maize seed Roundup-ready seed for NT, Hybrid for CV and open-pollinated for OCA	R1,092	R1,092	R368
Fertilizer	R969	R969	-
Insurance	R320	R320	R400
Transport	R340	R340	R270
Hedging	R280	R280	-

Key: variable costs i.e. diesel, maintenance & repair cost, labour, herbicide, and pesticides are reflected under the respective headings above (p9-12)
Source: OVK (2012) and Waterfall farmer, personal communication

2.6.2 Soya

The gross margin analysis reflects the yield of the follow-up crop, as a response to using cover crops and improved soil quality under a NT or CA system. Armour and Viljoen (2003) (i.e. at Bethlehem and Viljoenskroon in South Africa) and Lauer et al. (1997) (i.e. Minnesota and Wisconsin in USA) concluded that long term Maize-soya rotations outperformed mono cropping maize at all prices and N-rates tested. Soya in the long term rotation returned higher gross margins above certain costs. Armour and Viljoen (2003) used a Dynamic Linear Programming (DLP) optimization model and captured the beneficial effect of Soya ability to fix N on the following maize crop and the potential for better soya yields in subsequent years. The beneficial effect and the impact of Nitrogen (N) application rate on Maize yield on consequent crops was calculated by using two formuli Using the square root functions derived from Loubser & Nel (2000) as used in Armour and Viljoen (2003) for the area of land planted to soybeans in the preceding year, maize yield is calculated according to the equation: maize after Legume: $Y = 33 + 1036.N^{½} - 40,17.N$ where: Y = maize yield in kg ha^{-1}, and N = the nitrogen application rate in kg ha^{-1}.

Another relationship that is accounted for in the Armour and Viljoen (2003) model is that average soybean yields increase every year that soybeans are planted on the same soil. This does not necessarily occur in consecutive years, but within five years from each initial planting. This is due to the build-up and good dispersion of Rhizobium bacteria in the soil. Armour and Viljoen (2003) concluded to use an N-fix rate of 30kg N ha^{-1} by soya. Literature is quite diverse on nitrogen fixation rates of legumes. Sanford et al. (1995, p. 1441) concluded that nitrogen fixation (kg N ha^{-1}) was significantly correlated to legume dry matter yield (DM) (kg N ha^{-1}). The soya yield for the first planting is put on 1.25 t ha^{-1}. Yields in consecutive 8 years are modeled at 1.75, 2, 2.18, 2.30, 2.38, 2,43, 2.48 and 2.50 tons per hectare.

This model used a nitrogen fixation per ha rate of 30 kg N ha^{-1} for soya and grazing vetch which is lower than literature regression models reflected. The reason of adapting to 30 kg N ha^{-1} fixation rate as locally used by Armour and Viljoen (2003) is to use the same square root function for maize after a legume. N-fix benefits are expressed in higher yields of crops following legumes.

The price of soya per ton is R4,000 for all production systems. The production costs of the different systems are reflected below. The input costs for soya under CV/NT in year 1, 2 and 3-8 are R2,417, R1,992 and R1,553 respectively. The input costs for soya under OCA in year 1 and 2-8 are R1,190 and R518 respectively.

Table 6: Production costs of NT, CV and OCA respectively, for soya production

Item	NT	CV	OCA
Soya seed (year 1, 100% new) Roundup-ready seed for NT and CV, open-pollinated for OCA	R1,152	R1,152	R600
Soya seed (year 2, 67% new)	R772	R772	-
Soya seed (year 3-8, 33% new)	R380	R380	-
Fertilizer	R541	R541	-
Inoculants	R156	R156	R156
Insurance	R113	R113	R113
Transport	R106	R106	R106
Hedging	R88	R88	R88

Key: variable costs i.e. diesel, maintenance & repair cost, labour, herbicide, and pesticides are reflected under the respective headings above (p9-12)

Source: Own analysis based on OVK (2012), Armour and Viljoen (2003) and Waterfall farmer, personal communication

The soya yield ha^{-1} under NT is rated at 1.75 t and 1.41 ton ha^{-1} following a ley crop and a cover crop respectively. This benefit is not calculated under OCA. The model assumes an increase in yield after a cover crop under NT. The increase of soya yield following a cover crop is based on the effect of increased soil cover. Nel's (2010) figures, based on American studies, are used in this model: an increased maize yield of 37kg per 1% increase of cover above 30% soil cover. The 37 kg ha^{-1} increase is used albeit local trial figures are slightly higher. The increased average maize yield over two seasons as a result of increased soil cover in the local trials (paper 4) is 49kg per 1% increase of soil cover above 30%. Waterfall trial figures are used (see paper 4) for determining increase in soil cover. This model assumes a projected increased soya yield of 12.95% after a CC, based on increased soil cover percentage of 14% for Maize.

Table 7: Gross margins above specified costs of NT, CV and OCA respectively, for soya production

Item	Yr0	Yr1	Yr2	Yr3	Yr4	Yr5	Yr6	Yr7	Yr8
Gross margins above specified costs of NT/CV	R2,583	R5,008	R6,447	R7,147	R7,647	R7,947	R8,147	R8,347	R8,447
Gross margins above specified costs of OCA	R2,810	R4,282	R4,682	R5,082	R5,482	R6,082	R6,482	R6,882	R7,482

Source: Own analysis based on OVK (2012), Armour and Viljoen (2003) and Waterfall farmer, personal communication

2.6.3 Wheat

The CEB for wheat under NT and CV is based on the farm's long term yields average of 1.1 ton ha^{-1}. The CEB for wheat under OCA is based on 0.9 ton ha^{-1}. The yield increase in wheat under NT after the cover crop is based on a 30% increase in soil cover. The assumed wheat yield increase equals 27.75% resulting in 1.41 t ha^{-1}, based on projected figures derived from Nel (2010). The increase in soil cover is high because this cover crop replaces the bare summer fallow and has higher increase of biomass due to ideal growing conditions, as from January, as compared to inter- or directly seeded growth period of CC from late autumn to spring. The yield of wheat under OCA following a cover crop is set at 1.15 ton ha^{-1}.

The price per ton for wheat is R2,963. Interest is still 12%. The total cost for wheat under NT and CV excluding herbicides, pesticides, diesel and maintenance & repair costs are R1,253.15 ha^{-1}. The GMASC for wheat under CV and NT and wheat following a cover crop under NT are R2,006.15 and

R2,910.61 respectively. The GMASC for wheat under OCA and wheat following a cover crop under OCA are R2,212.26 and R2,952.27 respectively.

Table 8: Production costs of NT, CV and OCA respectively, for wheat production

Item	NT	CV	OCA
Seed	R216	R216	R216
Fertilizer	R713.40	R713.40	-
Insurance	R96.25	R96.25	R96.25
Transport	R93.50	R93.50	R93.50

Key: variable costs i.e. diesel, maintenance & repair cost, labour, herbicide, and pesticides are reflected under the respective headings above (p9-12)
Source: Own analysis based on OVK (2012) and Waterfall farmer, personal communication

2.6.4 Sunflower

The sunflower yield under CV and NT in the model is 1.2 t ha^{-1} based on the farm's long term average. The sunflower yield under OCA in the model is 0.9 t ha^{-1}. The yield increase of sunflower following a cover crop (mix) under NT is based on projected trial yield increase of maize after a cover crop. The yield increase was 738 kg ha^{-1} of maize after summer cover crops (see paper 4), which equals a yield increase of 18.45%. That figure was projected to increase the 1.2 t ha^{-1} yield for sunflower under NT to 1.42 t ha^{-1}. The yield for sunflower under OCA following a cover crop was set at 1.07 ton ha^{-1}. The increase of sunflower following soya was set at 1.84 and 1.80 t ha^{-1} for NT and OCA respectively. The figure of 1.84 t is projected from the square root function from the Armour and Viljoen (2003) soya-maize model, based on 50kg N ha^{-1} fertilizer rate under NT. The figure of 1.8 t ha^{-1} is based on the same increase in yield of 169% for sunflower following soya.

Table 9: Production costs of NT, CV and OCA respectively, for sunflower production

Item	NT	CV	OCA
Seed	R364	R364	R510
Fertilizer	R484.49	R484.49	
Insurance	R144	R144	R144
Transport	R102	R102	R102
Price hedging	R84	R84	R84

Key: variable costs i.e. diesel, maintenance & repair cost, labour, herbicide, and pesticides are reflected under the respective headings above (p9-12).
Source: Own analysis based on OVK (2012) and Waterfall farmer, personal communication

The price per ton for sunflower is R4,664. The increase in price in seed is due to an increase in plant population for improved weed control under OCA. Interest at 12% for the respective budget lines is R141 and R101 for NT and OCA respectively. The total cost for sunflower excluding herbicides, pesticides, diesel and maintenance & repair costs are R1,320 ha^{-1} and R941 ha^{-1} for NT and OCA respectively. The GMASC for sunflower under NT, sunflower following a cover crop under NT and sunflower following soya under NT are R4,277, R5,310 and R7,245 respectively. The GMASC for sunflower under OCA, sunflower following a cover crop under OCA and sunflower following soya under OCA are R3,257, R4,031 and R7,462 respectively.

2.6.5 Cover crops

Cover crops refer to the direct seeding or aerial seeding (also referred to as casting/inter-seeding or over-seeding). Cover crop mixes referred to in this model are oats/grazing vetch and fodder radish.

Table 10: Seeding costs of different cover crops strategies

Description	Costs R ha^{-1}
Direct seeding replacing bare fallow (maize-wheat rotation)	R1,325.26
Direct seeding after soya/sunflower	R994.56
Aerial seeding into standing maize (i.e. inter or over-seeding)	R1,532.16
Direct seeding of cover crops replacing one year cash cropping (Sabbath year)	R1,588.19

Source: Own analysis

The cover crop figures planted after soya/sunflower is cheaper as reflected as fodder radish is not planted after March. In that case an increased seeding rate of oats will be used. Cover crops replacing a cash crop include the planting of fodder sorghum with fertilizer allowing at least one grazing at 90-120cm. The winter cover mix is then directly seeded into the grazed fodder sorghum allowing re-growth of the latter. Aerial seeding is set R600 p ha^{-1}. The airplane's fuel use per hour of 30 l ha^{-1} air fuel is assumed as the equivalent of 48 l ha^{-1} of diesel.

2.6.6 Ley crops

Ley crops are included in the model. This paper modeled Teff (*Eragrostis teff*) as well as Eragrostis (*Eragrostis curvula*), Sainfoin &Smuts fingergrass mix (*Onobrachis viceafolia* & *Digitaria eriantha*), pure stand of Lucerne (*Medicago sativa*) or Sainfoin and a mix of Eragrostis and crown vetch (*Coronilla varia*).

Table 11: The input cost for different ley crops

Description	Costs R ha^{-1}
Eragrostis	R1,291
Eragrostis/Crown vetch	R5,104
Smuts fingergrass & Sainfoin	R2,852
Lucerne	R5,299
Sainfoin	R4,356

(Source: Own analysis)

Maize after 3year-Lucerne results in a modeled increase of 1,757 kg ha^{-1} due to N buildup of 64 kg ha^{-1}. Likewise increased yields for maize after Eragrostis & crown vetch followed by 2-3 years soya as up to 2,485 kg ha^{-1} due a combined buildup of N of 114kg ha^{-1}. Maize after 3-4 years of Sainfoin is modeled with an increased yield of 1,831 kg ha^{-1} due to a buildup of N of 54kg ha^{-1}.

2.7. Livestock and monetary grazing values

The inclusion of livestock into crop rotations is important, because the Eastern Free State EFS is a mixed farming area. No reference is made in the model about calving interval, conception rates, increased size & value of the herds and marketable units. The livestock management indicators would assumedly improve with better feed quality, legume-based pastures and good quality green feed in the form of cover crops. This model limits itself only to a monetary value of the crop grazing stipulated as graze gain. These graze gain figures are derived from the average daily weight (ADW) gain of beef steers multiplied by R20 per kg (assumed beef price), which again is multiplied by a stocking rate per hectare per day.

The conventional ways of grazing for a long extensive period of 6 weeks is discouraged. This model used a high impact grazing strategy with high stocking numbers for a short period of time. The highest feed source is a ley crop, legume-based pasture and the cover crop mix replacing bare fallow due to the longest summer period growth. This feed value gain is rated on an actual 120 animal units (AU) for 3 weeks on 30ha which equals 84AU ha^{-1} d^{-1}. This model, however assumed a maximum of 75AU ha^{-1} d^{-1}.

ADW gain figures for ley crops used in the model are based on local eastern Free State figures adopted from Fair (2008). Monetary graze value are based on an assumed R20 per kg price for beef at 75AU ha^{-1} d^{-1}.

Table 12: Average daily gain and graze gain figures of different ley crops

Crop	Smuts finger-grass	Eragrostis & Teff	Eragrostis/ Crown vetch mix	Smuts fingergrass/ Sainfoin mix	Lucerne	Grass (oats)/ clover	Sainfoin
ADW gain (kg d^{-1})	0.51	0.66	0.74	0.79	0.92	0.81	1.03
Graze gain value per grazing	R765	R990	R1,103	R1,185	R1,380	R1,215	R1,545

Source: Adopted from Fair (2008)

Table 13: Average daily gain and graze gain figures of different cover crops

Crop	Fodder sorghum	Oats	Fodder radish	Grazing vetch	Mix of oats/grazing vetch/ fodder radish	Fodder sorghum (grazed) fb oats/grazing vetch/ fodder radish	Mix of all
ADW gain (kg d^{-1})	0.66	0.70	0.81	0.81	0.77	0.66 & 0.75	0.81
Graze gain value per grazing	R990	R1,050	R1,215	R1,215	R1,160	R2,108	R1,215

Source: Adopted from Fair (2008)

The total gross margins over seven years reflect both the exclusion and inclusion of grazing of cover crops. The assumption is that if cover crops are not grazed, it increasingly contributes to increased weed suppression and pest control. OCA success derived from not grazing CC. This implies that Eastern Free State farmers, with their mixed farming practices will be more reluctant to practice OCA.

2.8. Assessment criteria for crop rotations

The different crop rotations are assessed on profitability, crop intensity (agronomic productivity), legume ratio, crop diversity, soil cover building ability, potential contribution to herbicide resistance, perceived riskiness, and environmental cost.

The environmental cost refers to a direct and or indirect load of the cropping system on the environment. The indicator here is the quantity of diesel used under the different crop rotations over seven years. The quantity of diesel used is converted determining the greenhouse gas emissions as a direct and indirect load on the environment; and also converted to Rand value (ZAR). The conversion calculations are based on a British system (Defra, 2012) due to the lack of similar tables in SA. It should be noted that actual figures might differ from SA's situation[6], but the British figures are used in assuming the environmental costs. The environmental cost is expressed in both kilogram carbon dioxide equivalent (kg CO_2e) and in a monetary value. The calculations are based on total liters per hectare used over seven years derived from the OVK input model mechanization cost list. The actual liters per hectare is multiplied with a conversion factor of 2.6769 and 0.5644 determining the total direct and indirect GHG in terms of CO_2 (in kg CO_2 e) of the different crop rotations under the different production systems. The total kg CO_2 e is divided by 1000 to obtain the quantity in tons.

The shadow price used as a so called carbon tax levy based on SA's proposed figure of the cost of R120 CO_2e t (Stafford, 2013 and DNT, 2013, p15). The price for a ton of CO_2 in Australia and British Columbia is R221 and R255 respectively (Stafford, 2013).

The formula (own analysis) used determining the total direct and indirect cost of GHG for the use of diesel ha^{-1} 7yrs is:

$$(X * Ci) + (X * Cii) = Y$$
$$\frac{Y}{1000} * R = Z$$

With:

X = liters of diesel ha^{-1} 7yrs

Ci = conversion rate indirect GHG of diesel ha^{-1} 7yrs

Cii = conversion rate direct GHG of diesel ha^{-1}7yrs

Y = Grand Total GHG (Direct and indirect loading of diesel) in kg CO_2 e ha^{-1} 7yrs

R = proposed cost per t CO_2

Z = Total direct and indirect environmental cost of the use of diesel in ZAR ha^{-1} 7yr

[6] The conversion rates and calculations differ per country. The reasons are due to different processing procedures, different type and behavior of machines and equipment. The extracting and transforming process of the primary energy source into energy carriers can be different per country i.e. different sources of energy, different content, composition (blend) i.e. e.g. diesel and quality of the energy sources. The calculation procedures and methodology differ per country. Emission losses from transmission and distribution of heat and electricity cannot be determined exactly. Each country estimates and determines therefore its own emission info, rates and losses.

Similar calculations are done determining the total indirect GHG in terms of CO_2 (in kg CO_2 e) of the amounts spent over 7 years on fertilizer, pesticides and other chemicals.
The formula used determining the total indirect cost of GHG for the use of fertilizer, pesticides and herbicides ha^{-1} 7yrs is:

$$(Ai * Fi) + (Aii * Pi) + (Aiii * Hi) = W$$

$$\frac{W}{1000} * R = T$$

With:

Ai = Amount spent on fertilizer ha^{-1} 7yrs

Fi = conversion rate indirect GHG for the use of fertilizer ha^{-1} 7yrs

Aii = Amount spent on pesticides ha^{-1} 7yrs

Pi = conversion rate indirect GHG for the use of pesticides ha^{-1} 7yrs

Aiii = Amount spent on herbicides ha^{-1} 7yrs

Hi = conversion rate indirect GHG for the use of herbicides ha^{-1} 7yrs

W = Total indirect GHG of fertilizer, pesticides and herbicides in kg CO_2 e ha^{-1} 7yrs

R = proposed cost per t CO_2

T = Total indirect environmental cost of the use of fertilizer, pesticides and herbicides in ZAR ha^{-1} 7yr

Herbicides were not mentioned explicitly in the British conversion tables (Defra 2012) and therefore the category 'other chemicals' were used. The conversion factors of 2.25, 0.97 and 0.76 for fertilizer, pesticides and other chemicals respectively were used when multiplying it with the amounts spent over seven years on those respective products. The total kg CO_2 e was here also divided by 1000 to obtain the quantity in tons. The shadow price used as a so called carbon tax levy based on SA's proposed figure of the cost of R120 CO_2e t (Stafford, 2013 and DNT, 2013, p15).

The profitability of a crop rotation is measured in highest net returns over seven years. Net returns per hectare are influenced by variable input costs. This is expressed as Gross margins above specified costs (GMASC). This is done pure economically as well as with the inclusion of abovementioned load to the environment.

The cropping intensity (CI) or agronomic productivity is also measured. The maize-wheat crop rotation has a low agronomic productivity, a concept borrowed from Reeves (1997). Crop intensity (Govaerts et al., 2009, p.111), refers to the standing crops per year expressed as a percentage of the months during the specific crop rotation period (i.e. in this case a score out of 84 = seven years). Derpsch (2001, p. 252) pleaded that farmers should, if possible, never leave land in fallow. Cropping intensity is linked with cropping diversity measured by the numbers of crops in the rotation over seven years as well as the legume ratio.

The cost of manual weeding was included under OCA. The calculations are based on only one weeding per cash crop season due to the low weed pressure of ≤ 0.2 and ≤ 2 weeds per m^2 at pre-planting and 50 days after planting respectively (trial figures, paper 4 of this thesis). Based on that weed pressure it is assumed that it takes 11 people 1 hour to hand-weed one hectare. That amounts to 8 ha per day, based on an 9-hour day. The window of opportunity for weeding is small and therefore the modeled 550ha needs to be weeded in ≤ 21 days. It takes three teams of 12 people (11 pp on minimum wage of R2275 per month and one supervisor on R4,550 per month) to weed the required 69ha per d^{-1}. It is assumed that the 33 people and the 3 overseers work at a wage of R106 and R212 d^{-1} for 21 days. The total amount equals R86,814, which if divided by total cash crop hectares of 550, equals R158 ha^{-1} for casual labor.

Fifty-three different crop rotations were modeled under different production systems. Four crop (i.e. 24 rotations alternatives) rotations under CV, NT, NT cover crops and OCA/ONT were compared over a period of seven years, namely: 1) M-W-M-W-M; 2) *M-S-M-S-M-S-M*; 3) S-M-SF-S-M-SF-S and 4) *M-S-W-S-M-S*. The remaining 29 alternative rotations referred to other NT alternatives including ley crops and fallow cover crops.

3. Results

3.1. Short-term gains of NT

No-till (NT) had higher gross margins for all four projected crop rotations over seven years as compared to conventional tillage (CV). NT scored 3.17, 1.23, 1.19, 1.16 times higher on the four different 7-year rotations respectively. Over a period of 7 years, NT is, on the average of the last 3 crop rotations 19% more profitable than CV for the same crop rotation. This is slightly higher than Du Toit’s findings (2007). Du Toit (2007) indicated reduced input cost of 12% among 30 farmers in favor of NT in the North West province of South Africa.

Table 14: Different gross margins above specified costs (GMASC) per hectare over seven years for NT and CV in ZAR

No	Crop rotation	Tillage system	GMASC (7yrs ha-1) No graze gain
1	M-W-M-W-M (CV)	CV	1,600
	M-W-M-W-M (NT)	NT	5,068
2	M-S-M-S-M-S-M (CV)	CV	20,803
	M-S-M-S-M-S-M (NT)	NT	25,606
3	S-M-Sf-S-M-Sf-S (CV)	CV	19,811
	S-M-Sf-S-M-Sf-S (NT)	NT	23,499
4	M-S-W-S-M-S (CV)	CV	13,847
	M-S-W-S-M-S (NT)	NT	16,072

Key: CV (Conventional tillage), NT (No-till), M – maize, S – soya, Sf – sunflower, W – wheat, cc – cover crops
Source: Own analysis.

3.2 NT, cover crops, livestock and reduced herbicide use

The NT system improved by planting cover crops (CC). The CC resulted on average in a 7% increase in diesel cost (see table5b). This refers to an increased diesel use (5.61 ha^{-1}) regarding the direct seeding of the CC, despite small savings in less spraying actions (0.88l ha^{-1}).

The CC on the other hand resulted in savings on chemicals. When CC were partially included in the rotations (2-4 years) it resulted in savings of 14%, 17%, 13% and 20% savings on chemicals, for the above mentioned four rotations respectively. When CC were included in all seven years it resulted in savings of 28%, 35%, 32% and 37% savings on chemicals, for the above mentioned four rotations respectively. This is in line with Pieri et all. (2002), i.e. results from Paraguay and the USA, who reported a decrease in herbicide use as up to 30% after the initial 3-5 years transition phase due to improved skills and knowledge.

When the model allowed CC to be grazed (i.e. one grazing), it resulted in the fact that crop rotations under NT CC (CA_{HEI} and CA_{LEI}) outperformed NT on GMASC on average by 1% (see table 4). NT with CC resulted in an increased planting area of approximately 5% per hectare due to removal of contour banks after a few years of implementing NT. However, this is not converted in monetary terms though.

Table 15: Different gross margins above specified costs (GMASC) for different crop rotations, with and without grazing of CC, under different tillage systems in ZAR

No	Crop rotation	Tillage system	GMASC (7yrs ha^{-1}) No graze gain	GMASC (7yrs ha^{-1}) CC grazed – graze gain
1	M-W-M-W-M (CV)	CV	1,600	1,600
	M-W-M-W-M (NT)	NT	5,068	5,068
	M-W-cc-M-W-cc-M	CA_{HEI}	5,374	7,694
	M-cc-W-M-cc-W-M-cc	CA_{HEI}	5,520	7,840
	M-cc-W-cc-M-cc-W-cc-M-cc	CA_{LEI}	4,899	7,219
	M-cc-W-cc-M-cc-W-cc-M-cc	OCA	4,466	4,466
2	M-S-M-S-M-S-M (CV)	CV	20,803	20,803
	M-S-M-S-M-S-M (NT)	NT	25,606	25,606
	M-cc-S-M-cc-S-M-cc-S-M-cc	CA_{HEI}	21,469	24,717
	M-S-cc-M-S-cc-M-S-cc-M	CA_{HEI}	23,104	26,584
	M-cc-S-cc-M-cc-S-cc-M-cc-S-cc-M-cc	CA_{LEI}	19,857	26,585
	M-cc-S-cc-M-cc-S-cc-M-cc-S-cc-M-cc	OCA	17,746	17,746
3	S-M-Sf-S-M-Sf-S (CV)	CV	19,811	19,811
	S-M-Sf-S-M-Sf-S (NT)	NT	23,499	23,499
	S-cc-M-Sf-S-cc-M-Sf-S-cc	CA_{HEI}	20,609	24,089
	S-M-Sf-cc-S-M-Sf-cc-S	CA_{HEI}	21,831	24,151
	S-cc-M-cc-Sf-cc-S-cc-M-cc-Sf-cc-S-cc	CA_{LEI}	15,823	23,247
	S-cc-M-cc-Sf-cc-S-cc-M-cc-Sf-cc-S-cc	OCA	14,384	14,384
4	M-S-W-S-M-S (CV)	CV	13,847	13,847
	M-S-W-S-M-S (NT)	NT	16,072	16,072
	M-cc-S-W-cc-S-M-cc-S	CA_{HEI}	12,498	15,282
	M-S-cc-W-cc-S-cc-M-S-cc	CA_{HEI}	12,472	17,112
	M-cc-S-cc-W-cc-S-cc-M-cc-S-cc	CA_{LEI}	10,281	16,545
	M-cc-S-cc-W-cc-S-cc-M-cc-S-cc	OCA	10,106	10,106

Key: CV (Conventional tillage), NT (No-till), CA (Conservation Agriculture), OCA/ONT (Organic Conservation Agriculture/ Organic No-till), M – maize, S – soya, Sf – sunflower, W – wheat, cc – cover crops
Source: Own analysis

3.3. Profitability and environmental costs of production systems

The rotation 1) M-W-M-W-M did not only have the lowest crop intensity of 51%, lowest number of crops (2), but it was also the least profitable rotation. The rotations with wheat scored the lowest of all four rotations due to low cropping intensity (i.e. fallow due to summer M and winter W), low yields and low product price. Crop rotations are more profitable with increased cropping intensity (agronomic productivity), increased crop diversity, and increased legume ratio. This can be seen in the 2) *M-S-M-S-M-S-M* and 3) S-M-SF-S-M-SF-S rotations where soya was added to the legume ratio.

Table 16: Assessment scores for four crop rotations under different production systems of different objectives

No	Crop rotation	Tillage system	Crop intensity	Number of crops in rotation	Legume ratio
1	M-W-M-W-M (CV)	CV	51%	2	0%
	M-W-M-W-M (NT)	NT	51%	2	0%
	M-W-cc-M-W-cc-M	CA_{HEI}	70%	7	9%
	M-cc-W-M-cc-W-M-cc	CA_{HEI}	63%	5	13%
	M-cc-W-cc-M-cc-W-cc-M-cc	CA_{LEI}	82%	7	22%
	M-cc-W-cc-M-cc-W-cc-M-cc	OCA	82%	7	22%
2	M-S-M-S-M-S-M (CV)	CV	71%	2	27%
	M-S-M-S-M-S-M (NT)	NT	71%	2	27%
	M-cc-S-M-cc-S-M-cc-S-M-cc	CA_{HEI}	79%	5	45%
	M-S-cc-M-S-cc-M-S-cc-M	CA_{HEI}	86%	5	40%
	M-cc-S-cc-M-cc-S-cc-M-cc-S-cc-M-cc	CA_{LEI}	93%	5	58%
	M-cc-S-cc-M-cc-S-cc-M-cc-S-cc-M-cc	OCA	93%	5	58%
3	S-M-Sf-S-M-Sf-S (CV)	CV	57%	3	27%
	S-M-Sf-S-M-Sf-S (NT)	NT	57%	3	27%
	S-cc-M-Sf-S-cc-M-Sf-S-cc	CA_{HEI}	71%	6	40%
	S-M-Sf-cc-S-M-Sf-cc-S	CA_{HEI}	67%	6	36%
	S-cc-M-cc-Sf-cc-S-cc-M-cc-Sf-cc-S-cc	CA_{LEI}	87%	6	58%
	S-cc-M-cc-Sf-cc-S-cc-M-cc-Sf-cc-S-cc	OCA	87%	6	58%
4	M-S-W-S-M-S (CV)	CV	60%	3	27%
	M-S-W-S-M-S (NT)	NT	60%	3	27%
	M-cc-S-W-cc-S-M-cc-S	CA_{HEI}	74%	6	40%
	M-S-cc-W-cc-S-cc-M-S-cc	CA_{HEI}	85%	6	45%
	M-cc-S-cc-W-cc-S-cc-M-cc-S-cc	CA_{LEI}	89%	6	54%
	M-cc-S-cc-W-cc-S-cc-M-cc-S-cc	OCA	89%	6	54%

Source: Own analysis

The final gross margins above specified costs with deductions of environmental costs in terms of GHG can be seen in table5b. The CC rotations, when grazed had the highest GMASC under all crop rotations outperforming even NT.

On average, NT had a 47% saving on fuel, as compared to CV. This figure excludes contour bank maintenance and erosion gully repair under CV, which would make the fuel saving even higher.

No-till had the highest returns on investment measured in highest gross margins above specified costs over 7 years ha^{-1}. NT had lowest direct and indirect GHG for diesel use. NT however had the highest indirect GHG emission to pesticides and other chemicals (herbicides). NT has low crop diversity and a relatively low legume ratio. NT with only 2 or 3 crops in the rotation contributes to the threat of the building up of herbicide resistance, especially glyphosate.

The direct and indirect loading of diesel use to the environment in terms of GHG was calculated separately as compared with the indirect loading to the environment in terms of GHG by the other external inputs (i.e. fertilizer, pesticides and herbicides). OCA has the lowest GHG load to the environment followed by CV and CA_{LEI}.

Table 17: Direct and indirect loading of the use of different inputs to the environment ha^{-1} 7yrs based on R120 t CO_2 for 4 sets of crop rotations

		R11.2 per L	R11.2 per L	Amount spent in ZAR ha^{-1} 7yrs			Environmental load in kg CO_2 e ha^{-1} 7yrs				Environmental load in ZAR ha^{-1} 7yrs				In ZAR (R)		No graze gain CC
Crop rotation	**Prod syst**	**Total liters ha^{-1} yr^{-1}**	**Total liters ha^{-1} 7yrs**	**Fertilizer (F)**	**Pesticides (P)**	**Herbicides (C)**	**Direct & indirect GHG: D**	**Indirect GHG: F**	**Indirect GHG: P**	**Indirect GHG: H**	**Direct & indirect GHG: D**	**Indirect GHG: F**	**Indirect GHG: P**	**Indirect GHG: H**	**TOTAL GHG in R ha^{-1} 7yrs**	**TOTAL GHG in R ha^{-1} yr^{-1}**	**GMASC (R ha^{-1} 7yr) (MINUS env. cost)**
M-W-M-W-M (CV)	CV	56	393	4,334	304	0	1,273	9,751	295	0	153	1,170	35	0	1,358	194	242
M-W-M-W-M (NT)	NT	28	198	4,334	240	4,130	643	9,751	233	3,139	77	1,170	28	377	1,652	236	3,416
M-W-cc-M-W-cc-M	CA_{HEI}	30	210	5,164	240	3,526	679	11,620	233	2,680	82	1,394	28	322	1,825	261	3,548
M-cc-W-M-cc-W-M-cc	CA_{HEI}	29	205	4,334	240	3,400	663	9,751	233	2,584	80	1,170	28	310	1,588	227	3,933
M-cc-W-cc-M-cc-W-cc-M-cc	CA_{LEI}	32	221	5,164	0	2,796	716	11,620	0	2,125	86	1,394	0	255	1,735	248	3,164
M-cc-W-cc-M-cc-W-cc-M-cc	OCA	29	201	0	0	0	650	0	0	0	78	0	0	0	78	11	4,388
M-S-M-S-M-S-M (CV)	CV	78	546	5,497	320	0	1,769	12,369	310	0	212	1,484	37	0	1,734	248	19,069
M-S-M-S-M-S-M (NT)	NT	42	297	5,497	320	4,449	964	12,369	310	3,381	116	1,484	37	406	2,043	292	23,563
M-cc-S-M-cc-S-M-cc-S-M-cc	CA_{HEI}	45	314	5,497	320	3,543	1,019	12,369	310	2,693	122	1,484	37	323	1,967	281	19,502
M-S-cc-M-S-cc-M-S-cc-M	CA_{HEI}	44	311	5,497	320	3,543	1,010	12,369	310	2,693	121	1,484	37	323	1,966	281	21,138
M-cc-S-cc-M-cc-S-cc-M-cc-S-cc-M-cc	CA_{LEI}	47	328	5,497	0	2,637	1,065	12,369	0	2,004	128	1,484	0	241	1,853	265	18,004
M-cc-S-cc-M-cc-S-cc-M-cc-S-cc-M-cc	OCA	45	312	0	0	0	1,010	0	0	0	121	0	0	0	121	17	17,625
S-M-Sf-S-M-Sf-S (CV)	CV	78	546	4,528	160	0	1,769	10,189	155	0	212	1,223	19	0	1,454	208	18,357
S-M-Sf-S-M-Sf-S (NT)	NT	42	297	4,528	160	4,345	964	10,189	155	3,302	116	1,223	19	396	1,753	250	21,745
S-cc-M-Sf-S-cc-M-Sf-S-cc	CA_{HEI}	45	312	4,528	160	3,741	1,012	10,189	155	2,843	121	1,223	19	341	1,704	243	18,905
S-M-Sf-cc-S-M-Sf-cc-S	CA_{HEI}	44	307	4,528	160	3,741	994	10,189	155	2,843	119	1,223	19	341	1,702	243	20,129
S-cc-M-cc-Sf-cc-S-	CA_{LEI}	47	326	4,52	0	3,74	1,058	10,18	0	2,843	127	1,223	0	341	1,691	242	14,132

		R11.2 per L	R11.2 per L	Amount spent in ZAR ha^{-1} 7yrs			Environmental load in kg CO_2 e ha^{-1} 7yrs				Environmental load in ZAR ha^{-1} 7yrs				In ZAR (R)		No graze gain CC
Crop rotation	**Prod syst**	**Total liters ha^{-1} yr^{-1}**	**Total liters ha^{-1} 7yrs**	**Fertilizer (F)**	**Pesticides (P)**	**Herbicides (C)**	**Direct & indirect GHG: D**	**Indirect GHG: F**	**Indirect GHG: P**	**Indirect GHG: H**	**Direct & indirect GHG: D**	**Indirect GHG: F**	**Indirect GHG: P**	**Indirect GHG: H**	**TOTAL GHG in R ha^{-1} 7yrs**	**TOTAL GHG in R ha^{-1} yr^{-1}**	**GMASC (R ha^{-1} 7yr) (MINUS env. cost)**
cc-M-cc-Sf-cc-S-cc				8		1		9									
S-cc-M-cc-Sf-cc-S-cc-M-cc-Sf-cc-S-cc	OCA	45	318	0	0	0	1,032	0	0	0	124	0	0	0	124	18	14,260
M-S-W-S-M-S (CV)	CV	67	466	4,273	160	0	1,512	9,614	155	0	181	1,154	19	0	1,354	193	12,494
M-S-W-S-M-S (NT)	NT	35	245	4,273	192	4,242	793	9,614	186	3,224	95	1,154	22	387	1,658	237	14,414
M-cc-S-W-cc-S-M-cc-S	CA_{HEI}	37	258	4,688	192	3,336	835	10,548	186	2,535	100	1,266	22	304	1,693	242	10,805
M-S-cc-W-cc-S-cc-M-S-cc	CA_{HEI}	38	267	4,688	192	3,273	866	10,548	186	2,487	104	1,266	22	298	1,691	242	10,782
M-cc-S-cc-W-cc-S-cc-M-cc-S-cc	CA_{LEI}	39	274	4,688	0	2,518	889	10,548	0	1,914	107	1,266	0	230	1,602	229	8,679
M-cc-S-cc-W-cc-S-cc-M-cc-S-cc	OCA	37	259	0	0	0	838	0	0	0	101	0	0	0	101	14	10,005

Key: D = Diesel, F = fertilizer, P = pesticides, H = herbicides. HEI = High external inputs, LEI = Low external inputs. CV (Conventional tillage), NT (No-till), CA (Conservation Agriculture), OCA (Organic Conservation Agriculture). M = Maize, S = soya, Sf = sunflower, W = wheat, cc = cover crops

Source: Own analysis

Conventional tillage had the highest diesel use ha^{-1}. Consequently the direct and indirect impact of the use of diesel on the environment is in all cases highest under CV. The amount of liters ha^{-1} over 7 years was converted to the total direct and indirect GHG loading to the environment in kg CO_2 e (carbon dioxide equivalent). The environmental cost price, based on a shadow price of R120 t CO_2 resulted in a carbon cost of R153, R212, R212 and R181 ha^{-1} 7yr for direct and indirect load of diesel to the environment under CV for the 4 crop rotations respectively. Similar environmental cost price comparisons for NT reflected R77, R116, R116 and R95 ha^{-1} 7yr respectively. If these figures were projected (as CO_2 e tax) to the farm level of 550ha cash crops it would cost the farmer annually R12,021-R16,657 for CV and R6,050-R9,114 under NT.

The highest indirect loading to the environment in kg CO_2 e by all crop rotations was undoubtedly caused by the use of chemical fertilizer followed by the use of herbicides. Chemical fertilizer, pesticides and chemicals were only compared on indirect GHG load to the environment. Chemical fertilizer rates were the same for CV and NT per crop which resulted in an equal direct and indirect loading of the use of fertilizer to the environment. Savings in N through biological nitrogen fixation was translated in increased yields of following crops and not in reduced fertilizer rates for those specific crops. Fertilizer use is the biggest contributor to the GHG of the different crop rotations. In fact, it even overshadows the savings on pesticides and herbicides under CA_{LEI}. Govaerts et al. (2009, p. 117) and Reeves (1997, p. 132) stated that without heavy chemical fertilizer applications, good crops yields are generally not possible under CV. That is, however, not applicable to CA_{LEI} and OCA with the highest legume ratio and where inorganic fertilizer can be reduced even to the extent of eliminating it completely (Davis et al. 2012). Savings on fertilizer would result in lower GHG for the CA variants, to an extent of having lower GHG costs than CV.

No-till has the highest direct and indirect loading of the use of herbicides to the environment.

3.4. Organic CA, ley crops and CC replacing annual cash crops

Ley crop rotations under CA were modeled separately from the initial four crop rotations (Table 14).

Table 18: Assessment scores for several ley crop and CC crop rotations under different production systems of different objectives

Crop rotation	Production system	Crop intensity	Number of crops in rotation	Legume ratio
Scc-Scc-M-Scc-Scc-M-CC	CA	86%	8	61%
S-M-Sf-CC-S-M-Sf	CA	63%	8	25%
M-S-CC-S-M-S-CC	CA	75%	7	42%
M-S-cc-CC-S-cc-M-S-cc-CC	CA	87%	7	55%
Scc-M-Sfcc-CC-Scc-M-Sfcc	CA	81%	7	61%
M-S-L-L-L-M-S	CA	80%	3	58%
M-S-Oat/clover-L-L-L-M	CA	87%	5	54%
M-S-teff-S-M-S-M	CA	67%	3	27%
M-S-teff-S-M-S-teff	CA	68%	3	27%
E-E-E-S-S-S-M	Ley	74%	4	27%
E-E-E-Scc-Scc-Scc-M	Ley	93%	7	40%
E-E&CV-E&CV-S-M-S-M	Ley	79%	5	33%
E-E&CV-E&CV-S-S-S-M	Ley	75%	5	42%
E-E&CV-E&CV-Scc-Scc-Scc-M	Ley	94%	8	55%
E-E&CV-E&CV-M-Scc-Scc-Scc	Ley	88%	8	55%
Sainf&Smuts-Sainf&Smuts-Sainf&Smuts-M--S-S-S	Ley	75%	3	67%
Sainf&Smuts-Sainf&Smu-Sainf&Smu-M--Scc-Scc-Scc	Ley	90%	6	81%
Sai&Smu-Sai&Smu-Sai&Sm-Sai&Sm-M-Scc-Scc	Ley	92%	6	82%
Sainf&Smuts-Sainf&Smuts-Sainf&Smuts-M-S-M-S	Ley	79%	3	58%
Sainf&Smuts-Sainf&Smuts-Sainf&Smuts-M-Scc-M-Scc	Ley	89%	6	67%
E-E-E-Scc-SFcc-Scc-M	Ley	93%	7	31%
E-E&CV-E&CV-Scc-SFcc-Scc-M	Ley	94%	8	46%

Source: Own analysis

Table 19: Direct and indirect loading of the use of different inputs to the environment ha^{-1} 7yrs based on R120 t CO_2 for ley & CC crop rotations.

		R11.2 per L		Amount spent in ZAR ha^{-1} 7yrs			Environmental load in kg CO_2 e ha^{-1} 7yrs				Environmental load in ZAR ha^{-1} 7yrs				In ZAR		
Crop rotation	**Prod syst**	**Total liters ha^{-1} yr^{-1}**	**Total liters ha^{-1} 7yrs**	**Fertilizer (F)**	**Pesticides (P)**	**Herbicides (H)**	**Direct & in-direct GHG: D**	**In-direct GHG: F**	**In-direct GHG: P**	**In-direct GHG: H**	**Direct & indirect GHG: D**	**In-direct GHG: F**	**In-direct GHG: P**	**In-direct GHG: H**	**TOTAL GHG R ha^{-1} 7yrs**	**TOTAL GHG R ha^{-1} yr^{-1}**	**GMASC (R ha^{-1} 7yr) (MINUS env. cost)**
Scc-Scc-M-Scc-Scc-M-CC	CA	41	286	4,515	160	2,637	926	10,159	155	2,004	111	1,219	19	241	1,589	227	18,168
S-M-Sf-CC-S-M-Sf	CA	38	266	4,403	160	3,892	862	9,907	155	2,958	103	1,189	19	355	1,666	238	15,939
M-S-CC-S-M-S-CC	CA	32	224	4,390	160	3,241	728	9,877	155	2,463	87	1,185	19	296	1,587	227	12,071
M-S-cc-CC-S-cc-M-S-cc-CC	CA	34	240	4,390	160	2,939	779	9,877	155	2,234	94	1,185	19	268	1,565	224	8,814
Scc-M-Sfcc-CC-Scc-M-Sfcc	CA	40	281	4,403	160	2,986	911	9,907	155	2,270	109	1,189	19	272	1,589	227	12,914
M-S-L-L-L-M-S	CA	34	241	5,335	160	3,297	780	12,003	155	2,506	94	1,440	19	301	1,853	265	6,905
M-S-Oat/clover-L-L-L-M	CA	29	203	4,794	160	2,693	658	10,787	155	2,047	79	1,294	19	246	1,638	234	3,764
M-S-teff-S-M-S-M	CA	37	262	5,171	240	3,694	849	11,635	233	2,808	102	1,396	28	337	1,863	266	18,528
M-S-teff-S-M-S-teff	CA	32	227	4,845	160	3,241	737	10,902	155	2,463	88	1,308	19	296	1,711	244	13,078
E-E-E-S-S-S-M	Ley	26	179	3,876	80	2,272	579	8,721	78	1,727	70	1,047	9	207	1,333	190	14,905
E-E-E-Scc-Scc-Scc-M	Ley	28	193	3,876	80	1,517	625	8,721	78	1,153	75	1,047	9	138	1,269	181	13,700
E-E&CV-E&CV-S-M-S-M	Ley	26	183	3,662	160	2,423	595	8,239	155	1,841	71	989	19	221	1,300	186	11,343
E-E&CV-E&CV-S-S-S-M	Ley	26	183	3,233	80	2,423	595	7,275	78	1,841	71	873	9	221	1,175	168	12,419
E-E&CV-E&CV-Scc-Scc-Scc-M	Ley	28	198	3,233	0	1,668	641	7,275	0	1,268	77	873	0	152	1,102	157	10,043
E-E&CV-E&CV-M-Scc-Scc-Scc	Ley	28	199	3,233	0	1,819	646	7,275	0	1,382	78	873	0	166	1,116	159	11,086
Sainf&Smuts-Sainf&Smuts-Sainf&Smuts-M--	Ley	25	177	3,649	80	2,423	575	8,209	78	1,841	69	985	9	221	1,284	183	13,887

S-S-S																	
Sainf&Smuts-Sainf&Smu-Sainf&Smu-M--Scc-Scc-Scc	Ley	27	192	3,649	0	1,819	623	8,209	0	1,382	75	985	0	166	1,226	175	11,278
Sai&Smu-Sai&Smu-Sai&Sm-Sai&Sm-M-Scc-Scc	Ley	21	144	3,108	0	1,334	468	6,993	0	1,014	56	839	0	122	1,017	145	10,211
Sainf&Smuts-Sainf&Smuts-Sainf&Smuts-M-S-M-S	Ley	25	177	4,077	160	2,272	575	9,173	155	1,727	69	1,101	19	207	1,396	199	14,397
Sainf&Smuts-Sainf&Smuts-Sainf&Smuts-M-Scc-M-Scc	Ley	27	188	4,077	0	1,970	608	9,173	0	1,497	73	1,101	0	180	1,353	193	12,827
E-E-E-Scc-SFcc-Scc-M	Ley	28	193	3,820	0	1,616	625	8,595	0	1,228	75	1,031	0	147	1,254	179	16,779
E-E&CV-E&CV-Scc-SFcc-Scc-M	Ley	28	198	3,177	0	1,767	641	7,149	0	1,343	77	858	0	161	1,096	157	12,871

Key: D = Diesel, F = fertilizer, P = pesticides, H = herbicides. HEI = High external inputs, LEI = Low external inputs. CV (Conventional tillage), NT (No-till), CA (Conservation Agriculture), OCA (Organic Conservation Agriculture). M = Maize, S = soya, Sf = sunflower, L = Lucerne, E = Eragrostis, CV = crown vetch, Sainf = Sainfoin, Smuts = Smuts fingergrass, cc = cover crops, CC = Cover crops replacing a year of cash cropping with the intention of building up soil cover (Sabbath year).

Source: Own analysis

The best ley crops are legume-based pastures i.e. reductions in external inputs. Good examples are the rotations with three or four year Sainfoin/ Smuts fingergrass and three-year Eragrostis/ Crown Vetch combined with or followed by S-M with CC rotations.

Legume-based ley crops have higher legume ratios as compared to OCA (perennial legumes vs. annual soya and grazing vetch plantings) whilst having a similar CI and equal high number of crops. OCA is lower on input costs (R ha^{-1}) and also has slightly higher gross margins above specified costs (R ha^{-1}). The GHG load of diesel to the environment is higher under OCA then under CA legume-based ley cropping, but is lower on indirect GHG from fertilizer, pesticides and herbicides. If ley crops can be used for a longer period then the modeled 2-4 years, then it becomes an even more viable option for OCA and will reduce direct GHG to the use of fertilizer and chemicals.

Legume-based pastures and grass pastures (ley crops) reduce tractor passes significantly and consequently all related costs. A diversity of legumes should reduce the fertilizer rates of follow-up crops, although this was not modeled.

Organic CA has the lowest direct and indirect load in GHG of all crop rotations. It is obvious that without any fertilizer, herbicides or pesticides, this alternative can be rated as the most environmental friendly of all rotations modeled. Diesel use is inevitable under annual cash cropping and direct seeding of CC. The average diesel use under OCA/ONT is 201, 312, 318 and 259 l ha^{-1} 7 yrs for the four different crop rotations respectively. This compares similarly with NT and CA_{HEI} and CA_{LEI} rotations.

The gross margins above specified costs minus the direct and indirect environmental load of diesel to the environment are projected lowest under ONT. The gross margins above specified costs of ONT are still lowest even if the indirect cost of fertilizer, pesticides, and chemicals to the environment are deducted. The second lowest category in this regard is ley crops. The following rotations had the lowest environmental loading of all non-organic rotations modeled (see table 6a, 6b): Sainf&Smuts-Sainf&Smuts-Sainf&Smuts-Sainf&Smuts-M-Scc-Scc, E-E&CV-E&CV-Scc-SFcc-Scc-M, E-E&CV-E&CV-Scc-Scc-Scc-M and E-E&CV-E&CV-M-Scc-Scc-Scc. The final GMASC of the 4 abovementioned ley rotations are R10,211, R12,871, R10,043 and R11,086 per ha^{-1} 7 yrs respectively.

3.5. Multiple objectives and sustainability

Cover crops were the critical success factor in the different CA production systems CA (HEI), CA (LEI) and OCA.

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The production systems need to adhere to economic as well as environmental criteria.

Table 20: Scoring and ranking of cropping systems on gross margins and GHG per hectare over a period of 1 and 7 years. Based on the S-M-SF-S-M-SF-S crop rotation and for CA-ley systems: E-E&CV-E&CV-Scc-SFcc-Scc-M and Sainf&Smuts-Sainf&Smuts-Sainf&Smuts-M-Scc-M-Scc

No	Cropping system	CI	# crops	Leg-ume ratio	% score: comb soil cover & diversity	GMASC R ha^{-1} yr^{-1}	GMASC R ha^{-1} 7yrs	Grand Total GHG R ha^{-1} 7yrs	Grand Total GHG R ha^{-1} yr^{-1}	% score: combined GMASC & GHG	% score on sustainability
1	OCA (CC grazed)	*87%*	*6*	*58%*	***68%***	3,115	21,808	124	18	**86%**	77%
2	CA_{HEI} (CC grazed)	*69%*	*6*	*38%*	***47%***	3,446	24,120	1,703	243	**68%**	58%
3	CA_{LEI} (CC grazed)	*87%*	*5*	*58%*	***63%***	3,321	23,247	1,691	242	**64%**	63%
4	CV	*57%*	*3*	*27%*	***21%***	2,830	19,811	1,454	208	**64%**	42%
5	CA ley (CC grazed); E-E&CV-E&CV-Scc-SFcc-Scc-M	*94%*	*8*	*46%*	***84%***	2,492	17,447	1,096	157	**64%**	74%
6	CNT	*57%*	*3*	*27%*	***21%***	3,357	23,499	1,753	250	**59%**	40%
7	CA ley (CC grazed); Sainf & Smuts-Sainf&Smuts-Sainf&Smuts-M-Scc-M-Scc	*89%*	*6*	*67%*	***84%***	2,357	16,500	1,353	193	**55%**	69%
8	CA_{HEI} (CC not grazed)	*69%*	*6*	*38%*	***47%***	3,031	21,220	1,703	243	**50%**	49%
9	S-M-Sf-CC-S-M-Sf (CC grazed)	*63%*	*8*	*25%*	***42%***	2,515	17,605	1,666	238	**50%**	46%
10	OCA (CC not grazed)	*87%*	*6*	*58%*	***68%***	2,055	14,384	124	18	**50%**	59%
11	Scc-M-Sfcc-CC-Scc-M-Sfcc (CC & cc grazed)	*81%*	*7*	*61%*	***74%***	2,146	15,019	1,565	224	**36%**	55%
12	CA_{LEI} (CC not grazed)	*87%*	*6*	*58%*	***68%***	2,260	15,823	1,691	242	**32%**	50.1%
13	Scc-M-Sfcc-CC-Scc-M-Sfcc (CC grazed & cc not grazed)	*81%*	*7*	*61%*	***74%***	1,483	10,379	1,565	224	**27%**	50.5%

Key: CI=cropping intensity or agronomic productivity. HEI = High external inputs, LEI = Low external inputs. CV (Conventional tillage), NT (No-till), CA (Conservation Agriculture), OCA (Organic Conservation Agriculture). M = Maize, S = soya, Sf = sunflower, E = Eragrostis, CV = crown vetch, Sainf = Sainfoin, Smuts = Smuts fingergrass, cc = cover crops, CC = Sabbath year by using CC

Source: Own analysis

Organic CA and CA variants, while allowing CC to be grazed once scored best on the two criteria of highest GMASC and lowest environmental costs in terms of GHG. CV scores slightly higher than NT on this combined score.

Crop production systems were also assessed on additional multiple objectives: soil cover (cropping intensity) and cropping diversity (legume ratio & number of crops). CA with ley crops scored best on the multi objectives of building up soil cover and increased crop diversity. These results in cropping systems contributed most to building up soil cover and soil organic matter, nutrient recycling, increased soil water conservation and making use of biological regulation mechanisms. Ley crops were followed by crop rotations including a Sabbath year with combined cash- and cover cropping. The CA variants with cover crops were third best followed by crop rotation with a Sabbath year without any other cover cropping. NT and CV performed equally poor by not building up soil cover and by having low crop diversity.

This paper refers to the economic and environmental sustainability when assessing the crop production systems on all objectives. NT scored the lowest on the combination of all objectives followed closely by CV. NT is not a sustainable alternative to CV. NT is only the beginning of a process of introducing more economic and environmental sustainable tillage systems. Crop production systems 1, 5 and 7 are best in economic and environmental sustainability. These – systems are: OCA, CA ley and CC (Eragrostis & Crown Vetch) and CA ley (Sainfoin & Smuts finger grass), respectively.

The tillage systems and crop rotations are also assessed on risk reduction & return on investment variability, livestock integration option and labor conditions.

All direct seeding has lower risk and higher return on investment than CV with a significant investment in tillage prior to planting. All the cover crop systems and ley cropping can provide the farmer with an alternative source of feed in case of extreme dry seasons. Green growing CC reduced the risk of feed shortages in late winter and spring. The same CC reduce the threat of veld fires and reduce the blowing away of cash crop residue during the same months. The crop rotations which allowed CC grazing, translating into livestock AWG and increased GMASC, outscored all other systems.

OCA included one manual weeding, which offers short term jobs to 36 people on 550ha. If this opportunity is managed well, including more neighboring hectares, it can lead to increased job creation.

4. Conclusions

The first rotation of M-W is not a profitable crop rotation in the EFS of South Africa irrespective the tillage system used. This rotation has a low cropping intensity and low crop diversity. Crop rotations over 7 years with ≥ three crops per year are more profitable. If this M-W rotation is continued then highest GMASC are with OCA at R4,388 ha^{-1} 7yrs which equals R626 ha^{-1} yr^{-1}.

CA with CC grazed (graze gain) has the highest GMASC ha^{-1} 7yrs. NT has the highest GMASC when CC graze gain is omitted from the CA rotations for all three other remaining crop rotations 2) *M-S-M-S-M-S-M*; 3) S-M-SF-S-M-SF-S and 4) *M-S-W-S-M-S* modeled. NT also has the highest indirect load to the environment by the use of fertilizer, pesticides and chemicals. Despite that NT still has the highest GMASC (crop produce income – fixed and variable cost – total direct and indirect GHG in kg CO_2 e for diesel - indirect GHG in kg CO_2 e for fertilizer, pesticides and chemicals) of R3,366 ha^{-1} yr^{-1}, 3,106 ha^{-1} yr^{-1}, and R2,059 ha^{-1} yr^{-1} for the rotations 2-4 respectively. NT, however, is not the desired outcome due to not building up adequate soil cover, risk of herbicide resistance, relatively low crop diversity, high external levels of inputs and low score on biological regulation functions. NT scored lowest on economic and environmental sustainability followed by CV.

Cover crops should feature into the NT systems. These rotations have slightly lower load to the environment especially with savings of 33% in chemicals and less spraying actions. Cover crop rotations use on average 7% more diesel than the same NT rotations without CC. These cover crop rotations also have lower GMASC than pure NT. CC-based rotations are more multi objective and countered the risks of glyphosate resistance and positive contribute to increased soil organic matter, increased crop diversity & cropping intensity, reduced risk of veld fires and feed shortages.

Organic CA is the final result of the stepwise process or journey of improving NT. OCA is economically and environmentally found most sustainable of all crop production systems modeled. More research is however needed on OCA. Other authors have contributed the success of CA to cover crops. This paper's findings modeled on the positive results of NT cover cropping (previous chapter) are in line with that. More research is needed on large scale NT and CA enterprises (i.e. weed control, yield data, gross margin analysis, and livestock integration).

CA crop rotations including ley- and cover crops had the lowest environmental costs of all inorganic crop rotations modeled. The legume-based pastures especially feature strongly here with 3-4 year of Sainfoin/Smuts fingergrass and Eragrostis mixed with crown vetch followed by different soya & maize and CC options. These ley crop rotations are however outperformed by other rotations economically, but scored second best on economic and environmental sustainability.

Finally, NT (i.e. direct seeding of crops) should be adopted in order to start the step-wise improvement process to low external CA systems and OCA, which have low external impacts and achieve multiple objectives. The summer-summer cash crop rotations with soya had a higher legume ratio and cropping intensity than the fallow-based systems. Cover crops are the success of CA and made it possible to improve the cash crop rotations. Leguminous cash crop and cover crops can decrease the demand for inorganic fertilizers which was found to be the biggest polluter in terms of indirect GHG. Cover crops are needed in order to reduce all types of external inputs except diesel for the CA systems. The cover and ley crop rotations are found to be most multi objective.

The model did not include leaching of N from inorganic fertilizer. The model did not include the direct costs in terms of GHG of the use for fertilizer, pesticides and herbicides.

There was a 70% success rate modeled for casting of CC, imitating aerial seeding into a standing crop, as compared to the direct seeding of it. Findings in paper 4 of this thesis found that casting of CC is possible in the eastern Free State of SA, but more research is needed on this topic of cover seeding and relay cropping.

More research is needed on the economics of converting old established pastures to legume-based pastures. More research is also needed on various other livestock-related indicators beyond average daily gain figures for livestock on CA systems. The inclusion of cover and ley crops, for soil cover and grazing, is important and shows that livestock can be well integrated into NT/CA systems. This finding counters one of the perceptions many conventional farmers in the Eastern Free State have; which is, most probably, the main barrier for not converting to NT/CA: the perception that livestock cannot be integrated with NT cropping.

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PAPER 4

IMPROVED SOIL QUALITY UNDER NT COVER CROPPING IN THE EASTERN FREE STATE

Abstract

A minimum data set (MDS) is required when conducting a comparative soil quality assessment between crop production systems because there are many different indicators for consideration. The indicators for this comparative soil quality assessment for this MDS in this paper are soil organic carbon and plant available water capacity. Sub indicators are soil cover build-up levels, weed pressure levels, soil organic carbon levels, soil final water infiltration rates, soil water wetness levels and crop water productivity (CWP). The soil cover was measured using the line-transect method. Weed counts were conducted by using a ¼ m^2 randomly thrown hoop. Soil carbon levels were measured at depths of 0-5cm as well as 5-20cm. The soil final water infiltration rates were determined by using a double ring tension infiltrometer. Soil wetness was determined by weekly readings with an irrometer moisture reader after installing double Watermark soil water tension instruments per treatment replication at different soil depths. The soil depth was 100cm and 50cm in 2011, but with insignificant differences in readings it was re-installed at depths of 50cm and 30cm for 2012 and 2013. The crop water productivity was measured by measuring the accrued beneficial biomass over three years divided by the quantity of water used. The actual rainfall figures were used for quantifying the water received during the three years.

The different crop production systems under assessment were different no-till (NT) variants. The starting point of the trials was conventional NT and different NT options including mulch and cover crops (CC). Conventional farming practices (CV) were found unsustainable in other papers of this thesis and it was therefore not considered for the trials. Ample literature reflected more sustainable results under NT variants as compared to conventional NT i.e. NT without good crop rotations and adequate soil cover. The stepwise improvement of NT is referred to as Conservation Agriculture (CA). CA is founded on the simultaneous adherence to three principles: minimum disturbance of the soil, permanent soil cover and sound crop rotations. On farm trials were laid out over a period of four-years at Waterfall at Ladybrand in the eastern Free State (EFS) of South Africa (SA). Every treatment had four repetitions which were randomly selected. Treatment 1 to 4 were conventional NT, NT with grass mulch, NT with oats-based CC and NT with stooling rye CC, respectively. Additional research has been conducted in addition to the trials in the form of off-site water infiltration assessment linked to measuring soil carbon levels. Ten pairs of treated sites and untreated reference sites were compared in 2011 and 2013.

Highest soil carbon levels were found under pasture and natural veld. NT cover crops had the best combined score after measuring the different MDS indicators. The soil water conservation is highest under NT with cover crops.

Keywords: Soil organic carbon, final water infiltration rates, soil quality, cover crops, CA, soil water conservation

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1. Introduction

South Africa's soils in general are degraded, imbalanced and over-utilized; have high weed pressure, are low in organic matter (Mills and Fey, 2003; Burger, 2010) and nutrients (P, K, Mg and Ca). Without heavy chemical fertilizer applications good crops yields are generally not possible (Govaerts et al. 2009, p. 117 and Reeves, 1997, p. 132). South Africa's arable land is low in organic matter (Rantoa, 2009; Du Preez et al., 2011) and prone to erosion (Laker and Smith, 2006), soil compaction and soil crusting (Laker, 2004). Van Oudtshoorn (undated cited in Laker and Smith (2006) and (Scotney and McPhee, 1990 cited in KZN-No-till-Club, 2008) argued that 60% of SA's arable land has top soils with low organic matter contents (<0.5% organic carbon). Burger (2010) argues that soil degradation is largely related to the decline in soil organic matter. Monoculture cereal production, intensive tillage, short-to-no fallow periods and limited crop rotation have contributed to this in the commercial sector. Tillage results in soil erosion and land degradation (Decker et al., 2011; Mills & Fey, 2003; Le Roux et al., 2007; Compton et al., 2010; and Derpsch et al., 2006). Soils became half dead and lack soil life (Fair, 2008). Conventional tillage practices (CV) are economic and environmentally not sustainable (see paper 3 of this thesis).

Soil conservation is important for sustainable crop production. Various publications refer to soil health, soil fertility and soil quality. Soils differ in texture, mineralogy, organic carbon content, structure, chemistry, physics, fertility, etc. and soil quality is therefore specific for each soil. Soils have their own inherent and distinctive quality. For example, all being equal, a loamy soil will have a higher water-holding capacity than a sandy soil; thus, the loamy soil has a higher inherent soil quality – a characteristic which is also referred to as "soil capability" (USDA, 2001). More recently, soil quality has come to refer to the dynamic quality of soils, defined as the changing nature of soil properties resulting from human use and management (USDA, 2001). Soil capability cannot be influenced by management, but the dynamic quality of soils is in the farmer's hands.

The research in this chapter is based on a wider definition of soil quality, and goes beyond the focus on the productive potential of the soil. Reeves (1997) supports this approach, as scientists, policy makers, and the general public have become more environmentally-conscious. Definitions of soil quality have expanded from being associated only with productive potential, to the soil acting as an environmental buffer, protecting watersheds and ground-water from agricultural chemicals and industrial and municipal wastes, and sequestering carbon that would otherwise contribute to global climate change.

In relation to soil quality, the water-use efficiency of conventional farming practices can also be questioned. Fallow, as part of the crop rotation, is common in the eastern Highveld area in order to store pre-plant water quantities and breaking pest cycles. Increasing the length of the fallow period before planting increases the amount of pre-plant stored water in the soil, thereby reducing the risk of drought damage to the crops (Bennie and Hensley, 2001). This method of using fallow as part of a crop production system is contested by Derpsch (2001, p. 252), Sooby et al. (1997), McNee et al. (2008) and Denef et al. (2011) & West and Post (2002) both quoted in O'Dell et al. (2013). Bare fallow, as part of a crop production system is contested as it leads to a reduction in soil organic matter (and soil carbon), is prone to erosion and scores low on agronomic productivity.

Soil water levels can be measured by the different levels of precipitation utilization of different production or management practices for dry land crop production or rangeland utilization. This is expressed or measured as a precipitation use efficiency (PUE) value (Bennie and Hensley, 2001), also known as rain-use efficiency (RUE) (Snyman, 2004). The PUE will improve by reducing runoff and evaporation and increasing soil water storage, e.g. with various mulch practices (Bennie and Hensley, 2001). CA improves soil water conservation (Govaerts et al., 2009:111, Govaerts, 2007, Sommer, 2007, Reeves, 1987), which reduces the threat of erratic rainfall & variation in rainfall in this semi-arid region (O'Farrell et al., 2009). Consequently, it increases the level of available soil water. Hellegers et al. (2009) used the concept of crop water productivity (CWP) which has also been described as "the value of water" or "net return to water" (Young 2005). CWP is not the same as PUE, although related in reflecting net return to water. Both methodologies can be used in translating the measured rainfall into production unit ha^{-1} or monetary value ha^{-1}. CWP is a less cumbersome method with its focus on the beneficial biomass produced by dividing it by the measured rainfall. The PUE method is also a division sum but its focus is more on quantifying fluctuations in soil water levels i.e. runoff, evaporation, transpiration and deep percolation.

Conservation Agriculture (CA), also referred to as no-till (NT) with crop residue retention (Neto et al., 2010 and Affholder et al., 2010) has proven to control soil erosion. In fact, no other technique has been so effective anywhere at reversing soil erosion (Derpsch 1999). CA is the implementation of the following three principles: minimum disturbance of the soil, year-round soil cover and sound crop rotations including legumes. Kassam et al. (2009) recommended that crop rotations with three crops or fewer should not be called CA. NT in this paper would qualify as the adherence to the first principle of disturbing the soil as little as possible. Govaerts et al. (2009:113), Govaerts et al. (2006:172) and Zanatta et al. (2007:517) argued that NT without soil cover and or good rotations may score less on soil quality indicators as compared to CV.

Govaerts et al. (2006:99) stated that the movement towards CA-based technologies normally comprises a sequence of stepwise changes in cropping system management. No-till systems can develop step-wise into CA. The introduction of cover crops has contributed to that stepwise development of NT into viable and ecologically sustainable CA production systems. Cover crops have been identified as being probably the main reason for the world-wide success of CA (Derpsch et al, 2010; Steiner et al., 2001, Pierie, 2002, Moyer, 2011, Uchino et al., 2009). Cover crops are grown to protect and improve the soil quality. Recently the discussion of cover crops is linked to the attention of organic activity in the soils. Soils are seen as living organisms. Cover crops have also the potential to improve adherence to the two CA principles of soil cover and sound crop rotations.

Ample literature is available comparing NT/CA with CV. Most publications from all over the globe reflect more environmental sustainable results favoring NT/CA (Gassen and Gassen, 1996; Thierfelder & Wall, 2010; Nangia et al. 2010; Calegari et al., 1998; Derpsch, 2003). These advantages include the control of erosion and run-off, increased water infiltration, water-holding capacity of soil and rainfall use efficiency (RUE), increased soil organic matter and carbon build-up in the soils, and higher yields and gross margins.

Permanent soil cover with a thick layer of mulch has been a key factor for having success in NT in Latin America (Derpsch, 2001). Cover crops can reinforce the limited crop rotations in the eastern Free State despite the recent inclusion of soya. Can cover crops also provide the much needed soil cover and contribute to the increase of soil organic matter?

Soil scientists make use of a minimum data set (MDS) when determining or assessing soil quality (SQ) and indicating how it is measured. Scientists have developed quantifiable indicators for soil quality. Reeves (1997) provides a good overview of the development of these MDS.

Arshad en Coen (1992) recommended that the MDS should not be applied on short-term basis, but rather on long term experiments of 20-30 years in order to determine the impact of management practices on soil quality.

Soil carbon has been referred to as a good soil quality indicator (Reeves, 1997). Soil quality in croplands, can be evaluated by a minimum dataset (MDS) that include soil properties such as bulk density, infiltration rate, total carbon and nitrogen content, pH (De Bona et al., 2008) and electric conductivity. Soil organic matter can also be used as a soil quality indicator. Gregorich et al. (1994) emphasized soil organic matter not as a single parameter but as an integrative attribute related to several other soil properties included in MDS. De Bona et al. (2008) argued that soil quality should be assessed by a carbon management index. This index expresses the soil quality in terms of increments in the total carbon content and in the proportion of labile carbon fraction compared to a reference soil, generally that under native vegetation, which arbitrarily has a carbon management index of 100.

Soil organic matter has long been recognized as a key element in soil quality and productivity (Reeves, 1997). Soil organic carbon is integrally part of soil organic matter and stands normally in a ratio of approximately 1:1.724 (Ruehlmann and Körschens, 2009). Soil carbon serves as the energy source for microbial processes. Other soil quality indicators inextricably linked to soil organic carbon are all quoted in Reeves 1997: plant available water holding capacity; final infiltration rate; aggregate formation and stability; bulk density; soil strength; cation exchange capacity (CEC); soil enzymes and invertebrate bio-indicators like earthworms.

Maintenance and improvement of soil quality in continuous cropping systems is critical to sustaining agricultural productivity and environmental quality for future generations. The increases in atmospheric concentration of carbon dioxide (CO_2) and other greenhouse gasses (GHGs) have contributed to increases in global temperatures and associated climate change (O'Dell et al., 2013). O'Dell et al (2013) further reported that agriculture contributes 13.5% of all GHG world-wide. Soil organic carbon sequestration through CA can reduce CO_2 emissions (O'Dell et al., 2013, So et al., 1999). SOC is the most often reported characteristic identified in long-term studies. It is selected in this paper to be the most important indicator of soil quality and agronomic sustainability because of its impact on other physical, chemical and biological indicators of soil quality (Reeves, 1997).

Numerous global studies have been conducted measuring SOC sequestration rates (Scopel et al. (2005), Bayer et al. (2006), Doran and Parkin (1994), Gregorich et al. (1994), Reeves (1997) and Govaerts et al. (2005)). SOC buildup and carbon sequestration rates are found higher under NT/CA as compared to CV (Scopel et al. (2005), West and Post (2002), West and Marland (2002) and Woomer et al. (2004) quoted in Perez et al. (2005)). O'Dell et al. (2013) found in a study in Lesotho that NT had higher soil carbon sequestration rates as compared to CV. The increase in soil C sequestration was measured using Bowen ratio energy balance data collected over a 1.5 year period, comparing CO_2 flux between till and no-till treatments.

This paper attempts to fill the gap in local data. It provides and produced relevant baseline data for long term SOC sequestration rates under CA/NT cover cropping, and it lays the groundwork for future studies on SOC in the Eastern Free State region. Double annual cropping at the same field is unheard of; it is actually referred to as 'bankrupt farming'. However, the trials conducted for this study have shown that continuous cover cropping is possible over a three-year period and even in this limited time frame, it has improved the yields and crop water productivity. This paper also addresses the weakness in conventional ways of thinking about water conservation, fallowing and local crop production systems. This data is crucial for crop production against changing climatic conditions, fluctuating annual rainfall and variability in the annual rainfall distribution.

The minimum data set on soil quality for this paper used the following indicators: (1) soil carbon levels and (2) plant available water capacity. Sub indicators for the latter are: (2a) soil final water infiltration rates, (2b) soil water levels and (2c) crop water productivity. Data analysis was based on a period of three years (2011-2013). This relatively short-term period has its limitations in measuring changes in soil organic carbon and soil quality. Arshad en Coen (1992) recommended long-term studies of 20-30 years.

2. Methodology

2.1 Experimental site description

This research and trials were conducted on the farm Waterfall, Ladybrand in the Eastern Free State of South Africa. This farm was converted to NT in 2004. On-farm cover crops research started in January 2011 after the 2010 winter wheat harvest in December 2010.

2.2 Experimental design (treatments and replications)

The trials included four treatments, each with four repetitions. Treatment blocks were 3.6m wide (width of the NT planter) and 40m long. The blocks were randomly selected. The first treatment was NT wheat followed by maize. This reflects the conventional NT farming operations past 2004. The main crop rotation under CV, before converting to NT, was wheat followed by maize. NT has initially been implemented without significant soil cover (40-50%) and sound crop rotations (2 grain crops). Treatment two was the NT maize-wheat rotation with grass mulch after planting maize. Treatment three and four referred to the maize-wheat rotation including cover crops. Treatment three's cover crop mix was oats *(avena sativa)* /grazing vetch *(Vicia dasycarpa)* /fodder radish *(Raphinus sativus)*. Treatment four's cover crops included stooling rye *(Secale cereal)* / grazing vetch /fodder radish. The summarized version of the treatments was:

Table 21: Treatment and time-line of cover crop trials conducted at Waterfall during the period 2010-2013

Year and season→ Treatment ↓	May 10 – Dec 10	Jan 11 – Oct 11 Start of treatments→	Nov 11 – July 12	Mar 12 – Sept 12	Nov 12 – July 13	Mar 12 – Oct 13
T1 (NT)	Wheat	Bare fallow	Maize	-	Maize	-
T2 (NT)	Wheat	Bare fallow	Maize	Grass mulch	Maize	Grass mulch
T3 (CA)	Wheat	CC mix8	Maize	oats/ grazing vetch/ fodder radish	Maize	oats/ grazing vetch/ fodder radish
T4 (CA)	Wheat	CC mix8	Maize	Stooling rye/ grazing vetch/ fodder radish	Maize	Stooling rye/ grazing vetch/ fodder radish

Key: Mix 8 refers to the direct seeding of eight cover crops replacing bare fallow. A 4-row NT-tine-planter was used and two kinds of seed were mixed per seed hopper. The seed mixes per seed hopper were: pearl millet (Pennisetum glaucum (L.) R. Br) / fodder sorghum (Sorghum bicolor (L.)), stooling rye (Secale cereal) /grazing vetch (Vicia dasycarpa), cowpeas (Vigna sinensis) / oats (Avena sativa) and fodder radish (Raphinus sativus)/ pink seradella (Ornithopus sativus) respectively.

Glyphosate with 2-4D (a plant growth stimulant for increased uptake of glyphosate) was applied in September 2011 and 2012 killing winter- and spring weeds (including cover crops if applicable). The maize was planted in both years in November using 6:2:1 (32) fertilizer at a rate of 70kg and 80kg N/ha for 2011/12 and 2012/13 respectively. The plant population for maize was approximately 33,000 plants/ha. Glyphosate has been applied twice after planting in each of the respective seasons at rates of 3l/ha killing weeds. The cover crops in March 2012 and 2013 were inter-seeded into the standing crop of maize. Cover crop seed was casted by hand, simulating aerial seeding. The cover crop seed was worked in lightly in March 2012 but casted and left in March 2013. The cover crops were accidentally terminated with glyphosate and 2-4D in June 2013 killing autumn weeds before planting the cover crop mix on adjacent fields to a mix of oats, stooling rye, lupin, fodder radish and grazing vetch. The planting of this cover crop mix extended on the trial fields. Treatment 3 and 4 were consequently re-planted with the NT-planter with the above mentioned mix in June 2013.

The T4 cover crops (stooling rye, grazing vetch and fodder radish) had been terminated by glyphosate in late August in 2012 whilst the cover crops under T3 (oats, grazing vetch and fodder radish) had been terminated in late September 2012. Both T3 and T4 were left growing in October 2013 as the trial area was taken out of the crop rotation for a Sabbath year. Glyphosate is a non-selective herbicide and it kills plants by interfering with the synthesis of the essential amino acids. With other words glyphosate blocks the root growth of the plant and the plant dies as it cannot take up water (i.e. dehydration and desiccation).

2.3 Measurements and observations

Water infiltration (WI) studies were also conducted outside the trial area. This component is added to the trials in order to measure the longer-term effect and spatial comparison of some of the NT sites that have been under NT since 2004. Another objective of this additional component was to see the results of WI under pastures and natural veld when considering ley crops (as discussed in paper 3 of this thesis) under CA cropping systems.

Soil moisture levels were initially measured at a depth of 100cm and 50cm. Watermarks were installed by snug fitting them into pvc pipes. An irrometer moisture reader was used giving readings between 0 and 199 where 0 is wet and 199 is dry. Readings were taken weekly and occasionally bi-weekly. There were insignificant differences in soil moisture readings in 2011 at

100cm and 50cm depth and therefore the pipes were re-installed after maize planting at a depth of 50cm and 30cm. Some watermarks became defective during the years and were replaced.

Soil residue cover was evaluated using the line-transect method (Laflen et al., 1981). Weed counts were done by using a ¼m^2 randomly thrown hoop (Eash et al., 2011). The weed counts did not focus on different weed species but on individual weed plants. Weed counts identified the totals of broad leaf species and grasses per ¼m^{-2} and converted to weeds m^{-2}. Soil samples were taken at randomly selected locations and repeatedly with a minimum of five samples per trial repetition. All soil samples were taken at 0-5cm and 5-20cm depth. Soil samples were taken in September prior to planting a follow up cash crop. Maize grain yields were determined by hand harvesting of 10m randomized rows.

The final water infiltration rates were measured by using a double ring infiltrometer. The infiltration studies were conducted in September 2011 and 2013 prior to planting the cash crop. Soil samples were taken at all sites. All soil samples were again taken at 0-5cm and 5-20cm depth. The 0-5cm readings were included to pick up any potential changes in soil carbon. SOC was analyzed with a LECO TRUMAC instrument.

The soil quality assessment indicators were water infiltration rates and soil organic carbon. This assessment was extended beyond the trial plots at different NT farms in the eastern Free State (EFS) of South Africa. The reason for conducting this extended assessment was to include CV practices which were omitted in the trials. In addition, this assessment would open up more sites assessing short- and long terms effects (Arshad and Coen, 1992) of NT and ley crops.

The methodology used for comparing soil quality was comparing treated with a nearest possible untreated reference site and within 50m from the cropland sample site. This methodology allows the research to be ecotype specific (Knowler and Bradshaw, 2007) ensuring a high level of reliability of homogeneity of sites. The few (9) existing NT pioneers in the EFS were purposively selected. Neighbouring sites, where farmers were practicing CV, were then selected for comparison. Natural veld, often growing under the fences, was utilized as examples of relatively native and undisturbed vegetation as suggested by De Bona et al. (2008). Maphutseng, a CA research site in Lesotho (Eash et al., 2011 and O'Dell et al., 2013) has been included in the comparative assessment.

The crop water productivity (CWP) was measured by using the following formula adopted from Hellegers et al. (2009):

$$CWPi = \frac{Yi}{SR}$$

With

Y_i – yield of crop i (kg ha^{-1})

SR – actual water supply as seasonal rainfall (mm yr^{-1})

3. Data collection and analysis

This soil quality research is a comparative assessment and three variables are being compared: NT, NT with mulch and NT with cover crops. There is no conventional tillage control plot because the literature study (paper 1) and the sustainability assessment (paper 3) have reflected far more favorable results compared to those found in CV.

The second component of this comparative assessment is comparing the soil structure under different production systems: NT and CA. Final water infiltration rates were measured as an indicator for pore size distribution as indicator of pore size distribution represented by soil structure and biopores. Simply stated, biopores are holes or spaces created by soil organisms (tunneling insects, small animals, earthworms, or decaying roots) through biological activity. The assumption is that the better the soil structure (i.e. more soil aggregates, more soil pores, more root and subsoil biomass) and more biopores relate to bioactivity which in combination increase final water infiltration rate. Soil related data is compared and matched with the final water infiltration rates.

Statistical analyses were carried out by using IBM SPSS. The one way Anova or F-test were carried out in all cases. It was difficult to test some data in the sense that in certain cases there was a lack of replications. The geographical spread of locations (i.e. across areas with diverse mean annual rainfall) and the related lack of climatic control caused problems for applying statistical analysis.

4. Results

4.1 Soil organic carbon levels

4.1.1 Soil cover & weed counts

Soil cover build-up was highest, as expected, under the NT mulch and cover crop treatments. Treatments with highest soil cover had the lowest weed counts, thereby confirming the weed suppression effect of soil cover i.e. mulch or cover crop residue. These findings reflect those of Eash et al. (2011), Uchino et al. (2009), Ngouajio and Mennan (2005), Czapar et al. (2002) and Pieri et al. (2002). The mulch treatment (T2) resulted in highest soil cover followed by T3: oats/grazing vetch/fodder radish and T4: stooling rye/grazing vetch/fodder radish.

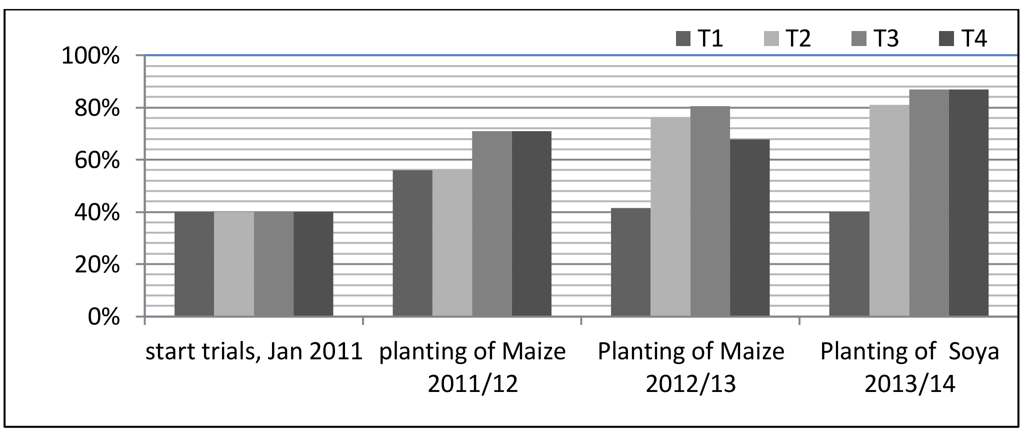
All four treatments started with a 50% soil cover in January 2011. Conventional NT (T 1) had the lowest soil cover after three years and this treatment was not able to either build or maintain the soil cover over the three years between 2011 – 2013. The November soil cover assessment at the time of maize planting for T1 was 56%, 55% and 40% for 2011, 2012 and 2013 respectively. This treatment also had the highest weed counts. Treatment 1's weed count dropped from a weed count of 95 m^{-2} at August 2011 to weed counts of 20 (pre-planting), 29 (50 days after planting) and 0.06 (pre-planting) m^{-2} during 2012 and 2013. The very low level in the last reading reflected the winter glyphosate application in June 2013 in conjunction with extreme dry conditions of no precipitation, except a 5mm rainfall event in August 2013, from April 2013 - 20 October 2013.

The T2 - NT mulch treatment's soil cover assessment at maize planting was 56%, 76% and 81% for 2011, 2012 and 2013 respectively. Mulch was only added after planting, which explains the 56% in 2011. Mulch was added to have a 100% cover just after planting. This treatment had the lowest weed counts and dropped from a weed count of 95 m^{-2} at August 2011 to weed counts of 0.68 (pre-planting), 2 (50 days after planting) and 0.02 (pre-planting) m^{-2} during 2012 and 2013.

The soil cover for the two cover crop treatments improved on the conventional NT T1 treatment. The November soil cover assessment at maize planting for T3 was 71% and 81% for 2011 and 2012 respectively. The soil cover was 63% and 87% at 23rd of October 2013 and 15th of November 2013 respectively due to increased growth of CC. Treatment 3's weed count dropped from a weed count of 35 m^{-2} at August 2011 to weed counts of 0.21 (pre-planting), 19 (50 days after planting) and 0.05 (pre-planting) m^{-2} during 2012 and 2013.

The November soil cover assessment at maize planting for T4 was 71% and 68% for 2011 and 2012 respectively. The soil cover was 56% and 87% at 23rd of October 2013 and 15th of November 2013 respectively. The 68% in 2012 is lower than T3's 81%. The reason is that T4's cover crops were terminated a month earlier than those of T3. Treatment 4's weed count dropped from a weed count of 35 m^{-2} at August 2011 to weed counts of 0.1 (pre-planting), 31 (50 days after planting) and 0.12 (pre-planting) m^{-2} during 2012 and 2013. The drop in soil cover of 13% between T3 and T4, as described above, resulted in a higher weed count of 12 m^{-2}. The EFS is characterized by strong winds between August and October blowing away soil, but also crop residue. The cover crops reduced the blowing away of maize residue.

Graph 1: Soil cover levels of the four treatments of the Waterfall trials over a 3 year period



The average build-up of soil cover percentages over the entire trial period (i.e. Jan 2011 – Oct 2013) were compared by using a one-way Anova and a significant difference was found. T1 was compared to T3 and T4. T2 was omitted due to the impracticality of mulching on large scale. There is a significant difference ($p=0.02$; $F = 5.169$) between the build-up of soil cover over the entire trial period of four years for NT (T1) and both cover crop treatments (T3 and T4).

There is a highly significant difference ($p=0.009$; $F = 10.396$) between the build-up of soil cover over the entire trial period of four years for NT (T1) and the crop treatment of T3.

4.1.2 Soil organic carbon readings – cover crop trials

SOC sequestration increased in three years under NT. The highest build up of SOC was at the 0-5cm level under NT with CC of 0.135% yr^{-1}. The highest build up of SOC at 5-20cm was under NT mulch at 0.027% yr^{-1}

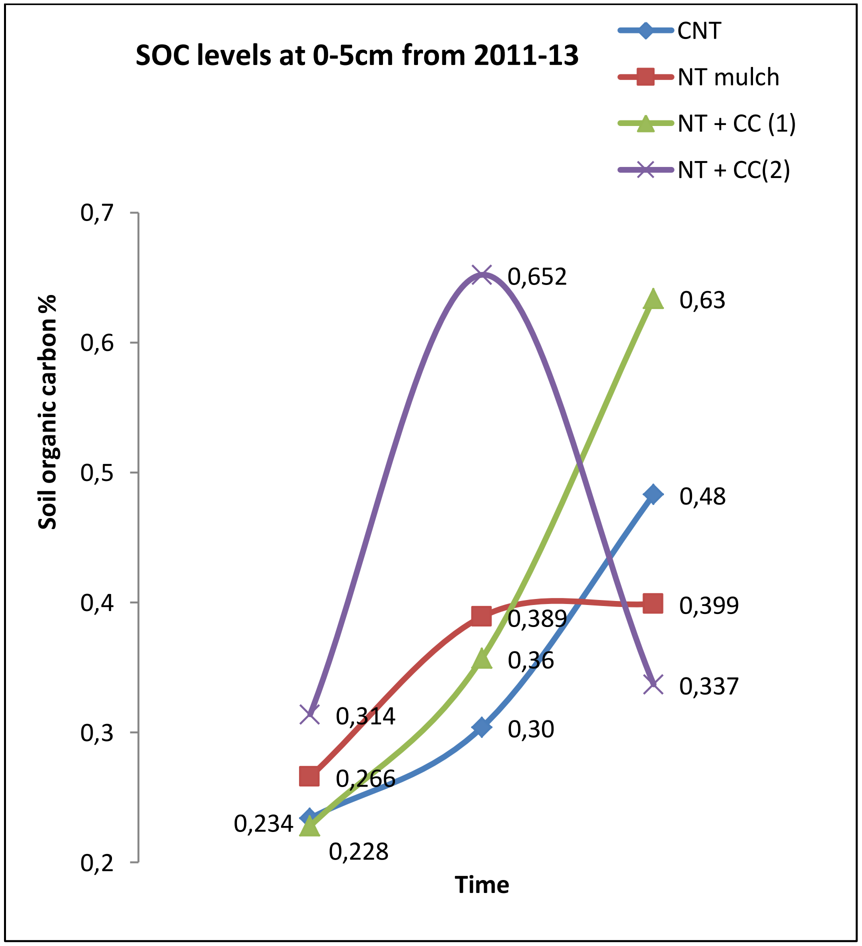
Table 22: Ranges of increased SOC yr^{-1} at 5-20cm and 0-5cm levels under different NT variants

Treatment	SOC (0-5cm) 3 year increase (%)	(0-5 cm) SOC% yr^{-1}	SOC (5-20cm) 3 year increase (%)	(5-20 cm) SOC% yr^{-1}
T1- Conventional NT	0.249	0.083	0.017	0.006
T2 – NT + mulch	0.133	0.044	0.08	0.027
T3 – NT + CC1	0.406	0.135	0.06	0.020
T4 – NT + CC2	0.023	0.014	0.04	0.014
Average (range)	**0.203**	**0.068**	**0.05**	**0.017**

Soil organic carbon was measured under the trials in January 2011, and in September 2011, 2012 and 2013 respectively. The graphs (2a,2b) below reflect SOC levels at 0-5 and 5-20cm analyzed by one lab over three years using the same extraction method.

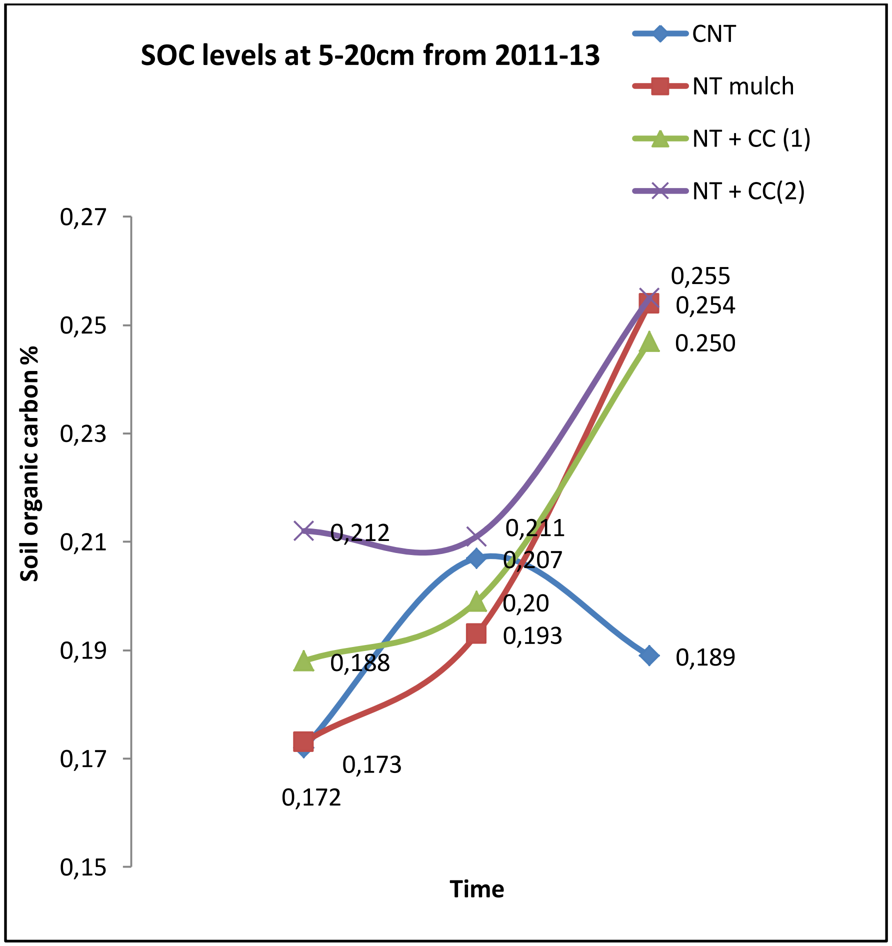
The oats-based cover crop mix (T3) showed an increase in SOC (0-5cm depth) of 1.35% per year whilst the stooling rye cover crop mix only showed an increase in SOC (0-5cm depth) of 0.14%. The results were therefore statistically tested and compared by using a one-way Anova ($F=3.077$; $p=0.130$). With $p=0.130$, it shows that there is no significant difference between carbon readings at 0-5 and 5-20cm soil depth when alpha = 0.05 and 0.10. The sudden increase and decrease of T4 (0-5cm) can only be explained in terms of the spatial variation in soils (O'Dell et al. 2013).

Graph 2a: Waterfall SOC trials at 0-5cm at 3 intervals: Sept 2011, 2012, 2013 respectively.



CNT = Conventional NT. CC1 is oats/grazing vetch/fodder radish. CC2 is the same, but stooling rye instead of oats
Source: own analysis

Graph 2b: Waterfall SOC trials at 5-20cm at 3 intervals: Sept 2011, 2012, 2013 respectively.



CNT = Conventional NT. CC1 is oats/grazing vetch/fodder radish. CC2 is the same, but stooling rye instead of oats
Source: own analysis

SOC was also measured at the comparative assessment off-site in September 2011 and 2013 respectively.

Table 22: comparative results of SOC levels (%) under NT/CV and veld at 0-5cm and 5-20cm depths in 2011 and 2013

Year:	2011						2013						Difference SOC% over 3 years					
Sample depth (cm)	0-5	5-20	0-5	5-20	0-5	5-20	0-5	5-20	0-5	5-20	0-5	5-20	0-5	5-20	0-5	5-20	0-5	5-20
Production system>>:	NT/ CA	NT/ CA	CV	CV	Veld	Veld	NT/ CA	NT/ CA	CV	CV	Veld	Veld	NT/CA	NT/CA	CV	CV	Veld	Veld
Site 1	0.497	0.347	0.475	0.410	-	-	0.789	-	0.460	0.317	1.590	1.280	0.292		(0.015)	(0.093)		
Site2	0.519	0.551	0.493	0.435	-	-	0.565	0.362	0.891	0.562	2.530	1.670	0.046	(0.189)	0.398	0.127		
Site3	0.330	0.281	0.475	0.378	1.020	0.223	0.449	0.332	0.505	0.428	1.990	0.726	0.119	0.051	0.030	0.050	0.970	0.503
Site4A	1.010	0.164	0.192	0.235	0.703	0.254	1.750	0.448	0.288	0.249	1.180	0.664	0.740	0.284	0.096	0.014	0.477	0.410
Site4B	0.425	0.255	-	-	-	-	0.601	0.428	-	-	-	-	0.176	0.173				
Site5	0.311	0.457	0.622	0.276	0.425	0.838	0.534	0.559	0.321	0.265	1.230	0.640	0.223	0.102	(0.301)	(0.011)	0.805	(0.198)
Site6	0.350	0.311	0.379	0.273	1.230	0.562	0.243	0.200	0.262	0.223	2.870	1.820	(0.107)	(0.111)	(0.117)	(0.050)	1.640	1.258
Site7A	0.457	0.380	-	-	-	-	0.575	0.472	-	-	1.510	0.994	0.118	0.092				
Site7B	-	-	0.312	0.268	1.970	0.810	-	-	0.317	0.373	2.890	1.680			0.005	0.105	0.920	0.870
Site7C	-	-	0.268	0.246	-	-	-	-	0.403	0.326	-	-			0.135	0.080		
Site8A	0.693	0.305	0.314	0.271	-	-	-	-	-	-	-	-						
Site8B	2.670	0.344	-	-	-	-	-	-	-	-	-	-						
Site9	1.570	1.240	1.180	1.130	1.060	0.690	1.600	1.220	1.380	1.290	0.875	0.794	0.030	(0.020)	0.200	0.160	(0.185)	0.104
Site10A	0.329	1.280		1.300	1.900	0.969	2.520	2.080	1.410	0.807	0.385	0.380	2.191	0.800	1.410	(0.493)	(1.515)	(0.589)
Site10B	-	0.954	1.240	0.607	-	-	-	-	-	-	-	-						
Add site 1	1.00	0.807	-	-	1.36	0.609	1.3	0.895	-	-	2.45	1.18	0.300	0.088			1.090	0.571
Add site 2	0.775	0.63	-	-	1.36	0.609	1.15	1	-	-	2.45	1.18	0.375	0.370			1.090	0.571
Add site 3	0.539	0.386	0.321	0.182														
Add site 4	0.392	0.336	-	-	1.33	0.423												
Add site 5	1.16	0.831	-	-	3.06	0.967												
Add site 6	1.56	0.61	-	-	2.24	0.864												

Year:	2011						2013						Difference SOC% over 3 years					
Sample depth (cm)	0-5	5-20	0-5	5-20	0-5	5-20	0-5	5-20	0-5	5-20	0-5	5-20	0-5	5-20	0-5	5-20	0-5	5-20
Production system>>:	NT/ CA	NT/ CA	CV	CV	Veld	Veld	NT/ CA	NT/ CA	CV	CV	Veld	Veld	NT/CA	NT/CA	CV	CV	Veld	Veld
Add site 7	1.02	0.944																
Add site 8	0.451	0.435																
Add site 9					0.809	0.516												

Source: own analysis. Note: site 8A and B data taken in 2012.

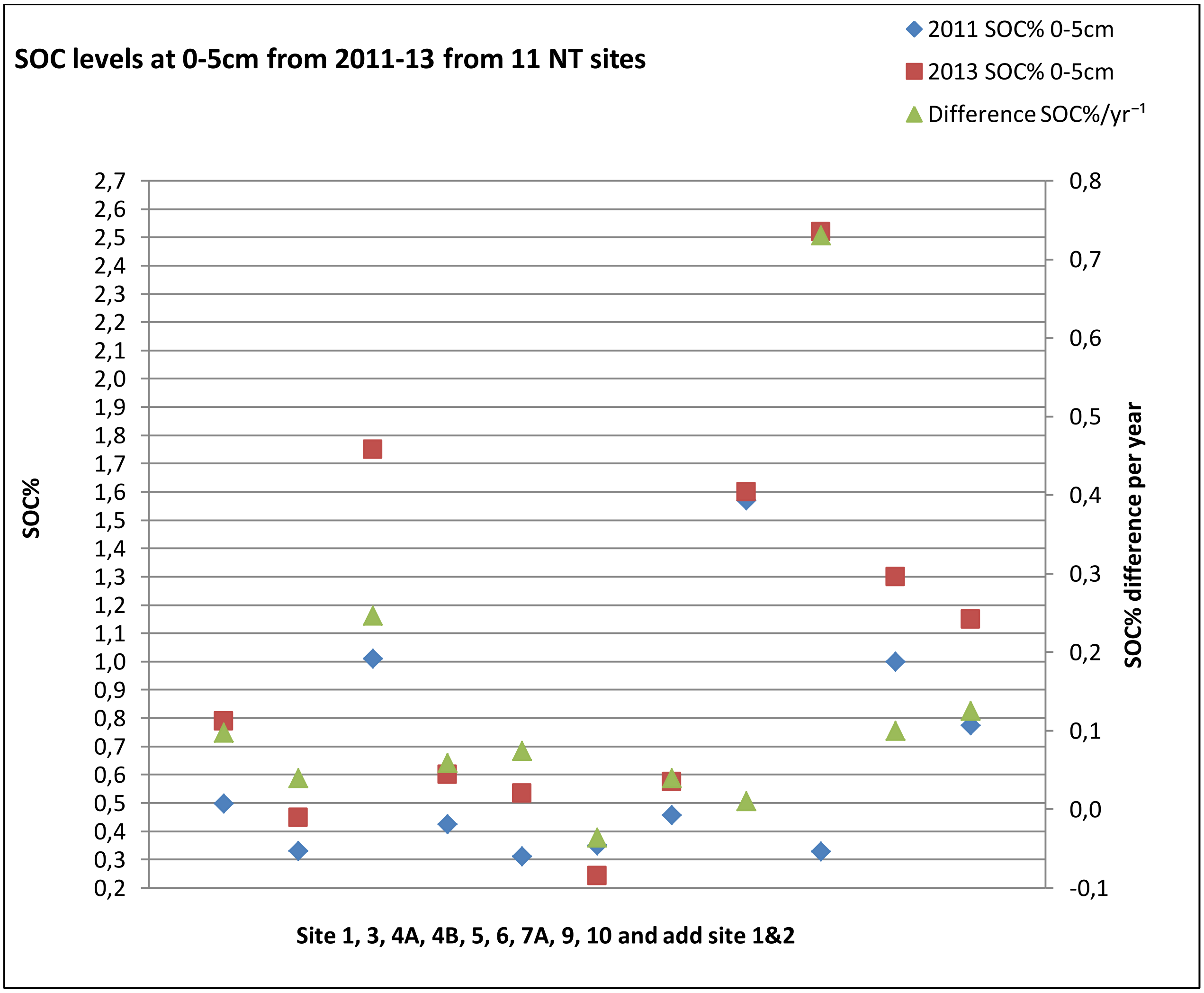
Add sites are additional sites for gaining insight in SOC levels. Bold figures in 2011 and 2013 highlight highest SOC under site specific comparison. All sites are within 600-800mm MAR area except sites 5, 6, 7A-C and add site 3-5 which fall in the 400-600mm MAR area.

There were nine and eight readings in 2011 and 2013 respectively were NT could be compared to neighboring CV fields on SOC levels at 0-5cm. SOC was higher at 6/9 and 5/8 in favor of NT. The results show higher rates of SOC build-up over 3 years as compared to CV. From the 10 NT sites (measured both 2011 and 2013) at 0-5cm four showed increased SOC% of >0.1% yr^{-1} were rate can be attributed to partial and continuous cover cropping. Five NT sites reflected increased SOC% of 0.02% - 0.07% yr^{-1}. Site 10 is omitted due to a high standard deviation.

There was no statistical difference in the SOC data when comparing all the different sites at 0-5 and 5-20cm depth. The assumption was that veld, as totally undisturbed, would have the highest SOC followed by NT and CV. It is generally assumed that changes in SOC would first be picked up in the 0-5cm layer. Reference was made in the introductory chapter that the effectiveness of statistical analysis was reduced by limited repetitions and comparisons of data over time across different agro-ecological zones. Site 3, 4a, 5, 6 and 9' s 2011 data was however compared with the 2013 data (i.e. 0-5 cm, complete and from one area) to assess any statistical significant difference in SOC buildup by using the F-test/ the one-way Anova.

The F and P values were (0.246; 0.633), (0.004; 0.948) and (3.669; 0.092) for NT, CV and veld respectively. Since the p values are higher than the alpha value of 0.05 we conclude that there is no difference between the means of the samples over a 3-year period. If however we changed the alpha value to 0.10 we then can conclude that the means for the veld samples are different. Cautiously one cannot state any significant differences at SOC sequestration build-up over a short-term period of 3 years. The fact that there are no significant changes between the samples might also refer to current NT systems without significant levels of biomass (i.e. soil cover).

Graph 3: increased SOC% levels at 0-5cm of 11 NT sites over 3 years reflected against annual difference in SOC%



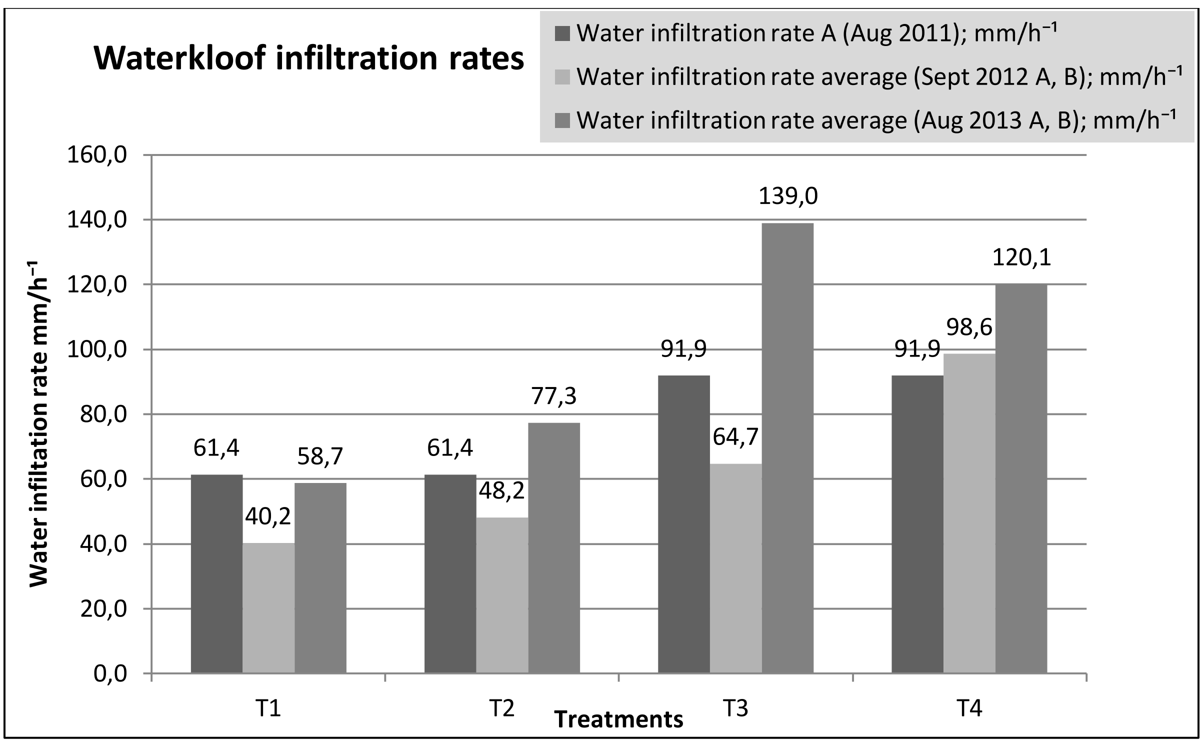
The highest SOC (both sampling depths) sequestration was under veld ranging from 0.4% - 3.06% in 2011 and 2013. Different sites, with high SOC levels at 0-5cm, were currently under cash cropping but were previously under pasture (details in brackets): Sites 4A & 4B (10 years followed by (fb) 3 yr cash cropping), 9 and 10A&B (30 years of pasture until 2008 fb 5 years of NT cover cropping) and 8B & add site 6-8 (26 years fb 1 and 2 year cash cropping). When looking at the SOC percentage increase or decrease of the NT data (i.e. in table 3 and graph 3) at 0-5cm depth over three years it is tempting to conclude that from the 11 entries (i.e. omit odd reading of site 10a) we see a 0.21% increase in SOC sequestration over 3 years (0.7% increase p.a.). By testing these data statistically by using a one-way Anova no significant difference is found in the buildup of SOC over 3 years at 0-5cm under NT in the eastern Free State of SA.

4.2 Plant available water capacity

4.2.1 Final water infiltration rates T1-T4

The results displayed some variability, but the highest final water infiltration rates were found in the two cover crop treatments, followed by the NT mulch treatment and lowest under the conventional NT treatment. The average water infiltration readings for T3 and T4 with three years of consecutive cover cropping increased every year as compared to T1 (conventional NT). The average soil water infiltration readings for T3 & T4 were 149%, 202% and 221% higher than T1 for pre-planting readings of 2011, 2012 and 2013 respectively. NT mulch (T2) was only marginally higher as compared to T1 of 120% and 132% for 2012 and 2013 respectively.

Graph 4: End-of-season soil final water infiltration rates under four different NT treatments in 2011-2013



The soil structure was assumed to be the same for all four treatments at December 2010. The mix of eight cover crops was planted in January 2011 under T3 and T4. This cover crop planting is referred to as “cover crops replacing bare fallow” in paper 3 of this thesis. Treatment 1 and T2, at that point in time were still the same i.e. T2 had build up no mulch yet. T1 and T2 without cover crops had water infiltration readings of 61.36 mm h^{-1}. T3 and T4 after the cover crops had water infiltration readings of 91.86 mm h^{-1}.

The final water infiltration rates improved over time under NT cover cropping (T3 and T4), as seen visually in graph 4 above. There was however no significant difference in final water infiltration rates when testing it statistically by using a one-way Anova. The statistical analysis (under 2.2) including more replications did show a statistical difference in final water infiltration rates.

4.2.2 Final water infiltration rates NT sites, compared to veld and CV

Natural veld had the highest final water infiltration rates followed by NT/CA and lastly CV (see tables 4 and 5), based on a 10 site reference assessment. Average final water infiltration rates cannot be given because each site is ecotype specific. The water infiltration comparative assessment at 10 sites (table 4) conducted in 2011 (and one reading in 2012) was highest under veld followed by CV and NT with 8, 2 and 1 highest readings respectively. The assessments in 2013 were conducted at the same sites as in 2011. The highest water infiltration readings were under NT/CA followed by veld and CV of 5, 4 and 1 highest reading respectively.

Table 23: Soil final water infiltration rate (in mm h-1): Results of the comparative final water infiltration assessment conducted (2011-2013) on different sites under CV, NT and natural vegetation (veld) in the eastern Free State

Site number	2011 (NT/CA)	2011 - (CV)	2011 (VELD)	2012 (NT/CA)	2012 (CV)	2012 (VELD)	2013 (NT/CA)	2013 (CV)	2013 (VELD)
Site 1	17	18	301	-	-	-	64	62	83
Site2	28	19	114	-	-	-	143	33	90
Site3	62	8	330	-	-	-	14	7	141
Site4	813	45	53	33	-	-	89	30	51
Site4 CTRL	33	45	53	30	-	-	33	30	51
Site5	7	4	15	-	-	-	36	74	70
Site6	12	12	68	-	-	-	48	41	68
Site7	8	14	21	-	-	-	48	42	41
Site8	48	51	15	-	-	-	329	51	51
Site9	56	71	55	-	-	-	286	87	72
Site10	-	-	-	39	4	42	-	-	-

**The reading of 813mm under NT in 2011 (site 4) was an average of two readings and can only be explained as exceptionally high indicating the impact of biopores on final infiltration rates. It was caused most likely due to underground tunnels of gerbils. Follow up readings were therefore taken in 2012 at those sites.*

The results show that there were 6 sites for both NT and CV that had improved readings in 2013 as compared to 2011. NT had the highest gain of 97 mm h^{-1} over the six sites with improved readings as compared to CV of 29mm h^{-1} (table 4).

The final water infiltration rates were higher in the 600-800mm area as compared to the drier 400-600mm areas. The latter had less soil cover during the entire research period of 3 years, which can be contributed to lower precipitation levels i.e. lower biomass levels, less cash cropping i.e. planting crops for standing feed and consequently different grazing periods ha^{-1}. All infiltration rates > 100mm h^{-1} (see table 5 below) were results of either one of the following: natural veld, cash cropping after pasture or cover crops repeatedly included into the rotations.

The odd reading of 813mm h^{-1} was removed and the control figure was taken. That control figure was confirmed in 2012. Sites 5-7 were taken out in an attempt to get rainfall areas more homogeneous (see table 5 at p 172 - description of sites). The treatments were compared in 2011 ($F = 3.510$; $p=0.056$) and in 2013 ($F=2.310$; $P=0.133$). At alpha = 0.10 and alpha = 0.15 we can read a significant difference in the final water infiltration rates. We argue that the differences most likely flow from factors like different annual rainfall figures (i.e. per ecotype) and ground water levels.

Table 24: Site description, history and background of NT sites used for final water infiltration & soil quality assessment in 2011-2013

Site no.	Start NT (yr)	MAR zone (mm yr^{-1})	Prior 2010 (if known)	Crop(s): 2010/11	Crop(s): 2011/12	Crop(s): 2012/13	Soil Cover % 2011	WI 2011	SOC 0-5cm 2011	Soil Cover % 2013	WI 2013	SOC 0-5cm 2013	Pasture feature in strongly	CC feature in strongly
Site 1	2006	600-800	M-W rotation	Maize	Wheat	CC after Wheat – grazing vetch	60%	17	0.497%	100%	64	0.789%		In 2013
Site2	2006	600-800	M-W rotation	Maize	Wheat	CC after wheat - oats	60%	28	0.519%	70%	143	0.565%		In 2013
Site3	2010	600-800	-	Maize	fallow	Maize	10%	62	0.330%	50%	14	0.449%		
Site4	2010	600-800	Eragrostis 10 yrs	Soya	Soya	Soya + CC Triticale	100%	813	1.010%	80%	89	1.750%	Prior to NT	In 2013
Site5	2008	400-600	Wheat	Soya	Soya	Soya	50%	7	0.311%	20%	36	0.534%		
Site6	2009	400-600	Maize	Oats	Soya	Soya	30%	12	0.350%	25%	48	0.243%		
Site7	2004	400-600	Grain sorghum	Oats	Oats	Grain sorghum	95%	8	0.457%	0%	48	0.575%		
Site8	2008	600-800	Pasture 30yrs before 2008	Maize + rye CC	Maize	Sugar beans +oats/grazing vetch	90%	48	1.570%	95%	329	1.600%	Prior to NT	All years
Site9	2008	600-800	Pasture 30yrs before 2008	Maize+ triticale/rye	Maize + grazing vetch	Maize + re-seeding of GV	80%	56	0.329%	90%	286	2.520%	Prior to NT	All years
Site10 (2012)	2007	600-800	Maize	Soya	Wheat	Land sold	80%	39	0.693%	-	-	-		
Additional sites	2007	600-800	Maize + W/FR/GV	S-Beans + CCMIX	Fodder Sorghum + GV	S-Beans +O/GV	85%	28	1.000%	95%	10	1.400%		All years
	2007	600-800	Maize W/FR/GV	S-beans /Cowpeas + CC MIX	Maize + GV	S-Beans +O/GV	40%	204& 339	0.775%	80%	129	1.100%		All years

Source: Own analysis.

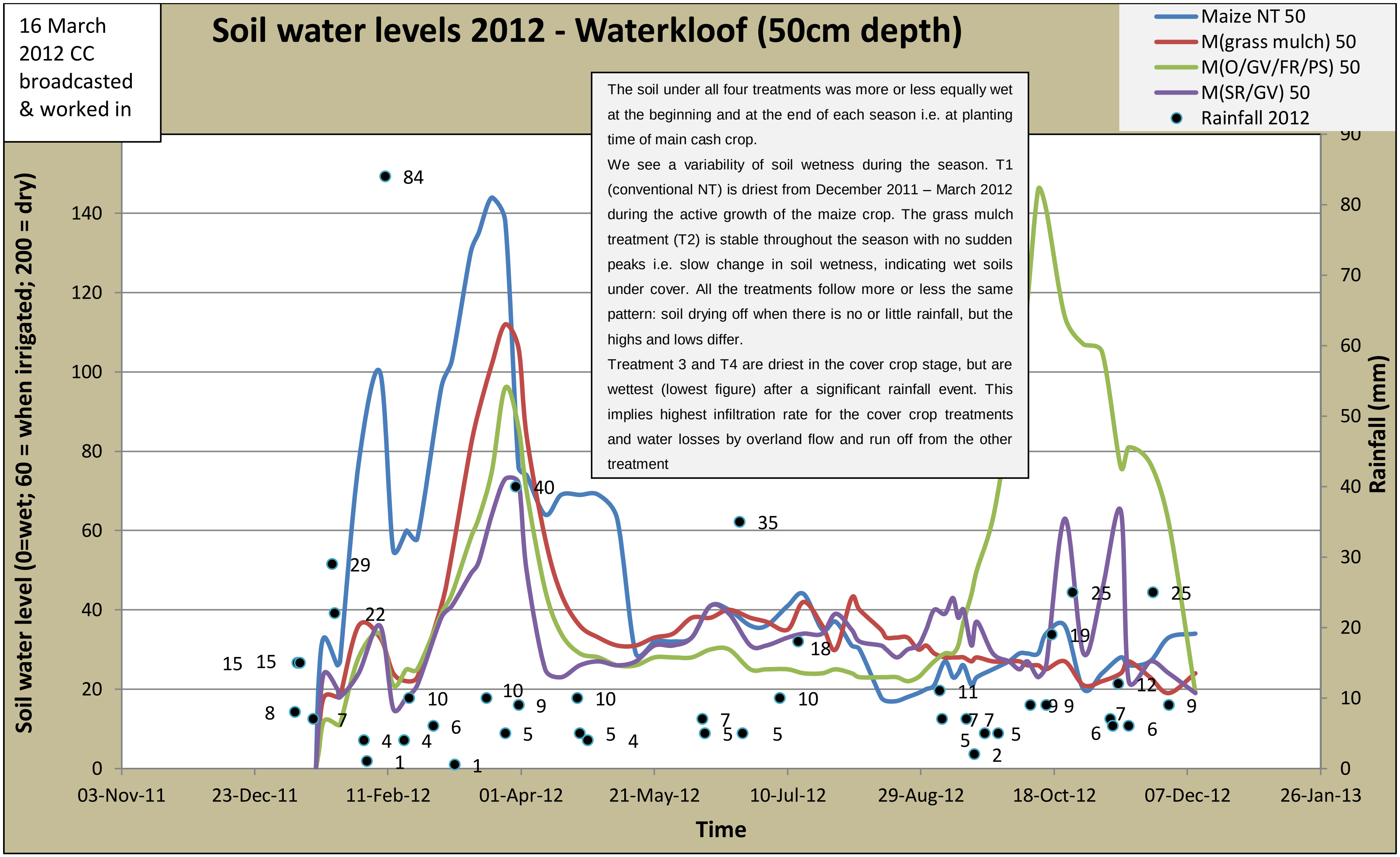
4.2.3 Soil water levels

The soil was equally wet in 2010/11 for all four treatments, after exceptional high rainfall that year (759mm) after January 2011 (when the initial mix of 8 cover crops were planted), till September 2011. The soil was more or less equally wet under all 4 treatments at depths of 100cm (readings between: 13-16) and 50cm (readings between: 16-22). The results are therefore not presented in detail here.

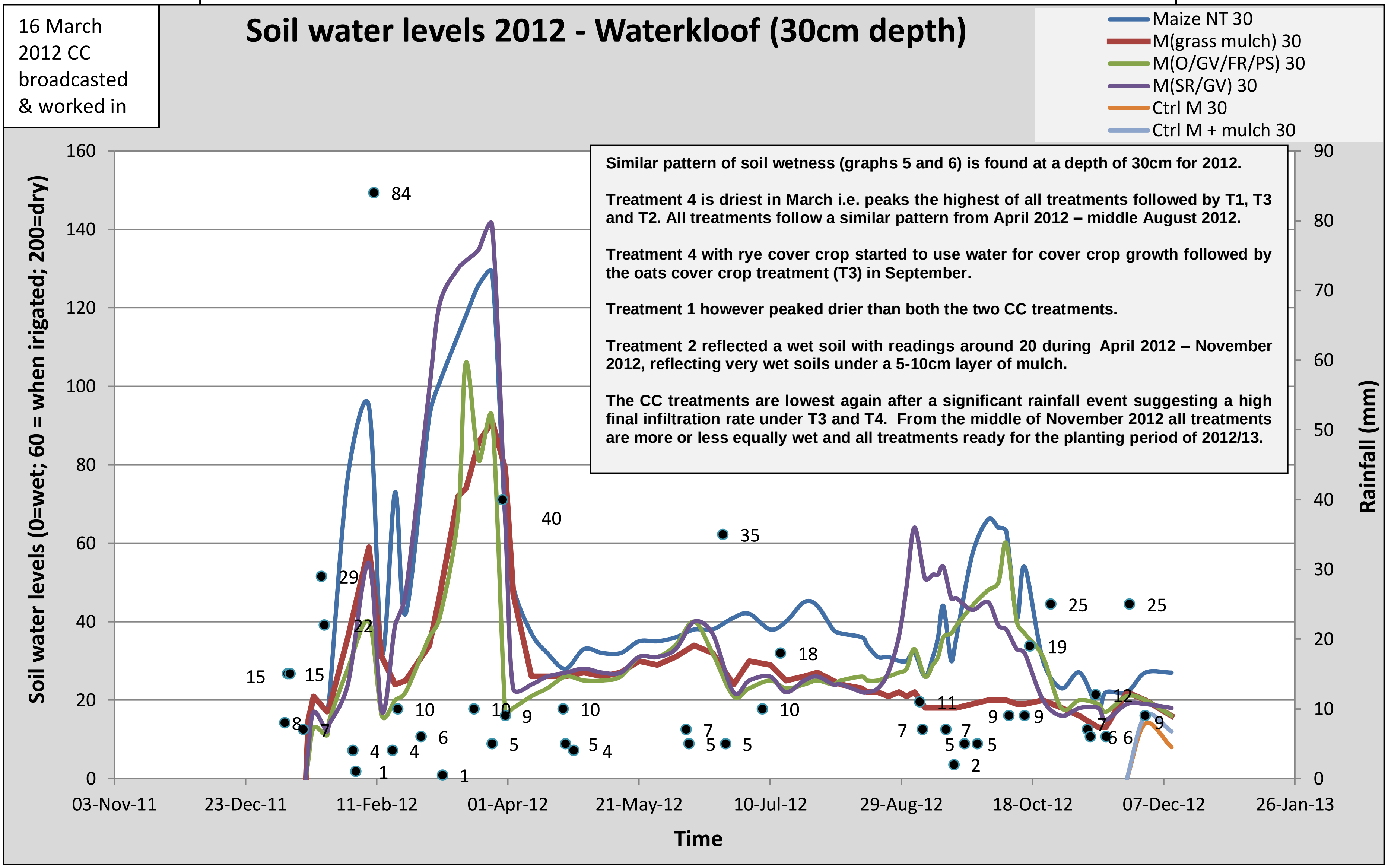
The months (August – July) of 2011/12 and 2012/13 had a seasonal rainfall of 508mm and 615mm respectively. The winter cover crops inter-seeded into standing maize in March 2012 received good rains of 65, 19, 0, 52, 28, 0, 37mm for the months of March - September 2012 respectively. The cover crops inter-seeded in March 2013 received hardly any rain, in contrast to 2012 cover crop period (May – Sept). The rainfall figures for the individual months of March 2013- September 2013 were 61, 0, 0, 0, 0, 5 and 0mm respectively.

The two cover crops treatments were able to produce double crops. Both set of cover crops (T3 and T4) performed well and produced cover yields of 1000, 1500 and 2500 kg ha^{-1} for T3 (2011/12), T4 (2011/12) and T3&T4 (2012/13) respectively.

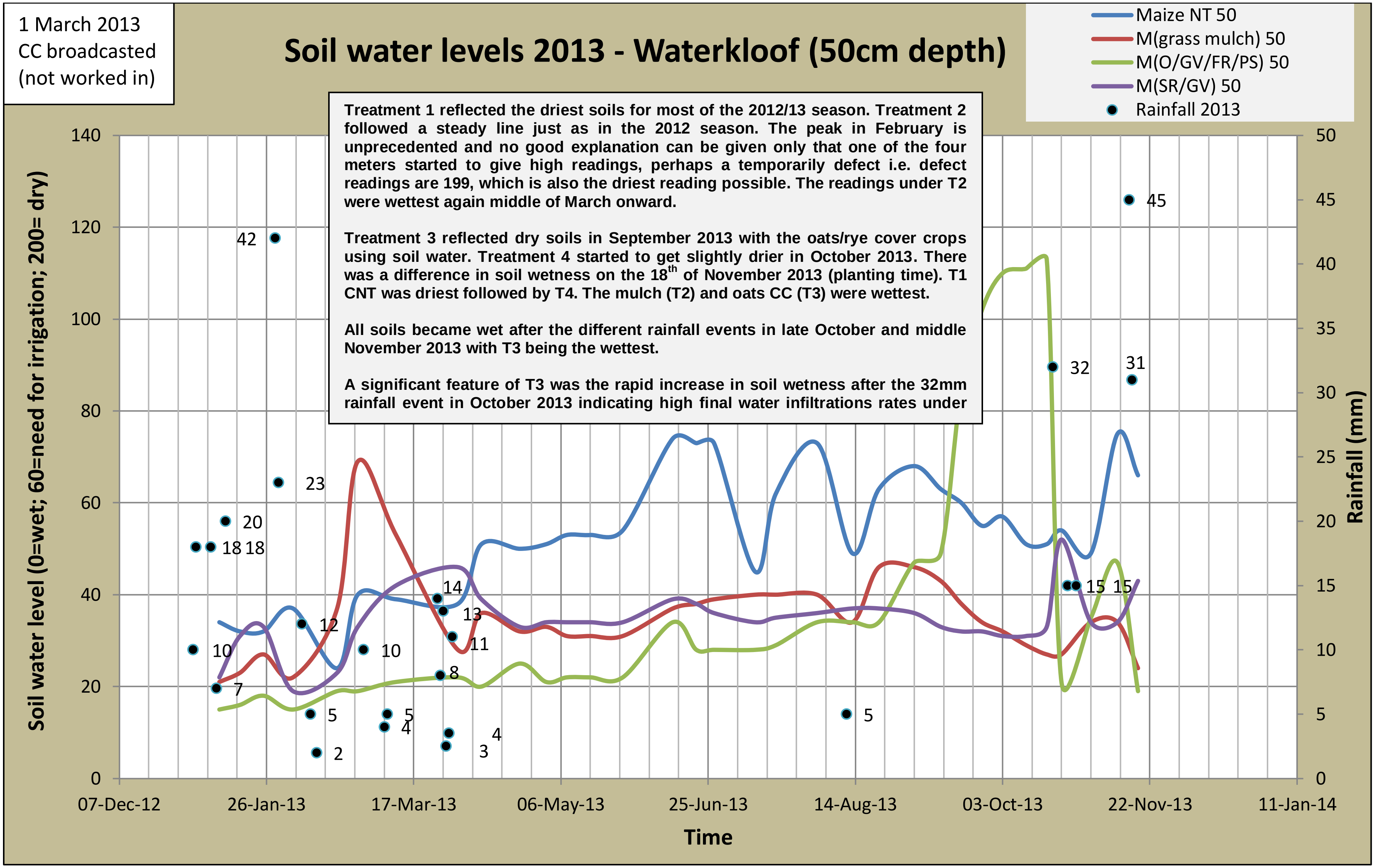
Graph 5: Waterfall trial data: soil water levels for 4 different treatments in the 2011/12 season at 50cm depth



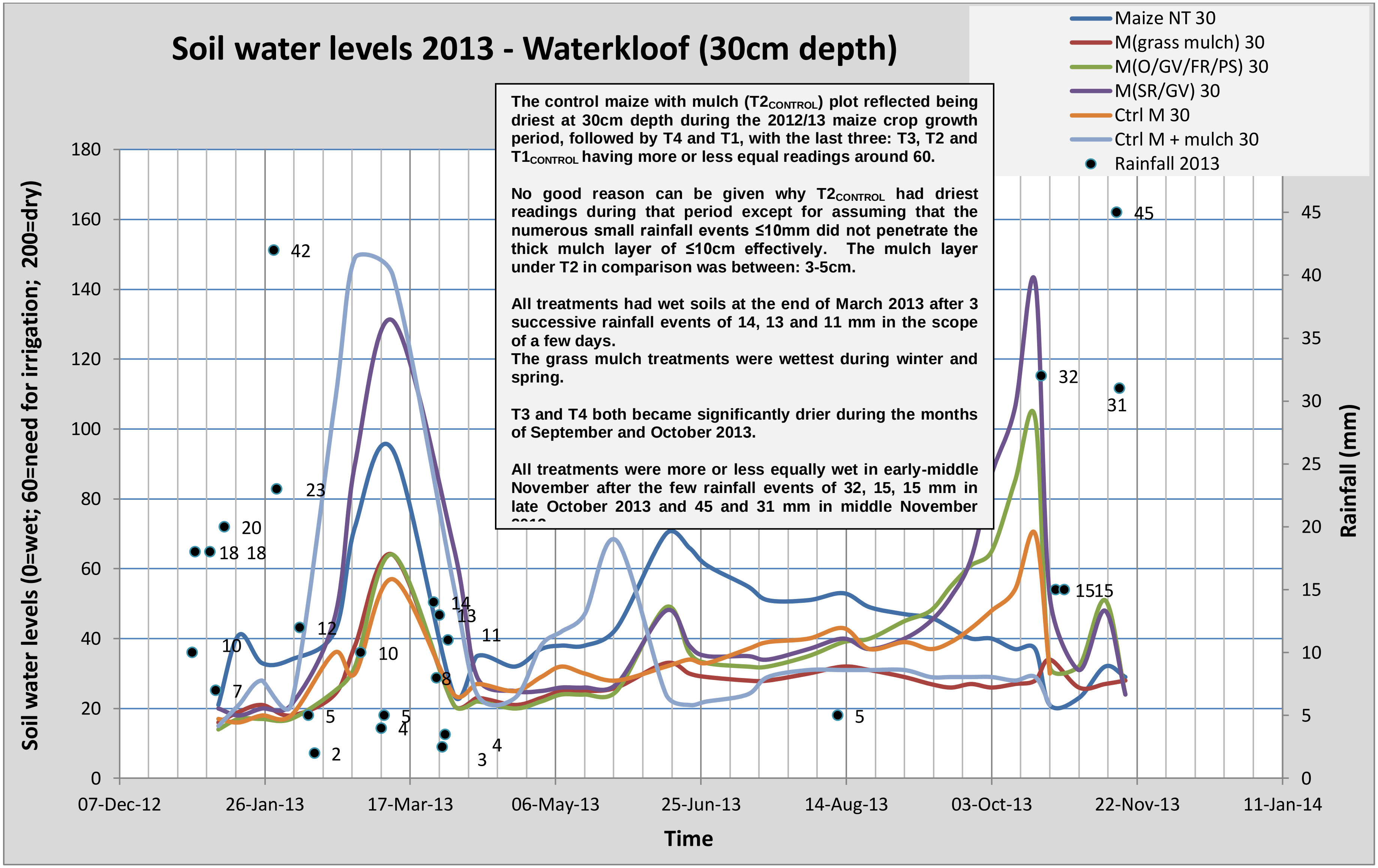
Graph 6: Waterfall trial data: soil water levels for 4 different treatments in the 2011/12 season at 30cm depth



Graph 7: Waterfall trial data: soil water levels for 4 different treatments in the 2012/13 season at 50cm depth



Graph 8: Waterfall trial data: soil water levels for 4 different treatments in the 2012/13 season at 30cm depth



The ideal cover crop planting period was found to be around March each year. All four graphs (graphs 5-8) showed wet soils in March i.e. when the main cash crop should start drying off, leaving excess moisture for CC growth. The cover crop treatments (T3 and T4) are wettest or equally wet at the planting stage of cash crops in November of 2012 and 2013. This reinforces the findings of Sooby et al., (1997), McNee et al., (2008) and Seif and Pederson (1978) that timely rainfall is required to establish a successive crop. The limiting feature in the environment is good spring rains.

A comparison of the treatments based on the average wetness at 30cm depth for the period 2012 lead to the following conclusions. The difference between NT (T1) and mulch (T2) is highly significant (p=0.000; F=15.706). The difference between NT (T1) and the oats-based cover crop (T3) is highly significant (p=0.001; F=11.433). There is no significant difference between NT (T1) and T4 (p=0.322; F=0.988).

4.2.4 Crop water productivity (CWP)

The CWP was highest under the two CC treatments (T3 and T4) followed by T2 and T1 (table 6). The total beneficial biomass (Y_i) accrued over the 3 years was 5,491, 6,342, 13,940 and 15,482 kg ha^{-1} for treatment 1-4 respectively.

Table 26: Description of beneficial biomass accrued under different treatments over a period of 3 years from January 2011 – November 2013, during the Waterfall cover crop trial period

Description of beneficial biomass (Y_i in kg ha^{-1})	T1	T2	T3	T4
CC 2011 after wheat (mixture of fodder sorghum, millet, grazing vetch, stooling rye, oats, cowpeas, pink seradella and fodder radish)	-	-	3,500	3,500
Maize 2011/12	4,333	4,710	5,157	5,362
CC 2012 after maize	-	-	1,000	1,500
maize 2012/13	1,158	1,632	1,783	2,720
CC 2013 after maize			2,500	2,400
TOTAL	5,491	6,342	13,940	15,482

Source: Own analysis

The seasonal rainfall was 2031mm from January 2011 when the mix of 8 cover crops was planted till 18th of November 2013 before the 2013/14 cash crop plant season. The CWP_i was 2.70, 3.12, 6.87 and 7.62 (kilogram beneficial biomass per millimeter of rain) for treatment 1-4 respectively. Double cropping i.e. higher crop intensity or agronomic productivity, was possible under T3 and T4 without jeopardizing cash crop yields, which were in fact highest under T4 followed by T3. The maize yields under the CC treatments T4 and T3 were 1.23, 1.19 and 2.35, 1.54 times higher than the conventional NT maize yields for the 2011/12 and 2012/13 seasons respectively.

By mere looking at the table we see accrued biomass over the trial period under T3 and T4. However, when testing the maize yields statistically by using a one-way Anova, there was no significant difference due to lack of replications. This implies no decline in maize production under NT when using cover crops.

4.3 MDS scoring

The complementary comparative SQ assessment results were in favor of veld/pasture followed by NT variants and lastly CV (table 7b). The trials results indicated that NT cover crops followed by NT mulch are the best NT variants (table7a).

Table 25a, 25b, 25c: Soil quality MDS indicators, tested through trials and complementary research, compared under different crop production system in the eastern Free State

Description MDS indicator	Sub Indicators (trials)	CNT	NT_{MULCH}	NT_{CC}
Soil organic carbon	Soil cover build-up	√	√√	√√√
	Weed pressure	√	√√√	√√
	SOC sequestration (%)	√	√√	√√√
Plant available water productivity	Soil final water infiltrations rates in mm h^{-1}	√	√√	√√√
	Soil water levels i.e. wetness of the soils	√	√√√	√√
	Crop water productivity	√	√√	√√√
TOTAL		6	14	16

Source: Own analysis

Description MDS indicator	Sub Indicators (comparative assessment)	CV	$NT_{VARIANTS}$	Veld/ pasture
Soil organic carbon	Soil cover build-up	√	√√	√√√
	SOC sequestration (%)	√	√√	√√√
Plant available water productivity	Soil final water infiltration rates in mm h^{-1} NT vs. CV with natural veld as benchmark	√	√√	√√√
TOTAL		3	6	9

Source: own analysis

Description MDS indicator	Statistical analysis report	CNT	NT $_{MULCH}$	NT $_{CC}$	CV	NT $_{VARIANTS}$	Veld/ pasture
Soil cover (T1-T4)	There was a significant difference in soil cover when comparing CNT (T1) with T3 (oats-based cover crop mix) and T4 (stooling rye based cover crop mix). Highly significant difference between T3 and T1.	-	√√	√	n/a	n/a	n/a
SOC trial (T1-T4)	Statistically no significant difference	-	-	-	n/a	n/a	n/a
SOC (other sites: NT, CV, veld)	With the alpha value at 0.10 SOC values for veld are different. No significant difference between CV and CNT	n/a	n/a	n/a	-	-	√
Final water infiltration (T1-T4)	Statistically no significant difference	-	-	-	n/a	n/a	n/a
Final water infiltration (other sites: NT, CV, veld)	With the alpha values at 0.10 and 0.15 Final water infiltration readings are different.	n/a	n/a	n/a	-	√	√
Soil water levels (average wetness of soil) (T1-T4)	There was a significant difference in average soil wetness when comparing CNT (T1) with T2 (NT mulch)/ T3 (oats-based cover crop mix). No significant difference withT4 (stooling rye based cover crop mix).	-	√√	√	n/a	n/a	n/a

Key: n/a implies not tested as part of research design.
Source: own analysis.

5. Conclusion

Soil carbon levels and plant available water capacity are good indicators of the minimum data set comparing the soil quality under different crop production systems. The two main indicators had useful sub-indicators of soil cover, weed counts, soil organic carbon sequestration and final water infiltration rates, soil water level (wetness) readings and crop water productivity. From the trial data we can conclude that NT with continuous cover cropping was found statistically more sustainable than conventional NT. The data from the additional sites found statistically no difference between CNT and CV.

The conventional NT was outperformed by NT mulch and NT cover cropping with statistical significance on soil cover buildup and average soil wetness. The soil cover build-up was highest under NT with added mulch of 95%-100% and had consequently also lowest weed counts. NT cover crops however resulted in highest soil cover at planting of main cash crop as compared to NT mulch which was topped up to 100% after planting. There was statistically no significant difference between the SOC and final water infiltration rates of the four treatments. The cover crop treatments, however, scored highest on crop water productivity, although there was not a significant difference found on the maize yields over the two years. This brings us to the point of a potential misread of the data. The visual trial data (i.e. not statistically tested) tend to be interpreted overwhelmingly in favour of NT mulch (T2) and NT cover cropping (T3,T4) above conventional NT (T1). Statistically, by using a one-way Anova with the alpha value of 0.05, there was no significance difference between the two main MDS indicators of SOC and final water infiltration rates between the four treatments. In most cases we did observe a difference between the oats-based cover crop mix T3 and the stooling rye-based cover crop mix T4 that is sometimes in favour of T3 (i.e. soil cover, SOC, and average soil wetness) and sometimes in favour of T4 (i.e. final water infiltration rates and CWP). NT cover cropping outperformed CNT (T1), but we recommend more in depth research on cover crop varieties and cover crop mixes.

Conventional farming (CV) practices were not included in the trials and therefore addition NT sites in the eastern Free State were selected and compared with a nearest possible untreated CV reference site and within 50m from the cropland sample site. Statistically there was no difference in SOC under NT and CV. With the alpha value at 0.10 SOC values for veld are different. The final water infiltration readings are different with the alpha values at 0.10 and 0.15. The interpretation of the additional site readings is in favour of veld followed by NT and CV. Based on limited data NT was not found to be statistically significantly better than CV. These findings made us to assume that NT is only practiced recently (i.e. short period of time), without proper soil cover, and without sound crop rotations (see table 5).

More financial-related research is needed on CC, mulching and ley crops, adding cost-benefit analysis to the results of this paper. The trials did not include research on pastures or ley crops, but the complementary findings suggest strong consideration of including ley crops and or pastures into NT crop rotations.

The trial findings concluded that double cropping is possible in the eastern Free State. The CWP of the two CC treatments had on average a 2.68 and 2.32 times higher reading than conventional NT and NT mulch respectively. The trials showed that NT cover cropping is more environmental sustainable than NT mulch or CNT. It can be concluded therefore that CA, as an improved variant of NT cover cropping, is a climate change mitigation strategy as compared to CNT and CV. The findings in this paper found that NT cover cropping (CA) reduces the risk of farming against the background of increased rainfall variability i.e. quantity as well as seasonal distribution as a result of climate change. We assume that SOC will consequently improve under NT cover cropping.

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PAPER 5

CONVENTIONAL FARMING, CONVENTIONAL NETWORKING: THE ACTOR NETWORK THEORY EXPLAINS STUNTED AND HYBRID NETWORKS

Abstract

Farmers in the eastern Free State adopted no-tillage (NT). This term should not be confused with Conservation Agriculture (CA), which is an approach to farming that conserves resources like water and soil. It is based on three principles: disturb the soil as little as possible, apply permanent soil cover and have good crop rotations that include legumes. NT is one of the three CA principles. The adoption of CA is increasing globally. Farmers in the eastern Free State of South Africa are gradually improving their NT systems towards CA, but it is not merely 'technology transfer', but a construct of a whole new production system. Gradually more and more farmers are switching to no-till or at least minimum-till farming. Operating amidst an unsupportive NT-farming network, the initial converts to no-till or NT-pioneers faced challenges like lack of equipment, information and technical knowledge. However, they overcame those challenges. Farmers, through innovative thinking, by trial and error and by obtaining information through different networks, made no-till work on their farms. This paper draws upon concepts and discourse of the Actor Network Theory (ANT). This theory, also called the 'sociology of technology' or 'sociology of translation', is tremendously useful in studying innovations and their adoption. It helps in understanding the relationships between people and technology. ANT is applied successfully in a number of studies, and this paper reflects the theory's usefulness when dealing with social and natural issues related to CA. ANT is also useful in interdisciplinary research. This paper draws on the 'translation' concepts as introduced by Callon (1986).

Keywords: Actor Network theory, CA, knowledge, problem solving ability, interface, networking

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1. Introduction

Conservation Agriculture (CA) is an approach to farming, classified under 'sustainable agriculture', that ensures the use of agricultural practices which conserve water and soil and are environmentally non-degrading, technically appropriate, economically viable and socially acceptable (Du Toit, 2007). CA is based on three principles and can therefore be defined as crop production systems in which the soil is mechanically disturbed as little as possible; crop and other plant residues are retained on all or much of the soil surface at all times; and two and preferably more types of crops are planted on the same land as inter or cover crops or in sequence or defined rotation (Fowler, 2004).

In an historical overview since 1973/4, all continents show increasing adoption rates of no-till. In fact, the adoption of Conservation Agriculture is still growing globally. A total of approximately 105-110 million hectares are currently being cultivated globally according to the principles of CA (Derpsch, 2008; Derpsch et al., 2010). North America constitutes 46.8% of the world's adoption rate, while South America and Australia 37.8% and 11.5% respectively. South Africa is referred to as the Sleeping Giant in no-till by Derpsch (Derpsch, 2003 and Fowler, 2004). There is much scope for no-till, but thus far little has been done about it.

Another paper in the thesis compares CA with conventional agricultural cropping practices (CV) on environmental- and economic sustainability. Different authors have analyzed the effects of soil erosion and land degradation as a result of conventional tillage (Decker et al., 2011, Mills and Fey, 2003, Le Roux et al., 2007, Compton et al., 2010 and Hall, 1997). The results of the comparative assessment were significantly in favor of CA. CV was found to be environmentally unsustainable. CA, on the other hand, was found economically and ecologically sustainable, provided all three CA principles were consistently and simultaneously applied.

However, the question regarding the adoption of CA in the eastern Free State of South Africa, and its social sustainability, remained unanswered. If CA is technically so good, why is its uptake relatively low? Nine out of the ten local interviewed no-till (NT) farmers adopted the technique in order to reduce input costs. Local conventional farmers did not adopt NT because of lack of information and lack of good NT examples. They furthermore assumed that livestock could not be integrated with NT; they anticipated a financial dip in the first three years after adoption; they perceived adoption at this stage to be risky and could not afford loss in income or invest in NT equipment whilst still having a barn full of tractors and equipment.

This paper goes beyond that initial adoption question and looks for answers that could explain the relations between people and technology. The Actor Network Theory helps formulate an explanation in this regard.

The purpose of this paper is twofold. The first is to briefly review conceptual issues involved with the innovation of no-till cropping and conservation agriculture. The main argument, drawing upon the Actor Network Theory (ANT), is that farmers possess “agency” as a result of networking, which enables the uptake of an innovation of NT and in addition to develop into CA. NT is created through new networks and relationships involving actors and non-human ‘actants’ (Greenhalgh, 2010) like soil, (cover) crops, herbicides, livestock and farm implements. The term ‘Actants’ is used to refer to phenomena that have causal impact. The new networks constitute a new cropping agriculture and a new production system of CA.

The second purpose of this paper is to illustrate the use of the Actor Network Theory as a valuable approach by analyzing ten NT-pioneers and several conventional farmers in the Eastern Free State. The ANT helps in answering the question of why some farmers in the eastern Free State adopt NT and CA, whilst others do not. Those that are not adopting still ‘hang in’ old networks of information dissemination, whilst adopters expanded their network and formed new hybrid networks.

2. Theoretical perspectives

2.1. Actor-Network Theory

What social theory can best explain the interaction between society and nature by describing the adoption of an innovation? Classical sociology refers to the disjuncture between the two initial main schools of thought: action-oriented and structure-oriented theories. Giddens bridged those two paradigms with his Structuration theory in the 1980’s (Giddens, 1979 and 1984). Post-structuralist social theory suggests that agency is located neither in individuals nor in social structures, but rather is an emergent property of networks or collectives (Goodman, 1999 cited in Trauger, 2008). This lead to the Actor Network Theory (ANT).

The ANT originated from a totally different perspective as the classical sociology. Although being a post-structuration and post-social theory, it did not develop out of the classic sociological dualism of symbolic interactive and structures. ANT developed out of the disciplines of sociology and technology (Stanforth, 2006). The ANT proposes new possibilities for understanding structure as a network and agency as the outcome of networking (Trauger, 2009, p. 117). Part of the book from Mosse and Lewis (2006) gives insight in a lengthy and comprehensive overview of how ANT supplemented the actor-oriented approaches. Mosse and Lewis (2006, p. 14) stated that it is with the use of the 'translation concept' that the Actor Network Theory (ANT) has enriched earlier actor-oriented approaches.

The concept of "translation" in this paper refers to a 'desired' change from conventional ways of farming to no-till and eventually to Conservation Agriculture. The difference between NT and CA has been highlighted in detail in other papers of this thesis. CA refers to a point in time, in which NT and the two other CA principles – adequate soil cover and sound crop rotations – are applied simultaneously. In practice, farmers may introduce one element first, and later, the others. This may make CA more acceptable, as farmers gradually adapt to it. NT, for example, without significant cover and crop rotations might score less on soil quality parameters than CV (Govaerts et al., 2006, p. 172). Suffice it to say that NT, as one of the three CA principles, needs to be supplemented with good soil cover and legume-based crop rotations in order to 'obtain' that desired change of ecological and economic sustainability (Reeves, 1997 and Zanatta, 2007).

The ANT explains socio-technical change well. The ANT has been selected for this paper for a number of reasons. Firstly, ANT is well established and several publications reflect its usefulness in social-nature research, policy formulation and technology studies (Stanforth, 2006; Mosse and Lewis, 2006; Noe and Alroe, 2003; Coughenour, 2003; Trauger, 2009; Tatnell, 2002; Bush and Juska, 1997; Johnston, 2001; Bear and Eden, 2008; Power, 2005; Fenwick, 2010; Paget et al., 2010; Kraal, 2007 and Mikus, 2009). Secondly, the ANT has been comparatively stable, with later presentations building on the original theory, probably because the theory is "owned" by a relatively small group of writers (Stanforth, 2006, p. 38). Thirdly, it offers "open-minded" application tools for dealing with interdisciplinary problems in social-ecological systems, and it is capable of addressing complex social–ecological interactions. In sum, "the ANT decentres the inevitabilities of structure, provides relational ontologies of agency and resistance that address the frictions of distance and acknowledges the agency of non-human actors in social and political change" (Trauger, 2009).

2.2. The five stages of the Actor-network Theory (ANT)

The ANT helps us understand the relations between people and technology (Stanforth, 2006, p. 38). The translation process is practically explained on the basis of four stages: problematization, "interessement", enrolment and mobilization. A fifth stage – dissension – can happen, whereas the four stages become repetitive. The translation refers to a two-stage process: the conversion of conventional farming to NT and secondly the gradual improvement of NT to CA.

2.2.1 Problematization

Problematization, in this research, refers to an actor that analyses a situation, defines the problem and proposes a solution (Norbert and Schermer, 2003). Different actors operate in the area and have so their views on agriculture, agri-business, NT, just to mention a few. Who are the actors involved, and can they be defined? At this point we postulate that NT is ecologically and economically more sustainable than conventional farming (Mupangwa et al., 2007, p. 3; Dowuona and Adjetey, 2010; and Scopel et al., 2005). The adoption of NT would surely make rational sense from the point of view of financial outlays as well as management of the natural resource. If farmers do not adopt NT then reasons should be identified. Each actor, over and above farmers, has at this stage, their own obstacle(s) and reasons for not promoting or adopting NT i.e. referred to as the barriers to the adoption of NT. In this paper we also refer to it as the "obstacle problems" (Callon, 1986, p. 8).

Callon (1986) stated that "translation" is a process, never a completed accomplishment, and it may fail. If CV farmers don't adopt NT, then it reveals a stunted 'process of translation' and can therefore be called a failed translation. The translation is successful when conventional farmers are able to convert to NT and secondly the NT-pioneers are in the process of developing the NT system into CA on their farms. Two NT-pioneers' narratives are documented in another paper of this thesis. Both have emerged as successful NT farmers. Their proposed solution to their price-cost squeeze effect and declining profitability was implementing a no-till farming system. Both converted to NT around 2003/4.

2.2.2 Interessement

"Interessement" is the group of actions by which an entity (any of the local actors) attempts to impose and stabilize the identity of the other actors that it defines through its problematization. In other words, the main agents attempt to make others interested in the solution proposed (Norbert and Schermer, 2003). To interest other actors is to build devices which can be placed between them and all other entities who want to define their identities otherwise (Callon, 1986).

Each entity (i.e. people and social structures (e.g. farmer organizations)) enlisted by the problematization can submit to being integrated into the initial plan or, inversely, refuse the transaction by defining its identity, goals, projects, orientations, motivations, or interests in another manner. The actors' identity and goals are interdependent. An actor or actors may or may not interest others. Ties are cut, weakened or reinforced to create allies. The identity of the interested entities is modified all along the process of interessement. The process of attempting to influence other people destabilizes social structures.

2.2.3 Enrolment

Enrolment implies that the solution proposed by the key actor is accepted as a new concept. A new network of interests is generated (Norbert and Schermer, 2003). Callon (1986) warns the reader that success is never assured, no matter how convincing the argument made by leading actors. The issue is to transform a question – Can NT or CA offer sustainable alternatives to conventional commercial farmers on sandy soils in mixed farming contexts in the EFS – into a series of statements made by leading actors that provide more certainty. For example: farmers want to explore NT; there are good NT/CA examples in the area on sandy soils; farmers are concerned about sustainability; CA caters for livestock; CA improves soil structures; investment in direct seeders and spray equipment is required; conventional equipment can be modified and CA is profitable.

2.2.4 Mobilization

Mobilization implies that the new network starts to operate and implement the solution proposed. Who speaks in the name of whom? Who represents whom? The masses are represented by a few, but will they follow them? Mobilization is this paper means that conventional farmers start to adopt and successfully implement NT. Secondly, the NT-system develops gradually into Conservation Agriculture i.e. the implementation of the three key CA principles simultaneously.

2.2.5 Dissidence

A fifth stage in the process is dissidence (Callon, 1986, p. 15). Literally it means a difference in opinion, so much so that actors are not converting to, nor implementing or promoting NT. The cycle becomes repetitive - the causes of the difference in opinion need to be re-addressed. The proposed solutions need to interest actors in order for them to enroll and to get mobilized.

3. Methodology

The NT farmers (n=10) were interviewed by using semi-structured interview techniques and narratives (n=2). The interviews were conducted in an informal participatory manner; often when working/ travelling together on the farm. Interviews were often in the form of a dialogue or conversation. The farmers in the eastern parts of the eastern Free State were selected purposively on the basis of those farmers who have already adopted NT. Currently, only a few NT farmers can be found in that area, and all were included in the interviews. Farmers' names were provided by fellow farmers and by staff from the local co-operative (the snowball method). The ANT is applied at the NT-pioneer level.

Conventional farmers were interviewed by means of two focus group discussions and five individual interviews. The focus group farmers in the Ladybrand area were invited via the OVK farmer group. The OVK Ladybrand-area chairman invited farmers via bulk sms. Farmers that were interviewed individually were selected purposely as well. The five individual farmers were selected as being one of OVK's local farmers with the highest annual financial turnover. This was done to ensure the best CV farmers to be included in the research. A panel of experts from OVK and farmers was assembled to assess farmer lists which included 241 farmers from the Zastron area (i.e. Zastron, Boesmanskop, Wepener and Hobhouse) and 1291 from the eastern parts of the eastern Free State (i.e. Fouriesburg, Ficksburg, Tweespruit, Clocolan, Excelsior and

Ladybrand). The purpose was to determine NT adoption rates amongst farmers in two composite areas in the eastern Free State.

This paper applies the Actor Network Theory (ANT) to the Eastern Free State farming context by two parallel running processes. The ANT is explained in detail below. The two processes are. Firstly, the process related to conventional farmers. No-till is proposed as an alternative to conventional ways of farming. The question: "Is NT a sustainable alternative for them?" will be answered by assessing the five stages of the ANT. Secondly, the ANT is applied to the interviewed NT-pioneers. The question: "Did the no-tillage systems develop into CA?" will be answered again with the use of ANT. The two processes are simultaneously answered, under the provided sub-headings.

4. The ANT applied: CV farmers and NT-pioneers in the Eastern Free State

4.1 Problematization

Problematization, in this research, refers to an actor that analyses a situation, defines the problem and proposes a solution (Norbert and Schermer, 2003). The problem is that conventional ways of farming in the Eastern Free State are ecological and economically not sustainable. The problem is worsened as adoption of NT in the Eastern Free State is low, despite literature postulating that NT is ecologically and economically more sustainable than conventional farming.

Paper three and four of this thesis have highlighted declining soil quality under conventional farming systems. It was irreversibly stated that without heavy chemical fertilizer applications good crops yields are generally not possible (Govaerts et al. 2009, p. 117 and Reeves, 1997, p. 132). The problem is worsened in that farmers not only need to apply high rates of fertilizer, but that the fertilizer use or uptake is often inefficient. Zimmer (2000) argued that when soil minerals are out of balance it results in a poor uptake of the nutrients by plants. He refers to this as soils being "locked up". Consequently farmers then over-fertilize their fields. Many farmers face consequently another challenge i.e. declining gross margins.

Converted NT farmers however are looking for appropriate solutions and technical knowledge. The NT-pioneers were able to start NT despite the unsupportive conventional network. They managed to overcome the initial challenges of ridicule, lack of equipment, lack of technical knowledge, and lack of management and application knowledge of herbicides. The “obstacle problem” i.e. challenge for NT farmers is how to constantly improve their current NT system to a CA production system. CA implies here that NT is complemented with adequate levels of permanent soil cover and practiced in a system with sound legume-based crop rotations. In addition, what can NT-pioneers do when insurmountable challenges are exposed in their newly adopted NT systems? The NT-converters did not have the practical hands-on experience of their newly implemented NT systems. Who do they turn to for advice?

Alwyn, Farmer B’s son, made a descriptive statement: “NT exposes the weaknesses of your soil”. What did he mean by that? As the soil settles in into the ‘not-tilled’ state, any nutrient and mineral imbalances in the soil would be exposed in the crop performance. An imbalanced soil is ‘tight’ and lacks oxygen. Plant roots struggle to grow. “This slow depleting process in the soil is not easily picked up when farmers remain tilling the soil”. Tillage aerates the soil, at least initially. Crop residues are worked into the soil through primary tillage such as ploughing and ripping, bringing fresh nutrients to the surface. The buried weeds and crop residues are allowed to break down. This speeds up the mineralization process and released minerals consequently provides a short-term source for the plant.

Over the years, soil quality deteriorated slowly under conventional tillage and -management. Tillage results in the decline of soil organic carbon (SOC) (Decker et al., 2011; Mills & Fey, 2003; Le Roux et al., 2007; Compton et al., 2010; and Derpsch et al., 2006). Many CV are not convinced that tillage is neccesarily degrading the soil. Many soils in the Eastern Free State have lower SOC readings for soils soils under CV as compared to NT/CA (see paper 4 of this research). This slowly and gradual decline in soil quality (SQ) is not recognized, which ~~I~~in this paper is called a backlog. The problem of declining SQ is there, although not perceived by many CV farmers. Many CV farmers measure farm performance in financial terms only. If the crop yields decline than many CV farmer find resort in using improved seed cultivars and apply higher fertilizer rates. Simply said, the crop yields remain the same, but the SQ decreases gradually.

Easter Free State farmers typically applied lime and gypsum every 5-10 years. This is done, in order to correct calcium deficiencies, and the calcium/magnesium ratio, in the soil. Many NT and CV farmers applied it irregularly, when they thought of it. Farmers got their soils sampled, but often at irregular intervals. Regular intervals are regarded as annually at the end of season or at least before a new planting season. Presumably this soil testing was done for farmers, irrespective their production system, free-of-charge by fertilizer companies in exchange of purchasing their products. The general soil sample recommendations do not consider soil mineral balances, but rather recommend adding a specific N-P-K fertilizer to supply the main nutrients that are missing. When soil minerals are out of balance it results in a poor uptake of the nutrients by plants. Zimmer (2000) refers to this as soils being “locked up”. Consequently farmers then over-fertilize their fields. There is little awareness amongst the farmers about soil mineral balances. Nobody was feeding the soil, but rather stuck to a feed-the-plant approach with generic fertilizers. As a result of these conventional practices the soil quality dropped which is evident in soil mineral and nutrient imbalances, decreased soil organic carbon, a decreased water-holding capacity of the soil and water infiltration rates. Zimmer (2000) stated that plants need several mineral nutrients and there is more to soil than N-P-K and lime.

The NT-pioneers indicated what their initial problems were after converting to NT. Seven out of ten NT farmers confirmed that lack of NT equipment was the biggest challenge of NT. NT requires a good planter or direct seeder with proper discs to cut through crop residue at planting. In addition, good boom sprayers are needed for weed control.

The second biggest challenge was the lack of technical information. Four out of ten NT respondents indicated that lack of technical knowledge, information and support was a problem. Farmers were actually financially ‘forced’ to convert to CA in order to reduce their variable costs and continue farming. Nine out of the ten NT-pioneers adopted NT for economic reasons, in an effort to reduce costs as a result of the cost-squeeze effect.

Weed control and an herbicide program was the third biggest challenge mentioned by three out of ten NT farmers. Equipment is expensive, but it is currently becoming more available; many conventional farmers already have a boom sprayer as mechanical weeding is partially being replaced by chemical control. This is due to the rising cost of diesel. NT farmers in the Eastern Free State are also adjusting conventional planters into NT planters at a far better rate than purchasing them new. Farmer B from Zastron and Farmer A from Ladybrand, being the very first farmers to start NT in the area in 2004, went to other ‘established NT-areas’ in South Africa. Both farmers obtained advice and converted their own conventional planters into NT planters. Farmer A bought John Deere units in KwaZulu-Natal and Farmer B obtained advice from

Australia and Swellendam, Western Cape. Three years later NT-pioneers from Westminster, Zastron and Clocolan built their own planters. Three of the ten interviewed NT-pioneers went on a NT study tour to Australia in 2005/6. This tour was organized by farmer B's son who was working in Australia by then. Two NT-pioneers were exposed to NT whilst working on NT farms in the USA. Two NT-pioneers bought new NT planters. One planter was imported from Brazil.

4.2 Interessement

"Interessement" is the group of actions by which an entity (any of the local actors) attempts to impose and stabilize the identity of the other actors that it defines through its problematization. In other words, the main agents i.e. NT-pioneers attempt to make others interested in the solution i.e. NT is proposed as a 'solution' to declining soil quality, declining gross margins, and inefficient use of fertilizer under CV systems.

The solution 'offered' to the NT-pioneers is Conservation Agriculture (CA). CA means the adherence to the three key principles: disturbing the soil as little as possible, obtaining year-round soil cover, and apply sound crop rotations (i.e. more than three crops including legumes), simultaneously. The NT-pioneers basically started adopting NT. The literature refers to this initial stage of NT as conventional NT (CNT). CNT is NT without high levels of soil cover and without sound crop rotations.

Farmer B and Farmer A are two NT-pioneers whose narratives are described in detail in another paper of this thesis. Both Farmer B and Farmer A have organized farmer days since 2005/6. Both have assisted conventional farmers with setting up NT trials on their farms. Both have acted as a source of information for many farmers who were inquiring about planter modifications, herbicide options and rates, and NT farm management. Both have facilitated farmer meetings, but the meetings eventually ceased. In the case of Farmer A, at first, five conventional farmers in the NT study group attended, and then four, then three and currently the farmer group has ended unceremoniously. On closer inquiry, one farmer stated that he did not really have time for it and another one stated that there was no one to step up as a facilitator and organizer of the group. Social networks can either operate formally or informally. Both are important. Clearly, a formal network was not particularly effective. Does this perhaps suggest that informal networks are more effective?

Both Farmer B and Farmer A stopped organizing farmer days, as both got tired of convincing other farmers, debating and 'dragging' them to understand that NT works. They acted as norm entrepreneurs, but did not get support. These initiatives were taken when the NT farmers did not have improved gross margins yet, 2-4 years after they converted to NT. Perhaps a formal network will require more hard evidence of profitability, before it becomes an effective channel of communication. Effectively, it was a problem of timing? Firstly, the NT-pioneers gradually improved and diversified their NT systems. Secondly, the labour and diesel costs are rising, which might result in a better response.

The NT-pioneers are still information brokers and decided to rather focus their energy into progressing their own NT operations into CA. They gained knowledge that can be disseminated through the new network at a later stage. None of these conventional farmers have converted to NT, despite clear evidence of gradual success at Farmer A's farm. The most mentioned barrier to NT adoption was the fact that CV farmers believe that NT and cattle grazing cannot be combined. This relates to the issue of timing, because the NT-pioneers still struggle to build up adequate levels of soil cover, whilst still grazing cash crop residues. The cover crops (i.e. research since 2010) on farmer A's fields gives currently a more complete view of NT than ten years ago. The cover crop research offers solutions to the grazing dilemma and offers a way out to continue mixed farming. The initial NT systems until now (2004-2014) were developed from within conventional ways of farming. Hence, the reference to NT systems without soil cover and good crop rotations as conventional NT (CNT).

The local co-operative, does not actively promote CA. They hosted an NT-planter demonstration in 2006 on Farmer A's farm. There has not been widespread enrollment into NT. The input suppliers, in general, have representatives visiting farmers, but they are, in general, not knowledgeable about CA. Consequently, discussions about NT are very informal and superficial. Alwyn, Farmer B's son stated that the herbicide rep learns from them as the system develops.

The adoption of NT in the other parts of the eastern Free State i.e. Fouriesburg, Ficksburg, Clocolan, Excelsior, Ladybrand and Tweespruit is 2.54% (own analysis) and is much lower than the adoption rate of 11.62% (own analysis) in the drier areas of Hobhouse, Wepener, Boesmanskop and Zastron.

Five out of the ten NT pioneers were exposed to NT through travelling, working and networking in South America, USA and Australia. Three out of ten saw it work at nearby NT-pioneers farms. Four out of the ten conducted their own literature research by reading NT information, publications and NT promotion material. It shows the importance of the internet use and easy global dissemination of knowledge. NT farmers got more interested as they all reported huge savings in fuel use and machine maintenance costs.

Once the challenges were overcome, the NT-pioneers' interessement grew. Challenges were overcome in several ways. Five out of ten farmers built their own equipment. Three out of ten farmers obtained their own information, conducted their own research, and learned by doing through trial and error. Two out of ten farmers sold old equipment.

Most NT-pioneers did not mind spending time with and advising interested farmers that intentionally want to learn more about NT. This happens approximately bi-monthly. This is an indication of the increased interest for NT. Many overseas visitors, via Lesotho NT networks, also got involved at Farmer A and Farmer B's farm. This highlights the importance of global networks. Farmer A and his wife run a B&B on their farm and have hosted several international CA experts, via a newly formed network. These included soil scientists from the University of Tennessee, a retired key staff member of Monsanto, United Nations staff, and members of the Lesotho CA task force. Some of these new visitors in the network were able to assist Farmer A with his unanswered questions. All the above mentioned people, via the newly formed network, where promoting NT. Although we assume that these people promote NT for soil and water conservation, it does not exclude other reasons such as for profits in monetary terms (i.e. sales of glyphosate-based products and genetically modified seeds) or indirect objectives (i.e. personal profit through extended research opportunities or NT photo galleries). The interest of the network members raises the question of the interface between conservation and profits.

4.3 Enrolment

Enrolment implies that the solution proposed by the key actor is accepted as a new concept. The issue is to transform the question – Can NT offer sustainable alternatives to conventional commercial farmers on sandy soils in mixed farming contexts in the EFS – into a series of statements made by leading actors that provide more certainty. For example: farmers want to explore NT; there are good NT/CA examples in the area on sandy soils; farmers are concerned about sustainability; CA caters for livestock; CA improves soil structures; investment in direct seeders and spray equipment is required; conventional equipment can be modified and CA is profitable.

The CV farmers did not ‘accept’ NT as a solution. Their challenges, Callon (1986) calls it “obstacle problems”, were not adequately addressed. The sub-questions or series of statements, as mentioned above, were answered negatively.

4.3.1 The CV farmers did not enroll i.e. accept NT as a solution

There are different reasons why conventional farmers in the Eastern Free State of South Africa have not adopted NT. Gradual success on NT pioneers’ farms have, however, been recorded i.e. increased gross margins, increased soil cover and good crop stand. Despite gradual improvements in NT farming after 5-10 years, the uptake of NT remains low (2.5% among 1241 farmers in the eastern part of EFS).

Farmers are neither encouraged nor discouraged by local stakeholders to practice NT. Banks, co-op and credit suppliers are not concerned about what production system a farmer practices, as long as they can repay their loans. Credit agencies actually sustain their business on the interest derived from outstanding loans. Agricultural extension and agricultural research are non-existent on white commercial farms. There are agricultural extension offices, but no government-sponsored research or extension is geared towards NT. Fertilizer suppliers would experience neither profits nor losses from NT. There are reductions in fertilizer procurements among NT farmers in other countries where NT has been practiced for a long time, but this issue is not applicable locally. NT farmer numbers are low and they still apply relatively high rates of fertilizer, but ultimately fertilizer rates might decrease as the soil quality improves. Similar scenarios are there for other input suppliers. The only exceptions are the herbicide dealers. They have increased business due to the increased use of herbicides under NT.

Many CV farmers have not adopted NT, which is linked to mindset, attitude and perceptions. At least eighteen reasons can be extracted from the social research conducted from this study:

4.3.2 Mixed farming and livestock

CV and NT farmers repeatedly stated that they are cattle farmers, which suggests an important value placed on livestock. The beef and mutton market has been more reliable in the past than cropping. CV farmers are bound by different perceptions regarding livestock integration restricting them from converting to NT. CV farmers assume that NT does not allow animal grazing due to the buildup of soil cover under NT. Animal grazing and NT can be integrated as can be seen in the two narrative NT case studies (paper Two) and in the economic model (paper Three). NT requires wise grazing strategies such as inclusion of ley and cover crops into the crop production systems, establishment of legume-based pastures, adequate fertilization of existing pastures and short intensive grazing of crop residues.

CV farmers acknowledge the build-up of soil cover under NT, but their animal stocking numbers are so high that they cannot afford to loose cash crop residues as a source of feed. There is no soil cover build-up under CV as cash crop residues are fed to animals during July-September. Losing crop residues effectively implies cutting back on stocking numbers. Livestock income is however the most stable as compared to fluctuating grain prices.

NT is however in its infancy stages and far more research is needed addressing this interface of grazing and cropping.

CV farmers believe that cattle grazing cause soil compaction. CV farmers therefore feel that soil needs to be worked i.e. loosened after 2-3 months of grazing. CV farmers feel that direct seeding is not effective on ‘compacted’ soils. They therefore believe that NT will undermine their cattle grazing regimen.

4.3.3. Financial issues and risk

CV farmers have conducted price comparisons. Savings on diesel are perceived to be offset by increased use of herbicide as well as the gradual increase in the cost of herbicide.

CV farmers believe that the need for NT is not urgent as their operations are still profitable

CV farmers have invested in CV production systems and are still bound by loans and payback schemes. They cannot, therefore, make an expensive shift to new NT equipment. NT planters are expensive. That also leaves CV farmers with the question of what to do with their 'new' CV equipment.

CV farmers have all the necessary equipment for CV farming. The system works for them. The production programs and management systems are in place and NT would require changes in practices such as herbicide spraying and methods of working. Spraying of chemicals as associated with NT is done best in the morning or late afternoon (not during the heat of the day). This disrupts certain farmers' work plans and work load i.e. nothing to do during mid-day and demands workers to work overtime. Another example is the mechanical weeding of crops such as sunflowers. Farmers reported that weeding in a standing crop gave the plants a boost as if fertilizer top dress was applied. The reason for the apparent boost might be the (slightly) working in of weed plant material and rapid oxidation and mineralization, making nutrients and minerals available to the plant. Mechanical weeding is not associated with NT.

4.3.4 Information and knowledge

CV farmers are not encouraged by the few examples of NT, as NT crop yields are either the same or in some cases looks less impressive than CV fields ('ag shame' fields). In the NT literature, it is emphasized that soil quality improvement is a slow and long term process.

CV farmers haven't seen fully-fledged examples of CA, but rather slow and gradual improved NT systems. There are, as yet no CA champions with extraordinary results. The NT farmers have different standard of implementation, which differs due to different reasons: lack of technical knowledge, learning curve on weed and pest management, learning curve on soil cover, and seeding issues. NT standards are sometimes lowered as NT has been practiced with low levels of soil cover and, initially, limited crop rotations.

The other side of the coin is that many farmers don't see, know or hear about the good upcoming NT examples. There are inadequate local information dissemination frameworks.

Most CV farmers are ill-informed about NT. Many CV farmers do not know how NT works, where and how to start. Part of the problem is that it is no-one's job to tell them. Government extension agencies are not providing no-till options and technological backup. Who can provide local advice if they have questions? A negative attitude developed in some cases around NT, which is not necessarily based on facts, but rather on feelings, perceptions or hearsay.

Some CV farmers prefer to let others carry the risk of experimenting with new technology. They may adopt CA later when the issues and problems are sorted out.

There is an issue of aesthetics as well: CV farmers found NT fields untidy. A mind-shift is needed in this regard, to assess fields on the basis of their environmental sustainability, and not only on the basis of appearance. CV farming has created an inappropriate visual standard for.

CV farmers have tried NT for a short period of time or on small sections of designated fields by using NT farmers' planters. These own trials were often conducted on the basis of inadequate information, or not on the best fields (and already 5-8 years ago) and not necessarily with the right equipment. When crop performance was not ideal, NT was blamed for it. These CV farmers dropped out and developed a critical attitude towards NT. They are less likely to convert to NT in future.

A mix of literature regarding NT is circulating in farmer magazines. Not all literature is necessarily in favour of NT. This raises the question about the completeness and the validity of literature. Farmers reported that comparisons should not only include production figures but also labour figures, maintenance and repair costs, and water use efficiency.

4.3.5 degradation issue

Many farmers do not believe that tillage is degrading the soil and therefore they do not feel the need to adopt NT for soil conservation purposes.

Many CV farmers view sustainability in terms of 'sustained income' and are not convinced about the statement that "they are farming on borrowed time". Once again, tillage is not regarded as destructive to the soil.

Farming is about making money and surviving, which makes environmental issues of minor importance. Farmers cannot afford to make mistakes. The gross margins are thin.

Farmers mentioned an increase of rodents under NT. Gerbels, mice and rats dig tunnels in the soil, eat seed & damage crops. Fields under rodent attack poses a threat for animal (i.e. leg related injuries) and tractor traffic.

4.4 Enrolment of NT-pioneers from Conventional NT to CA

The NT-pioneers have recognized the limitations of conventional NT. The NT-pioneers, contrary to the CV farmers, enrolled in their process. CA, with its three key principles, is seen as the sophisticated stage of CNT. The NT-pioneers entered into the process of improving their NT-systems.

Seven out of the ten interviewed farmers saw themselves as the main promoters of NT in the area. Reasons for being the main promoters are: "that nobody promotes something he doesn't believe in" and farmers have seen it work for them. Nine out of the ten farmers indicated that the success of NT on their farm was measured in terms of increased gross margins. Four out of ten farmers also indicated that success of NT is measured in both reduced tractor costs in terms of less maintenance and repairs, and improved soil quality and or soil restoration. The NT pioneers' advice, mentioned by eight out of ten farmers, for other farmers is to continue asking questions and obtain further advice, convincing themselves and start doing their own on-farm research.

The NT-pioneers started to look for solutions improving their NT systems. NT-pioneers discussed whether to stick to their tine planters or to adjust to disc seeders. All farmers realized that soil cover needed to increase. Eight out of nine interviewed NT-pioneers adopted legumes into their crop rotations and the breakthrough came with the introduction of Roundup-ready soya. This crop made chemical weed control possible. Many CV farmers also started planting Roundup-ready soya for the same reasons. A detailed price comparison, linked to different production systems, reflects the prices and rates of agro-chemicals and diesel. This is reflected in paper Three of this thesis. New thinking around alternative grazing strategies, legume-based pastures, improved grass pastures, controlled grazing and reduced crop residue grazing was disseminated.

4.4.1 Mobilization

Mobilization implies that the new network starts to operate and implement the solution proposed. Mobilization in this paper means that conventional farmers started to adopt and successfully implement NT. Secondly, the NT-system develops gradually into Conservation Agriculture i.e. the implementation of the three key CA principles simultaneously.

The CV farmers were not 'mobilized' and did not adopt NT as an alternative strategy to counter the declining gross margins and declining soil quality under CV. The NT-pioneers, contrary, were mobilized. The newly formed networks assisted the NT-pioneers to continue in their quest of applying the three key CA principles simultaneously.

The new network started to operate around the year 2006, when six Eastern Free State farmers went on a NT-tour to Australia. The network was initiated by the case study farmer (i.e. farmer B) and his son who was working in Australia by then. The new thinking about how to improve the NT-systems became popular, and more and more NT-pioneers started to explore aspects of it.

What needs to be in place for an increased uptake or adoption of NT in the area? The NT pioneers attempted to answer this question, but there was not a single critical variable. Every farmer made different suggestions and all of the following were mentioned by at least one out of ten farmers: contractors, financial buffer, CA policy, research on soil, seeds and cover crops, knowledge, NT equipment, mindset. Two out of the ten farmers stated that CA champions and good NT examples needed to be in place before there will be an increased uptake of NT in the area.

Contractors can fill the gap by providing NT equipment i.e. a direct seeder and boom sprayer. Contractors might assist CV farmers with their own on-farm trials in order to assess and evaluate NT on their own farms. It remains, however, a question whether "NT-contractor" services would lead to an increased adoption of NT? That view of one NT-pioneer about "NT-contractors" is not uncontested. The few contractors in the eastern Free State are not geared up for NT-related work as most of them specialize in activities i.e. cutting and baling of grass or assisting with harvesting. Most NT-pioneers believe that a NT farmer should have his own equipment in order to utilize the few windows of opportunity (i.e. ideal planting and spraying conditions) optimally. One NT-pioneer did make use of different contractor services, but ‘enforced’ and insisted on what we can call contract farming. The reason for that was so that the farmer could count on the contractor’ services. The one contractor, who was contracted in 2010, to plant several hundreds of hectares came from the Western Cape, approximately a 1000km away. Another contractor (i.e. season 2010/11) was contracted to spray chemicals for weed control came from Bloemfontein, approximately 70-130km away. This specific NT-pioneer was not satisfied with the results of the spraying and this dispute ended in a court case. The same NT-pioneer joined forces with another nearby NT-pioneer (20kms away), for the season 2011/12. The one NT pioneer bought a six-row-NT-planter and the other NT-pioneer agreed to plant his own and the other’s fields. The acreage of 1500-2000 hectares was so high that, even by planting from 4.30am – 8.30pm, it could not be done satisfactory i.e. timeously. The farmers ran out of time. The two NT-pioneers realized that prioritization of whose fields to plant first became a problem. Both farmers wanted their crops to be planted as soon as possible after good spring rains that it became a potential source for conflict. Both farmers amicably agreed that this was not the solution for them. Both NT-farmers obtained own planters for the 2012/13 season. The one NT-pioneer bought the 6-row planter from the other NT-pioneer and modified one of his conventional planters into a second NT planter. The other NT-pioneer bought a new planter. The narratives in paper two indicated the challenges around the chemical weed control. The scope for the role of contractors by assisting NT-farmers, at this stage, appears to be very limited.

A financial buffer would help NT-farmers to overcome initial losses and “learning fees”. A bit more money in the bank would help farmers in procuring the right equipment.

A CA policy can spell out a top-down approach for the promotion of NT. This is not a far-fetched idea in itself as the promotion of NT in the United States of America, in the 1980s, was fostered via similar policies (i.e. conservation compliance act). Such an approach requires good implementation, follow-ups and monitoring. This approach is most likely not going to be effective in the Eastern Free State due to the already absence of government-funded research and agricultural extension.

The promotion of NT in South America (especially Brazil), on the other hand, developed via a bottom-up approach. A few farmers were desperately concerned over soil degradation and erosion. They were determined to find a solution to ensure long term viability of agriculture. The farmers did not allow failures to get in the way of eventual success and built a solution based on winter cover crops and no-till. Equipment companies came alongside to develop no-till drills and planters. Those concerned farmers formed "Friends of the Land Clubs" ("Clubes Amigos da Terra - CATs) at local level (Hebblewaith, 2010). These clubs: shared on farm experimentation with one another; held farmer field days. Industry sponsored and supported. It influenced local government and university research. Out of these clubs emerged national organizations to: work at national government level, disseminate information from one CAT to another and across Latin America, hold national no-till conferences and involve the agricultural industry at national level. Government research, universities and extension were slow to follow. The Brazilian farmers' success (i.e. good NT examples and NT champions) brought a change of heart. Support began to build first at local and then national level. Research came alongside to find answers to: nutrient needs, nutrient recycling, weed and pest management, crop rotations and soil quality changes" (Hebblewaith, 2010).

The result of the increased, but limited, uptake of NT could not be solely attributed to any of the factors, but rather as a result of new networks being formed. A quick survey was done in the Zastron area, by asking Farmer B (see paper Two), his son, and an OVK panel to go through a farmer list of 241 farmers from Hobhouse, Wepener, Boesmanskop and Zastron. Approximately twelve (11.62%) percent of the total number of farmers in his area have adopted NT since 2006. NT-planters are currently manufactured in Zastron. This entrepreneur believes that NT will grow. Zastron falls within the 400-600mm semi-arid rainfall area and the relatively high uptake of NT suggests a higher need for NT in areas with declining annual rainfall.

The herbicide dealers are learning with the farmers, and are able to spread best weed management practices in the region. It is clear that farmers themselves acted as powerful knowledge brokers. This is in line with (Brown and Ashman, 1996; Crossman, 2003; Isham, 2002; and Derpsch, 2008) 'change happens from within' i.e. the local farming network. "Spread of a favoured technique is seldom because farmers have evaluated it on the basis of scientific studies of its consequences. Rather, most people depend mainly on a subjective evaluation of an innovation that has been made by their neighbours/friends who have previously adopted it" (Friedrich et al., 2008). The question of "Who promotes CA in your area?" was asked to the NT farmers. Seven out of the ten farmers replied "We as farmers ourselves". This emphasizes the role of the local farming network, and yet we have seen that international networks play a critical role – possibly more important than the local farming network.

4.4.2 Dissidence

Callon (1986) introduced a fifth stage: dissidence. Literally it means a difference in opinion, so much so that actors in this case, conventional farmers, are not converting to nor implementing or promoting NT. The CV farmers argued that their barriers (i.e. clustered under sub-headings of: livestock integration, financial issues and risk, information and knowledge, and land degradation issues) to NT were unbridgeable.

There is no dissidence among the NT-pioneers, to such an extent, of not adhering to the three CA principles. Farmer B (i.e. case study farmer in paper Two of this thesis) mentioned dis-adoption of a few ‘NT-newcomers’. This phenomenon was mentioned in the late stages of the research. The reasons for dis-adoption were therefore not thoroughly assessed. The reason for this dis-adoption according to farmer B relates to ineffective weed control. This, however, is a speculation, and the issue of dis-adoption demands more future research.

5. Discussion

The adoption of NT and its development into CA involves aspects of ecology, sociology and economics. The adoption and development process consequently relates to several scientific disciplines. Interdisciplinary efforts are therefore of utmost importance to understand the innovation of CA and other social ecological systems (Miller et al. 2008; Gallopin et al. 2001; Lubchenco ,1997; Roux et al.,2006 and Eigenbrode et al., 2007).

ANT offers roads out of structure/agency dialectics and proposes new possibilities for understanding structure as a network, and agency as the outcome of networking (Trauger, 2009, p. 117). Farmers possess agency. The examples of the NT-pioneers reflected that the ANT is a useful approach explaining the adoption of NT. All ten of the interviewed farmers’ stories, struggles, challenges and solutions indicate the farmers’ agency as an outcome of networking. Farmers’ experiences regarding CA explain how certain changes took place over time. Their trial-and-error experiences and their innovative thinking reflect the capability of farmers as knowledgeable actors.

In their experiences, several themes can be identified.

Firstly, NT-pioneers were innovative regarding planters/ direct seeders and planting equipment. They modified conventional planters, and they managed to adjust spraying equipment.

Secondly, they are in a process of moving from NT to CA by rethinking and strategizing crop rotations. No-till is the principle to which all interviewed farmers adhered. As time went on, farmers focused more and more on building up soil cover, which remains a serious challenge. Farmers assessed their own crop rotations and an increasing number of NT farmers included legumes in their rotations. Soya is the most prominent legume in this regard. There is a ready market for it and the Roundup-ready cultivars, with its associated chemical weed control programme, allowed farmers to plant soya at large scale.

Thirdly, NT-pioneers are increasingly accumulating above-ground and below-surface residue on their soils. This is a very gradual process under conventional NT. This ‘gradual’ cannot be encompassed in a fixed timeframe. The time frame can differ and is dependent on various interrelated aspects: soil type, annual rainfall, stocking numbers, and whether or not cover crops and fallow are included into the crop rotations. If farmers are able to permit themselves a Sabbath year with summer cover crops, then the buildup of soil cover can be relatively quick i.e. one season. Once the layer of soil cover is present, it paves the way to introduce winter cover crops in addition to the main summer cash crop. For more details in this regard see paper Four of this thesis. Conventional NT, without grazing, cannot build up adequate soil cover. The November soil cover assessment (paper Four of this thesis) at the time of maize planting for conventional NT was 56%, 55% and 40% for 2011, 2012 and 2013 respectively. The soil cover under soya and sunflower is assumable even lower. The soya and other legumes for that matter are low in lignin (i.e. “woodiness of plant material”), have lower biomass production and are harvested earlier than maize. That implies that the land will be longer without a standing crop and decomposition of plant material starts earlier. The same applies for sunflower, although it is higher in lignin content than soya.

The main reasons for the slow buildup of soil cover are grazing of cash crop residues, moderate yields and consequently limited added organic matter for soil cover, and high decomposition rates of plant material in especially the summer months (i.e. hot and wet conditions). Strong winds from August to October also contribute to the blowing away of plant material on the soil. The buildup of soil cover is difficult for especially the farmers in the drier central and southern parts of the eastern Free State - an imaginary line can be drawn between Tweespruit and

Zastron. This is in line with the agro-ecological zones of South Africa. This area falls within the 400-600mm mean annual precipitation zone as adapted from the Department of Water Affairs (Smith, 2006). The eastern parts of the eastern Free State fall within the 600-800mm mean annual precipitation zone.

Fourthly, the herbicide programs have been fine-tuned and improved. Farmers have not yet experienced the problem of glyphosate-resistant weeds? Glyphosate-based herbicides are the most common herbicide used in NT systems. Spraying glyphosate in low application rates, under-sub-optimal conditions and repeatedly may result in weeds becoming resistant against glyphosate-based products like Roundup and generic types like Mamba, Springbok and Kalash. The NT farmers started to add wetting agents (e.g. Herbi boost i.e. to prolong the contact of glyphosate onto leaf area), in some cases vinegar (i.e. to stimulate leaf pores to open) and growth-stimulant types of chemicals (e.g. 2-4D i.e. stimulating plant growth and increasing the uptake of the glyphosate) to bind with the glyphosate products. The glyphosate products also developed over time in quality i.e. higher active ingredient levels. Farmers stated that chemical weed control was difficult. This can also be read in the two narratives in another chapter of this research. The NT-farmers have adjusted their herbicide and crop rotation programs to such an extent so as to minimize this weed resistance problem. The NT-farmers improved their hands-on management skills of chemical weed control i.e. determining optimal conditions for spraying (i.e. correct Ph of water and water quality, correct rates of glyphosate per ha^{-1}, correct water pressure when spraying, correct driving speed whilst spraying, correct types of nozzles, optimal time of spraying avoiding midday high temperatures, and adding supplement-chemicals).

Fifthly, the cropping intensity increased for five out of the ten interviewed farmers, and, as a result, these farmers are cutting out bare fallow as part of their crop rotations resulting in increased agronomic productivity. This in return leads to increased financial benefit. Fallow, as part of the crop rotation, is intrinsically part of the conventional ways of farming in the Eastern Free State (i.e. associated with water harvesting and breaking of pest cycles). The 50% of the NT-farmers cutting out fallow is a major step forward in increasing soil cover and profitability.

Finally, it is evident that farmers are able to convert to NT, despite lack of the following: NT equipment, technical knowledge, institutional- and legal support systems. The uptake of NT is, as it appears, the result of collaborative networks, often global networks (Coughenour, 2003) and farmers' capability and personal judgment (Van den Berg, 2010; Landers, 2009; and

Trauger, 2009). It seems that the interviewed NT-pioneers are serious in finding tailor-made farm solutions so that they can adhere to all three CA principles simultaneously. Farmers' roles are crucial in contributing and finding ecotype specific CA approaches for other farmers. This contributes to addressing the lack of technical knowledge on how to implement no-till and CA in the different ecotype-mixed farming contexts in the eastern Free State.

6. Conclusion

The Actor Network Theory, by using the concept of "translation" (i.e. the dual process of conversion from conventional ways of farming to NT; and improving NT to CA), is useful in innovation studies. The translation, converting from CV to NT did not take place at a large scale. The process of improving the NT systems into CA did take place. The innovation can only succeed if it is carried by a collective. As seen in this paper collectives can transcend local boundaries. The translation did not happen at the level of conventional farmers. The actors' diverse objections were not adequately solved or addressed. NT was not promoted in the Eastern Free State area, although Farmer A, Farmer B and the other NT-pioneers are promoting NT in the area. The road is still blocked by the various 'conventional' farmers' concerns about NT and CA. Non-adopters are still circulating in their old existing networks of information dissemination.

Adopters of NT became part of a new network, but this network is small in the Eastern Free. The new network was primarily driven by NT farmers themselves. This emphasizes the role of the local farming network, and yet we have seen that international networks play a critical role – possibly more important than the local farming network.

The success of CA is most evident when all three principles are applied simultaneously. The high NT adoption rates globally reflect that this technology works. CA also works in the Eastern Free State, but it is not simply a transfer of the technology. Farmers have the agency to apply or to refuse the standard universal set of three CA principles at all. The NT-pioneers experiences and innovative thinking proves that despite the challenges of lack of technical knowledge, lack of implements and amidst unsupportive institutional support, different solutions were found. The uptake and reconstruction of the innovation is the result of collaborative networks. Farmers started to modify and adapt their own planters. Farmers conducted their own research, made inquiries and convinced themselves. Farmers possess agency as a result of networking and enabled the innovation of NT to gradually develop into CA. NT is created through new networks and relationships between actors.

The Actor Network Theory is practical and can be applied to the study on the adoption of CA in the Eastern Free State of South Africa. The ANT is useful, as the concept of “translation” has enriched earlier actor-oriented approaches. The ANT helps us understand the relations between people and technology (Stanforth, 2006) and explains socio-technical change well. This paper agrees with (Trauger, 2009) who said that the ANT decentres the inevitabilities of structure, provides relational ontologies of agency and resistance that address the frictions of distance, and acknowledges the agency of non-human actors in social and political change.

The four stages: problematization, interessement, enrolment and mobilization are useful concepts and make the ANT an appropriate analytical tool to analyze the dissemination of new knowledge. It can be recommended for future use regarding social technology studies.

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