An investigation of *natuurboerdery* (natural farming) approach: a ZZ2 case study

by
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Declaration

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Abstract

The aim of this study was to provide the first in depth description of the *natuurboerdery* farming system as developed and adopted by ZZ2, a privately-owned farming conglomerate in South Africa. *Natuurboerdery* aims to increase agricultural productivity and sustainability while maintaining environmental integrity to contribute to overall sustainability. A case study research design using multiple sources and techniques for data gathering was applied to investigate the reasons for and process of converting from conventional farming to *natuurboerdery*, describe the principles and practices of *natuurboerdery* farming and document the changes and benefits realised by conversion.

It was established that ZZ2 converted to *natuurboerdery* farming due to the challenges associated with conventional methods of farming. The main challenges ZZ2 experienced were recurrent pests and diseases which were becoming difficult to control with inorganic pesticides, large decreases in yields and unsustainable production outputs or returns to support production costs mainly due to the escalating cost of inorganic pesticides and fertilisers. ZZ2 also became aware of the growing customer demand for healthy food produced by ethically accepted methods while minimising environmental degradation.

A conceptual framework was developed to describe the *natuurboerdery* farming system, based on five principles or health aspects: agro-ecosystem health, soil health, plant health, food health and human health. All of the practices developed and adopted by ZZ2 were described and classified in terms of this framework. *Natuurboerdery* integrates the use of inorganic fertilisers and organic soil amendments for soil health and plant nutrition; inorganic pesticides, fermented plant extracts from herbal plants with insecticidal properties, EM products, compost teas and biological control agents for plant protection.
The conversion to *natuurboerdery* resulted in changes and benefits which were described and classified under: strategic and technical, economic, social and ecological and environmental. The main findings were that soil health has improved, soil organic carbon levels have increased, the use of inorganic products for plant nutrition and protection has

decreased with significant cost savings, yields have risen, water availability has increased and energy spending has been reduced.

The conclusions drawn from the research findings indicate that *natuurboerdery* is neither organic nor conventional farming which indicates that inorganic and organic inputs are compatible in sustainable farming systems. The *natuurboerdery* farming approach is a potentially sustainable farming system which works with nature. Areas for further scholarship, research and recommendations have been identified to improve the sustainability of *natuurboerdery*.

Opsomming

Die doel van hierdie tesis was om die eerste in-diepte beskrywing van *natuurboerdery* saam te stel soos dit deur ZZ2 ontwikkel en gebruik is. ZZ2 is ‘n Suid Afrikaanse boerdery konglomoraat in privaatbesit. *Natuurboerdery* beoog om boerdery produktiwiteit en volhoubaarheid te verhoog, terwyl dit die integriteit van die natuuur in stand hou om tot algehele volhoubaarheid by te dra. ‘n Gevallestudie is as navosingsontwerp gebruik en verskeie bronne en metodes is toegepas om inligting in te samel. Die proses en redes vir die oorskakeling van konvensionele boerdery na *natuurboerdery* is ondersoek, terwyl die beginsels en praktyke van *natuurboerdery* beskryf is en die veranderings en voordele van die oorskakeling gedokumenteer is.

Dit is vasgestel dat ZZ2 na *natuurboerdery* omgeskakel het as gevolg van uitdagings wat met konvensionele boerderymetodes gesassosieer word. Die hoof-uitdagings wat ZZ2 ondervind het was terugkerende peste en siektes wat moeilik beheerbaar was met onorganiese plaagdoders, groot afnames van oeste en onvolhoubare produksie uitkomste of winste om die produksiekostes te dra. Stygende pryse van onorganiese plaagdoders en kunsmis was die grootste oorsaak van hoë produksiekostes. ZZ2 het ook bewus geraak van die groeinde klante-aanvraag vir gesonde kos wat op eties-aanvaarbare metodes geproduseer is en skade aan die natuurlike omgewing verminder.

‘n Konsepsuele raamwerk is ontwikkel om *natuurboerdery* as ‘n boerdery-sisteem te beskryf en is gebasseer om vyf beginsels of gesondheidsaspekte: agro-ekosisteemgesondheid, grondgesondheid, plantgesondheid, voedselgesondheid en menslike gesondheid. Al hierdie praktyke wat deur ZZ2 ontwikkel en gebruik is word in hierdie tesis beskryf en geklassifisseer in terme van die konsepsuele raamwerk. *Natuurbeordery* integreer die gebruik van onorganiese kunsmis en organiese grondwysigings vir grondgesondheid en plantvoeding. Geïntegreerde praktyke sluit in: onorganieise plaagdoders, gefermenteerde kruieplant-ekstrakte met insek-bestrydende einskappe, EM produkte, kompos-tees en biologiese beheeragente vir plantbeskerming.

Die oorskakeling na *natuurboerdery* het sekere veranderings en voordele gehad. Dit word geklassifiseer volgens die betrekking wat dit het op die strategiese en tegniese, ekonomiese, maatskaplike en ekologiese en omgewings-aspekte van ZZ2. Die hoofbevindings was verbeterde grondgesondheid, verhoogde organiese koolstofvlakke in die grond, laer gebruik van onorganiese produkte vir plantvoeding en beskerming met noemenswaardige koste-besparings, verhoogde oeste en waterbeskikbaarheid, en kleiner spandering op energie.

Die navorsingsbevindings wys daarop dat *natuurboerdery* nie organies of konvensionele boerdery is nie en dat onorganiese en organiese insette dus verenigbaar is in volhoubare boerdery-sisteme. Die *natuurboerdery* uitkyk is ‘n potensiële volhoubare boerdery-sisteem wat in staat is om saam die natuur te werk. Areas vir verdere studie, navorsing en voorstelle is geïdentifiseer om die volhoubaarheid van *natuurboerdery* te verbeter.

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I also want to thank ZZ2 for allowing me to be the first academic author of the *natuurboerdery* farming approach. Special thanks to Tommie van Zyl, the CEO, for allowing this project to happen, Bombiti Nzanza for his professional, social and academic advice which I have now chosen to be part of me. Special thanks to Piet Prinsloo and Johan Noffke for nurturing me in aspects of *natuurboerdery*.

Lastly I want to thank my family for their support and enduring hard times during my absence.

Table of Contents

List of Acronyms and Abbreviations

AKST	Agricultural Knowledge, Science and Technology
ASPO	The Association for the Study of Peak Oil and Gas
CBD	Convention on Biological Diversity
CEC	Cation Exchange Capacity
CEO	Chief Executive Officer
CH_4	Methane
CO_2	Carbon Dioxide
CSHI	Cornell Soil Health Indicators
DA	Department of Agriculture
DDVP	2,2 Dichlorovinyl dimethyl phosphate
DNA	Deoxyribonucleic
EIA	Environmental Impact Assessment
EIL	Economic Injury Level
EM	Effective Microorganisms
ET	Economic Threshold
FAO	Food and Agricultural Organisation
FAOSTAT	Food and Agricultural Organisation Statistics
FPE	Fermented Plant Extract
GBFT	Green Bucket Funnel Trap
GE	Genetically Engineered
GGAP	Global Good Agricultural Practice
GHG	Greenhouse Gas Emission
GM	Genetically Modified
GMO	Genetically Modified Organism
HDR	Human Development Report
HOD	Head of Department
IAASTD	International Assessment of Agricultural Science and Technology for Development
IPM	Integrated Pest Management

K^+	Potassium ions
MDGs	Millennium Development Goals
MEA	Millennium Ecosystems Assessment
N_2O	Nitrous Oxide
NO3-	Nitrate ions
NPK	Nitrogen, Phosphorus, Potassium
NRC	National Research Council
pH	Potential of Hydrogen
R & D	Research and Development
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
USDA	United States Department of Agriculture
WCED	World Commission on Environment and Development
WFF	Woolworths Farming for the Future
YBFT	Yellow Bucket Funnel Trap
YCP	Yellow Card Plastic

List of Figures

List of Tables

CHAPTER I: INTRODUCTION

"*Agricultural use of natural resources (soils, freshwater, air, carbon-derived energy) has, in some cases, caused significant and widespread degradation of land, freshwater, ocean and atmospheric resources. Estimates suggest that resource impairment negatively influences 2.6 billion people.*" (Watson *et al.*, 2008:3)

1.1 Background and motivation

Agricultural production forms the foundation of human life. It is responsible for the provision of food and nutrition security including livelihoods (Convention on Biological Diversity CBD, 2005:6; Tisdell, 2007:363 and Bohlen & House, 2009:1). This may explain the reason for the recent attention on whether the widely practiced conventional agriculture systems are able to sustainably maintain the current levels of production for the present and future generations. Many agree that, despite meeting the growing demand for food in the last half of the 20th century, conventional agriculture systems have resulted in negative environmental spillovers and unsustainable economic growth (Gliessman, 2007:3; Robertson & Swinton, 2005 and Tisdell, 2007:362).

Conway (1998) and Altieri (2000; 2004) confirm that conventional agriculture practices which have produced much agricultural growth are bringing about negative environmental, social and economic changes that will eventually undermine that growth and depress the level of agricultural production. This is supported by Kirschernmann (2009:54) who states that "the industrialization of agriculture which enabled us to dramatically increase production during the past half century also is a principal cause of the ecological degradation that now threatens our ability to maintain productivity". Gliessman supports this by stating that these practices, innovations, policies and techniques that brought the increase in productivity have undermined the basis for that productivity: "they have overdrawn and degraded the natural resources upon which agriculture depends – soil, water resources, and natural genetic diversity" (2007:3).

Several authors (Vogtmann, 1984; Sherr, 1999; Xu, 2000; Badgely *et al,* 2006; Bavec & Bavec, 2007; Altieri, 2007 and Kate, 2008) also share the same sentiments that conventional agriculture has caused environmental degradation and socioeconomic problems such as:

- deteriorating food quality and safety
- increased vulnerability of humans and animals to disease
- soil acidification
- ground and surface water pollution
- eutrophication due to leaching of nitrates form nitrogenous fertilisers
- depletion of water resources due to high extraction rates for irrigation
- biodiversity loss due to non-selective effects of pesticides on beneficial and non-beneficial insect pests and monoculture planting
- soil erosion and compaction due to repeated use and movement of heavy agricultural equipment.

According to Xu (2000) farmers and scientists have adopted alternative forms of agricultural practices which are sustainable in order to safeguard the interests of the future generations.The development of new forms of alternative or sustainable agriculture around the world is mostly as a result of the unsustainability of conventional farming on all three pillars of sustainability (economic, social and environmental).

I am an agronomist by profession with seven years experience in conventional agriculture management and was brought up in a community which practised subsistence farming using modern agriculture techniques. The first seven years of my profession was characterised by heavy dependence on the use of fertilisers and agrochemicals which we thought we understood very well but always faced challenges due to pests and diseases and high production costs mainly due to inputs. Also, as I grew up I noticed my community become food insecure due to decreased yields and everyone attributed this to the unavailability and high cost of fertilisers and hybrid seeds. These problems bothered me until I quit my job as an Agro Manager with a big agricultural company which practised modern agriculture on several thousands hectares to join a non-governmental organisation which promoted sustainable agriculture techniques to small scale farmers. However our knowledge was limited, this is when I thought of pursuing studies in sustainable agriculture and began a BPhil in Sustainable Development at Stellenbosch University.

My module in sustainable development gave me insight into the unsustainable nature of the global economy and I also noticed that conventional agriculture contributed significantly to the scenario. The module on systems and technologies for sustainable agriculture presented clues on how to overcome the problems of conventional agriculture. I was opposed to almost the majority in my class who were in favour of strictly organic agriculture. I thought the way forward was to blend conventional practices with organic and traditional practices.

It was the module on biodiversity and sustainable agriculture which caused me to have a complete turn from conventional agriculture when Dr Tarak Kate from India presented the consequences of conventional agriculture on small scale Indian farmers. This included shocking revelations that some of these farmers end up committing suicide after being failed by conventional farming. In this lecture I picked up a *Farmers' Weekly* of 24 April 2009 which carried the story "A green revolution launched at ZZ2". After reading about ZZ2 *natuurboerdery* farming approach I was excited with the practices of using composts, fermented plant extracts (FPEs) and compost teas and effective microorganisms (EM) for nutrient, pest and disease management and also to increase microbial diversity. I started communicating with Bombiti Nzanza, the Head of Department (HOD) for Research and Development (R & D) at ZZ2 who then invited me to his presentation on *natuurboerdery* at Stellenbosch University. It was at this time that I used the *natuurboerdery* farming approach for my case study for the managing sustainable agriculture enterprises module assignment. However I noticed that I had little understanding of the new farming approach as there was little information available on this new approach to commercial agriculture. From this point I decided that this was going to be my Master of Philosophy research thesis to allow me to explore and generate usable information about the approach through a case study research. I was also overwhelmed that I was going to be the first person to produce academic writing on this farming practice.

1.2 Problem statement

ZZ2 experienced agricultural production challenges associated with the practices of conventional agriculture. These challenges included soil borne diseases and high pest populations, decreasing yields despite increases in soil fertility (chemical measurements only based on NPK[1]), increased production costs and environmental degradation (van Zyl, 2009). This led to the development and adoption of the *natuurboerdery* farming approach. My preliminary investigations indicated that *natuurboerdery* is neither organic nor conventional farming.

I am of the idea that the development of sustainable agriculture systems is a necessity to feed the growing global population while restoring and maintaining environmental and ecological integrity and agroecosystem health. The principles and practices of *natuurboerdery* as developed by ZZ2 are in line with my idea and seem to be moving towards a more sustainable way of farming. However this has not been investigated and fully documented and hence my zeal to investigate it through an empirical research based on ethnographic research (observation and case study) (Mouton, 2001) to produce a qualitative and in depth description of *natuurboerdery*.

1.3 Research objectives

The objectives of this study are to investigate the *natuurboerdery* farming approach as practiced by ZZ2. I intend to discover what pushed them to first implement this new way of farming, the new practices which *natuurboerdery* incorporates and those which it no longer uses, as well as the impacts *natuurboerdery* has had on ZZ2.

[1] Nitrogen, Phosphorus and Potassium

In order to clearly formulate my thesis and argue it convincingly I am going to use research questions to precisely spell out the objectives of this study (Hofstee, 2006:85), as below:

- What were the reasons and steps of converting from conventional farming to *natuurboerdery*?
- What are the principles and practices of *natuurboerdery* farming?
- What are the benefits and changes occurring as a result of converting to *natuurboerdery*?

1.4 Definition of terms and concepts

According to Hofstee (2006:88) defining terms and concepts is necessary to create effective communication with the reader whenever there is any possibility of misunderstanding. This section defines concepts and terms as they are used in the problem statement and repeatedly used in this thesis.

i) Conventional farming: agricultural practices based on crop production technology improvement with special attention on high yielding hybrid seeds, inorganic fertilisers and pesticides, agro equipment and machinery that is driven by non renewable fossil fuel (Dixon and Gulliver, 2001 and Shiyomi and Koizumi, 2001).

ii) Sustainable agriculture: an agricultural system "... that over the long term, enhances environmental quality and the resource base on which agriculture depends, provides for basic human food and fibre needs, is economically viable, and enhances the quality of life for farmers and society as a whole" (Neher, 1992:51). In this thesis it is synonymous to alternative agriculture systems.

iii) *Natuurboerdery*: an approach to commercial farming adopted and developed by ZZ2. This approach is different to nature farming as developed by Mokichi Okada in Japan in the 1950's.

iv) Soil health: "emphasizes integrating and optimizing the biological, chemical and physical properties of soil as they affect farm profitability and environmental sustainability" (Abawi *et al.*, 2007:1).

1.5 Significance of the study

Bohlen and House (2009) emphasis for the need to balance and maintain sustainable food production systems for the burgeoning human population while maintaining integrity of natural ecosystems, agro ecosystems and global biodiversity. However many (Dixon & Gulliver, 2001; Smil, 2001; Shiyomi & Koizum, 2001; Jackson & Jackson, 2002 and Robertson & Swinton, 2005) argue that research and development of modern agriculture technology has been at the expense of integrated approaches for sustaining whole system productivity and agricultural systems for multi purposes[2]. The negative impacts of conventional agriculture discussed earlier in section (1.1) are re-stated by Shiyomi & Koizumi (2001:1), "the current agricultural systems does not consider the use of intra and inter specific interactions between organisms and the environment such as climatic factors and soils".

The development of the *natuurboerdery* farming approach offers opportunities which can address the above various perspectives and many authors support the development of farming approaches like *natuurboerdery* (Kirsherman, 2009; Bohlen and House, 2009) emphasise the need for developing the ecosystem paradigm as a solution framework for building sustainable agricultural ecosystems. Bohlen and House (2009:3) advocate for integration of industrial technology with ecological approaches to the management of agricultural landscapes to both mitigate ecosystem degradation and to enhance natural ecosystem processes.

This study is therefore important to generate new information which can be adopted under different farming systems to improve productivity and efficiency of sustainable agriculture practices and agro ecosystem management. As one of the first academic

[2] This includes the ecological integrity of farming systems and complex networks of biological interactions.

papers on *natuurboerdery* this thesis will provide the basis and backbone for academic and scientific research on the *natuurboerdery* farming approach. The information is also important to ZZ2 to enhance the strengths and identify and improve on the weaknesses of *natuurboerdery* practices through research and development.

1.6 Introduction to research design and methodology

The research design and methodology was designed to meet the research objectives and answer research questions outlined in section 1.3. The overall aim was to provide a deep understanding of the *natuurboerdery* approach as developed and adopted by ZZ2. This study was undertaken as a case study research using qualitative research methodology with multiple sources of data collection (documents or grey literature, observations and interviews). It is important to note that I was attached at ZZ2 as a student agricultural scientist in the R & D department for much of 2010. I thus had access and exposure to the people and systems at ZZ2. Chapter 3 details the research design and methodology used in undertaking this research and the justification, as well as detailing my role at ZZ2.

The first objective of the research was to investigate the reasons for and process of converting from conventional farming to *natuurboerdery* farming. However it was very important to first find and understand the nature and profile of ZZ2 as a private company, this involved reviewing the company website and informal interviews with staff. To obtain information and data to answer the research objective interviews of key people who have been at ZZ2 during the conversion period and those who were involved in the process were conducted using questionnaires in Appendix B to G with preset questions but involving probing to get clarification. A key document by van Zyl *et al.*, (unpublished) and other electronic documents in the form of PowerPoint presentations were also used. This allowed cross checking and verification of information gathered and the outcome of this process is presented in Chapter Four.

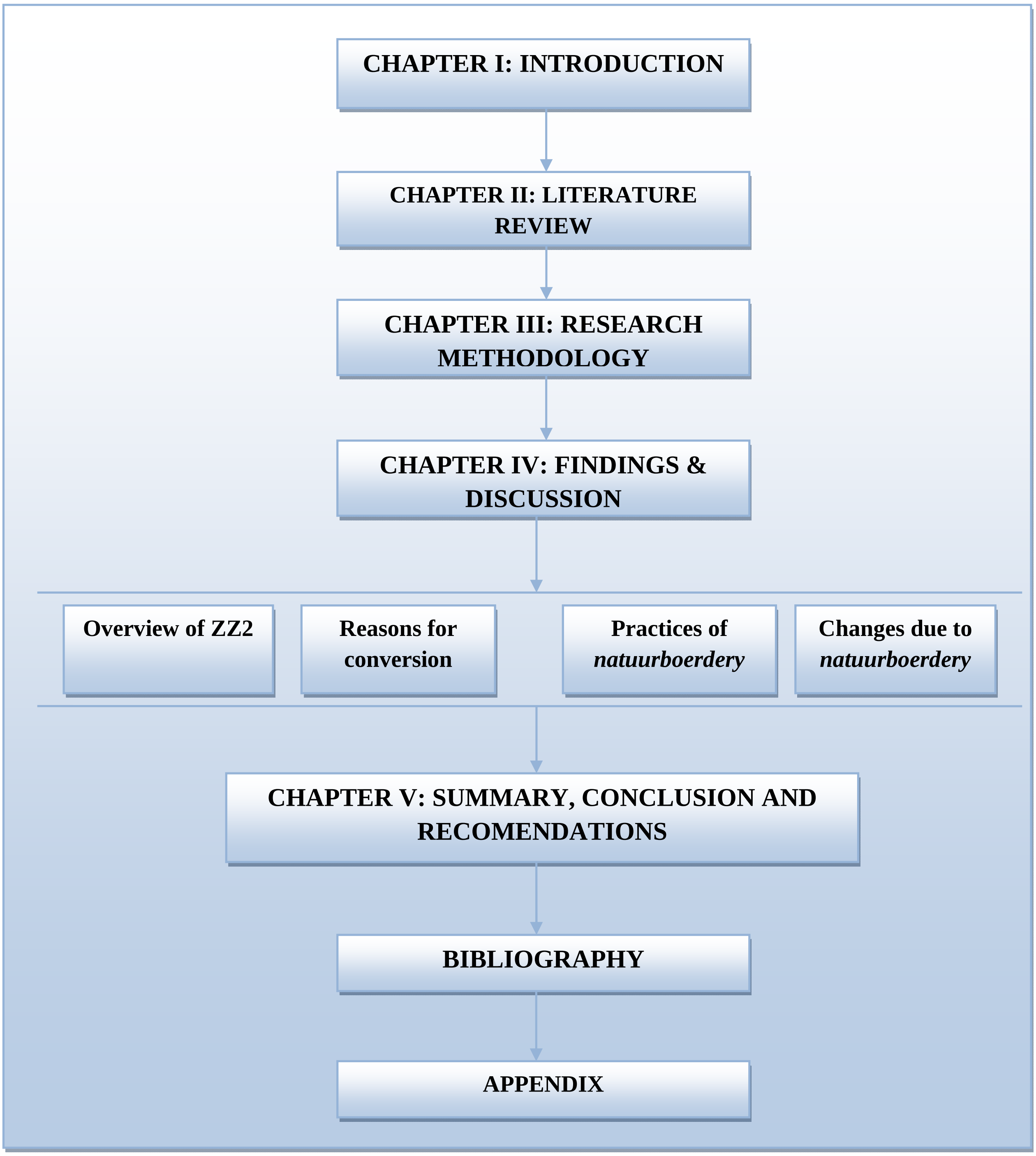
The second objective was to describe the principles and practices of *natuurboerdery* farming and formed the core of this study. Imperatively all sources of data collection were used, triangulation and crystallisation allowed cross checking of data and constructing a meaningful description of the *natuurboerdery* farming approach. The outcome of this objective was crucial in providing a basis for the analysis of objective three: to describe and explain the changes and benefits realised by converting to *natuurboerdery* farming approach. Furthermore some of the changes described were obtained by compiling data from past and present land records.

Conclusions, recommendations and areas for further research were drawn up by induction and deduction of the findings from the three research objectives. Recommendations were also based on my observation and understanding of the *natuurboerdery* farming approach and how it can contribute to the mitigation of the global polycrisis.

1.7 Outline of the thesis

The flow diagram in Figure 1 presents the outline of the thesis.

Figure 1: Thesis outline



CHAPTER II: LITERATURE REVIEW

2.1 Introduction

The literature review is presented in four sub sections and aims to provide an overview of different perspectives on global agricultural systems, review the key challenges to sustainable development referred to as the polycrisis and how agriculture is affected by and influences it, detail the practices of conventional agriculture, forms and principles of alternative[3] or sustainable agriculture systems, define agricultural sustainability and review approaches which can be used to develop and measure sustainability of agricultural systems. This creates a common understanding of agricultural systems and how the sustainability concept is useful in setting parameters for agricultural sustainability. The literature review concludes that the global economy is highly linked to agriculture and is unsustainable which calls for the need to develop and adopt alternative practices of agriculture which contributes to overall sustainability.

Section 2.2 provides an overview of the perspectives of the current global agriculture systems (conventional agriculture and alternative agriculture systems). A brief description of what is involved, aims of each system, key differences and the global coverage or extent is provided. This is to provide background to detailed discussions of the principles and practices of these systems presented in Sections 2.5, 2.6 and 2.7.

Section 2.3 provides detail of the polycrisis or global challenges (climate change and greenhouse gas (GHG) emissions, oil peak crisis, ecosystem degradation, land degradation, water crisis, population growth and urbanisation, inequalities and poverty) to sustainability and how agriculture affects it and is influenced by it. This is necessary in analysing research objectives[4] two and three by highlighting the need to change from

[3] This is synonymous with sustainable agriculture.

[4] i) To investigate the reasons and process of converting from conventional farming to *natuurboerdery* farming.

ii) To describe the principles and practices of *natuurboerdery* farming.

conventional agriculture to sustainable forms of agriculture and how the adopted practices mitigate the polycrisis.

Section 2.4 introduces the sustainability concept and the need for sustainable development. It also describes how the sustainability concept is useful in developing sustainable agriculture systems and the need to move away from conventional agricultural systems.

This is then followed by Section 2.5, 2.6 and 2.7 which review the practices of conventional and alternative agriculture systems respectively. This is necessary to provide a background of the current agriculture systems before looking at the principles of *natuurboerdery* under the research findings. It also helps to draw conclusions on how *natuurboerdery* differs from these two farming systems in Chapter Five.

2.2 Perspectives on global agriculture systems

This section gives brief definitions, overviews of and differences between conventional and alternative agricultural systems. This is important to facilitate discussions that follow. The current global agriculture systems vary from modern high input, high yielding practices to traditional and indigenous agricultural systems that have evolved since the Neolithic period (Altieri, 1990; Netting, 1993; Rosset, 1999; Bruinsma, 2003).

2.2.1 Conventional agriculture

At one end of the spectrum conventional agriculture practices are blamed by many (Matson *et al*, 1997; Vandermeer & Perfecto, 1997; Evenson & Gollin, 2003) as resulting in loss of biodiversity in order to enhance specialisation in fewer high input crops based on:

- Industrial model of increased production
- Economic and productive efficiency

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iii) To describe and explain the changes and benefits realised by converting to *natuurboerdery* farming approach.

- Controlling and managing nature as just another commodity

The inputs of conventional agriculture are synthetic fertilisers and pesticides produced with cheap fossil fuel, used for nutrient replacement and plant feeding and protection against pests and diseases (Tink, 1997 and Buntel, 1990). Conventional agriculture is also characterised by a high degree of mechanisation involving the use of heavy equipment and machinery and sophisticated irrigation technology (Dahlberg, 1993; Giller, 1997; Izac & Sanchez, 2001; IAASTD, 2009). However, the degree of specialisation and use of each practice differ.

2.2.2 Alternative agriculture

At the other end of the spectrum is the "broad category of alternative agriculture, which ranges from traditional indigenous practices to organic systems" (Chappelle & Lavelle, 2009:3). Different terminology has been used to describe and identify these closely related approaches; these are "low input, sustainable, ecological, agroecological, biological, and organic agriculture" (Pinstrup-Andersen, 2003); and "integrated plant nutrient systems, and no-till or conservation agriculture" (Merrill, 1983; Lockeretz, 1989; Vandermeer, 1995; Bruinsma, 2003).

There is a consensus among many authors (Dahlberg, 1993; Pretty, 2002 and IAASTD, 2009) that alternative agriculture practices offer opportunities to maintain a more holistic and multifunctional system. This involves the integration of natural ecological processes to a greater extent through high levels of recycling and the incorporation of the fundamental interconnection between agriculture, human culture and social issues which influence the food system (Dahlberg, 1993; Pretty, 2002 and IAASTD, 2009). The National Research Council (NRC) (1989) does not take alternative agriculture as a single methodology but rather as a range of management and technical practices for cost reduction, health promotion, environmental rehabilitation and enhancing biological interactions and natural processes. This is consistent with Bruinsma's (2003) and Lockerertz's (1991) evaluations that alternative agriculture practices use complementary strategies to increase sustainability.

2.2.3 Low external input agriculture (LEIA)

LEIA approaches have been developed to manage resources for agriculture to satisfy changing human needs, while maintaining or enhancing the quality of the environment and conserving natural resources (De Jager *et al.*, 2001). These approaches are essentially a middle ground between high input conventional agriculture and the alternative approaches, where inorganic chemical inputs are used in conjunction with organic methods and inputs. According to Smaling *et al.* (1996) and Pretty (1995) the aim is to combine low and high input technologies in an Integrated Nutrient Management Approach in order to maximise the use of local resources and optimise application of external inputs. De Jager *et al.* (2001) also argues that low economic returns to most agricultural production and existing market risks pose constraints to the use of external inputs.

2.2.4 Key differences

According to Chappell and LaValle (2009:3-4) the key methodological differences between alternative and conventional agriculture can be summed up in the following practices of alternative agriculture:

- Reduction and elimination of synthetic inorganic pesticides
- Minimal use of inorganic chemical fertilisers (which reduces fossil fuel use)
- Reduced reliance on heavy machinery and equipment when possible
- Replacement and reduction of inorganic inputs through a range of natural ecosystem processes including: longer fallow periods, use of green manures, crop rotations, intercropping, increased crop and animal diversity and use of natural enemies for pest and disease control.

2.2.5 The global extent of conventional versus organic agriculture

Since its inception in the 1950s, conventional agriculture has dominated world agriculture systems in terms of land coverage (Evenson and Gollin, 2003). This is supported by Fresco (2003) who states that conventional agriculture is practised on approximately 98 percent of the world's agricultural land. Meanwhile it is estimated that certified organic agriculture covers approximately 0.7 percent (31 million hectares) of world agricultural land (Rupela, 2006:1; Willer and Yussefi, 2007). An additional 62 million hectares is estimated to be under "organic wild collection", considered to be alternative agriculture management is equivalent to 1.4 percent of global agricultural land.

Agricultural production dominates the use of world's land resources and is mainly characterised by conventional agriculture systems which have resulted in disruption of the ecological processes of the natural environment. Alternative agriculture practices have potential to maintain and enhance environmental integrity by mimicking natural ecosystems.

2.2.6 Section summary

Today's global agriculture practices can be split into two major groups. Conventional agriculture is associated with the use of agrochemicals, heavy machinery and equipment and intensive irrigation. This is widely blamed for causing environmental degradation and loss of biodiversity. Alternative agriculture practices aim to mitigate the negative impacts caused by conventional agriculture. They achieve this by minimising or eliminating the use of agrochemicals through nutrient recycling, use of pest predators and mimicking the structure and functioning of natural ecosystems. However, conventional agriculture still dominates world agriculture production accounting for 98 percent of the world's cultivated land while certified organic covers approximately 0.7 percent (31 million hectares).

2.3 Agriculture and the polycrisis

"Now in the first decade of the 21st century, our system of food production must grapple with a sobering fact as it attempts to feed a world population that continues to grow: the techniques, innovations, practices and policies that have allowed increases in productivity have also undermined the basis of that productivity" Gliessman (2007:1).

This section will examine the factors that make up the global polycrisis and how agriculture is both affected by and affects it. According to Swilling (2009) a polycrisis "consists of a multiple set of nested crises that tend to reinforce one another" and that are not reducible to a singular cause and effect relationship. The polycrisis is reinstated by Swilling and Annecke (unpublished:2-3) who propose that there are “seven most significant mega-trends that are reshaping global socio-economic and ecological relationships”. To explain the scenario they refer to six documents and a website:

- **Eco-system degradation**: The United Nations Millennium Eco-System Assessment Report (MEA, 2005)
- **Global warming**: Intergovernmental Panel on Climate Change Report (IPCC, 2007).
- **Oil peak**: (www.peakoil.net).
- **Inequality**: The United Nations Human Development Report for 1998 (United Nations Development Programme, 1998).
- **Urban majority**: (United Nations 2006
- **Planet of slums**: The UN Habitat Report: The Challenge of Slums (United Nations Centre for Human Settlements 2003).
- **Food insecurity**: The International Assessment of Agricultural Science and Technology for Development (IAASTD).

From the polycrisis defined by Swilling (2009) and Swilling and Annecke (unpublished:2-3), I identified six significant trends (climate change and greenhouse gas emissions, oil peak crisis, ecosystems degradation, land degradation, population growth and urbanisation and inequalities and poverty) which I reckon that agriculture is both affected by and affects. I also added the water crisis which I consider to be pertinent to agriculture. These will be discussed in the following sections and they help to provide a background on the unsustainability of conventional farming practices and how sustainable agriculture practices help to mitigate the trends as discussed in Sections 2.5, 2.6 and 2.7 respectively.

These challenges represent key drivers for change and require a paradigm shift before we are hit by a human and environmental catastrophe. One of the key documents which gives a thorough account of the state of agriculture, resources and food security is the International Assessment of Agricultural Science and Technology for Development

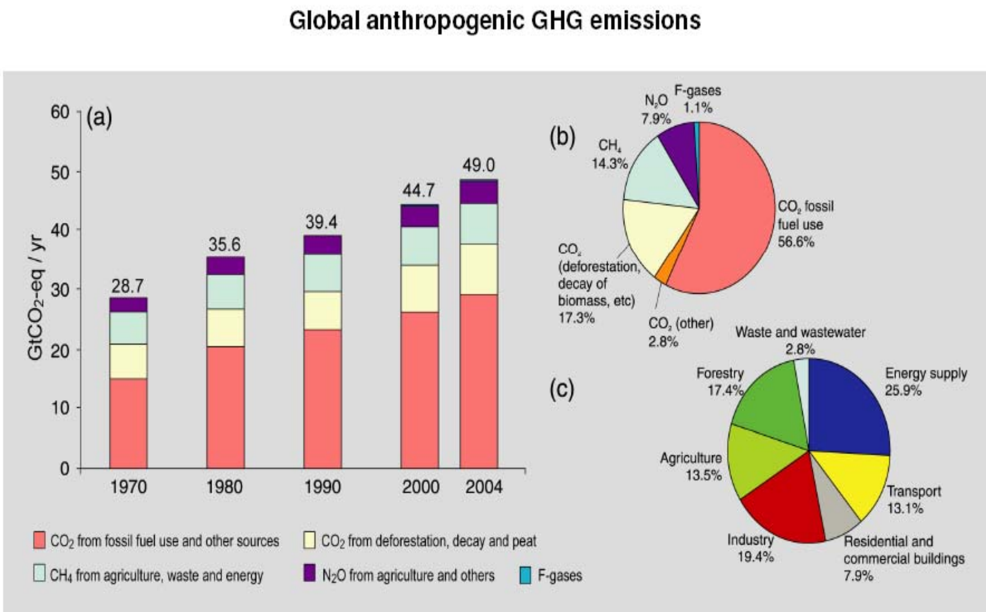
(IAASTD). The IAASTD is "an international assessment of the role of agricultural knowledge, science and technology (AKST) in reducing hunger and poverty, improving rural livelihoods and facilitating environmentally, socially and economically sustainable development" (IAASTD, 2008:2). The report reflects that there is an escalation of food prices while competition over land between food and bio-fuels grows. The report also notes that there is a break down in ecosystem services due to over use of resources which will be worsened by climate change and supports that 23 percent of all land is degraded to some extent.

2.3.1 Climate change and greenhouse gas (GHGs) emissions

The Intergovernmental Panel for Climate Change (IPCC) has documented the realities of climate change and global warming associated with the emissions of GHGs. The accumulation of GHGs in the atmosphere has reached 380 ppm which will result in a temperature rise of about five degrees Celsius during the 21st century (IPCC, 2007:1 and UNDP, 2008:8-9). Bartelmus (1994: 17) maintains that the accumulation of GHGs in the atmosphere has reached or surpassed threshold capacities of absorption of ecosystems to support this. The IPCC (2007:1) states that "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level".

Swilling and Annecke (unpublished) claim that about 70 percent of the GHG emissions are a result of the globalised and industrialised economy and human activities from fossil fuel combustion, deforestation and agricultural production. This is consistent with the IPPC (2007:4) findings that global increases in carbon dioxide (CO_2) and methane (CH_4) emissions are mainly due to fossil fuel use and agriculture and land use and also that the increases in nitrous oxide (N_2O) are primarily due to agriculture.

Figure 2: Global anthropogenic greenhouse gas emissions



Key: a) Global annual emissions of anthropogenic GHGs from 1970 to 2004. b) Share of different anthropogenic GHGs in total emissions in 2004 in terns of CO_2-eq. c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO_2-eq. (Forestry includes deforestation).

Source: IPCC, 2007:4.

As shown in Figure 2, the IPCC (2007: 4) indicates that agriculture activities contribute significantly to GHG emissions. The findings of the IPCC are supported by Kulshreshtha *et al* (2000:145) who give an account of agriculture as an important contributor of CH_4 and N_2O in Canada. They state that in Canada 33 percent of methane and almost 80 percent nitrous oxide emissions are a result of agriculture and agriculture generates 67 mega tonnes of carbon dioxide equivalent and up to 97 mega tonnes including all related activities.

The IPCC (2007:9) and UNDP Human Development Report (2008:17-18) concede that human development is impacted by climate change in ways which interact with social, economic and ecological processes. The IPPC (2007:9) further states that the impacts of climate change will depend on the level of adaptation, rate of temperature change and the socio-economic development pathway. The predicted impacts on agriculture can be explained and summarised as:

- Agriculture provides food and raw materials for human well being. Critical factors for agricultural production like temperature patterns and water availability will be altered by climate change. Unstable yields are likely to occur due to recurrent droughts, floods, storms and extreme temperatures. This is likely to result in food insecurity and malnutrition especially in developing countries.
- Human settlements and water systems for irrigation will be disrupted because of glacial melts, altered runoff patterns and ecological stress. It is predicted that 1.8 billion people will not have access to fresh water resources for consumption and general uses by 2025. The Andean region faces an imminent threat to water security because of the collapse of tropical glaciers.
- Species extinction and biodiversity loss is likely to occur due to failure to adapt to climate change.

(IPPC, 2007:9 and UNDP, 2008:17-18).

The impacts of climate change are non selective and will affect all forms of life, biological and ecological processes which support agricultural production. Both conventional and alternative agricultural systems contribute to the emission of GHGs.

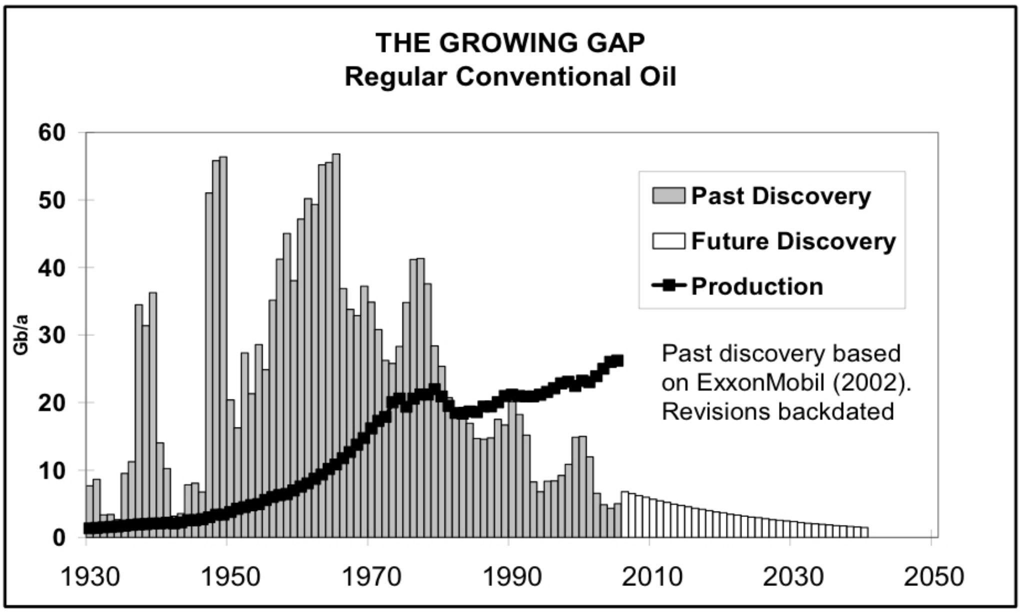
However conventional systems contribute most through intensified use of fertilisers, pesticides produced from fossil fuel and also extensive use of heavy machinery and equipment.

2.3.2 Oil peak crisis

"… Our exponential escalation in energy use, including that used in agriculture, is the principal reason that we have generated a food supply that grows geometrically as the human population…" (Hall and Day 2009:230).

Hall and Day (2009:230) argue that one of the most immediate impacts of the human economy relates to the decline in oil reservoirs commonly referred to as 'peak oil'. They stress that the global production of oil might have reached a maximum and is tailing off. This is supported by the so-called 'oil peak' community who emphasise that we either have already - or will soon - hit what they define as peak oil production (Campbell and Laherrere, 1998). The Association for the Study of Peak Oil and Gas (ASPO:2) predicts that "the rate at which oil is discovered globally has been dropping for decades and is projected to drop off even more precipitously in future years. The rate of worldwide consumption, however, is continuing to rise. Thus, the gap between supply and demand of oil can be expected to widen" (Figure 3).

Figure 3: Predictions and trends of peak oil discovery and production



Source: ASPO, 2007

The depletion or scarcity of oil has a bearing on agriculture and food production (Swilling and Annecke, unpublished). This view is supported by ASPO South Africa which connects oil with the production of essential inputs (fertilisers and pesticides) used in modern agriculture and powering of agro-equipment and also food distribution (2007). ASPO argues that the Green Revolution managed to boost agriculture yields to support the rapidly increasing global population using inputs derived from fossil fuel. This is supported by Hall and Day (2009:231) who emphasise that agricultural productivity averted hunger and famine based on cheap fossil energy. To further their argument they also quote from agronomist David Pimentel, ecologist Howard Odum and environmental scientist John Steinhart, who quantify the dependence of modern agriculture on energy, showing that “technological development is almost always associated with increased use of fossil fuels” (2009:231).

According to ASPO (2007:26), the major concern after oil peak is that world food prices will increase. This will mean hunger and starvation for many poor people especially those in less developed countries. Heinberg (2003:177) also argues that without cheap fossil fuels the world can sustainably feed only 2 billion people as compared to the current 6.4

billion people. The other implication of peak oil raised by APSO (2007) is that of competition between food and fuel. It suggests that competition will result from bio-fuel policies being implemented. Such policies are likely to make it more profitable for maize and sugarcane farmers to sell their produce for ethanol production rather than for food. This is a threat to food security especially for net food importing countries and the poor and landless people.

The peak oil crisis is now an accepted reality which will mark the end of cheap oil which drives most of the industrial processes. Conventional agricultural systems will be most affected due to their over reliance on inorganic fertilisers and pesticides produced from cheap oil. Also other processes in conventional agriculture use significant amounts of energy produced from the combustion of cheap oil.

2.3.3 Ecosystem degradation

The Millennium Ecosystem Assessment (MEA) was initiated by the United Nations to assess the status of ecosystems and to establish required action for their conservation and sustainable utilisation. The MEA (2005:9) defines an ecosystem as “a dynamic complex of plant, animal, and microorganism communities and the non-living environment interacting as a functional unit…” It also states that the range of ecosystems include the undisturbed natural forests, landscapes for human settlement and use and managed and modified ecosystems like agricultural land and urban environments

The MEA (2005:16) documents four key findings:

- Human activities have manipulated ecosystems more rapidly and extensively in the last 50 years compared to any other period of human life. These changes were mainly as a result of meeting the increasing demands for food, fresh water, timber, fibre and fuel. It is predicted that some of these changes constitute irreversible losses to biodiversity.
- Changes in ecosystems conditions have contributed to net gains in human well being and economic development. However these gains undermined many ecosystems services, increased risks of nonlinear changes, and exacerbated

poverty for some groups of people. There is an urgent need to address these problems to avoid diminishing the needs of future generations from ecosystems.

- There is a likelihood that this degradation of ecosystems will increase in the first half of the 21st century, which compromises the attainment of the Millennium Development Goals (MDGs).
- Positive development of degraded ecosystems while obtaining their services can be achieved by a paradigm shift in policies, institutions and practices.

Brussaard *et al* (2010:1) state that agriculture depends on natural capital invested in wild biodiversity and is enhanced by the interaction between human beings and the natural environment. They also reinforce that biodiversity is pivotal in sustaining agricultural production and the provision of ecosystem services confirming the MEA (2005) proposition. This also supports the argument put forward by the Convention on Biological Diversity (2005) that biodiversity is a precursor and valuable component in agriculture for regulation of bioprocesses such as soil formation, nutrient cycling and pollination. Despite the crucial and essential value of biodiversity, UNEP (2007:12-13) points out that there is "an increase in species extinction and reduction in agricultural genetic biodiversity". This is supported by Bartelmus (1994 citing McNeely *et al.*, 1990) and UNEP (1992) that:

- If the status quo is maintained, species extinction rates can reach 5000-15000 by 2020.
- Deforestation of tropical rainforests, which contain half of the world's biota, results in loss of 17 million hectares annually. This can result in extinction rates of 15000 to 50000 species per annum by the year 2020.

It is also important to note that forests not only provide habitat for species, they serve as a critical component of the hydrological cycle, sink for carbon (CO_2 sequestration), preserve soil, provides fuel wood and timber and have cultural and aesthetic value.

One question which might arise is: what is responsible for eroding our natural wealth? Gliessmen (2007:13) points out that "the loss of genetic diversity has occurred mainly because of conventional agricultures emphasis on short term productivity gains". It is clear that agriculture needs to adapt to ensure the regeneration and protection of ecosystems.

2.3.4 Soil degradation

Land is the primary resource for agricultural food production and a key source of raw materials for the globalised and industrialised economy. Most developing world economies are agro based relying on land resources for reproductive systems of agriculture, ranching, forestry and fishery. Swilling and Annecke (unpublished) confirm that "soils are the primary resource when it comes to food production and cannot be taken for granted, this is the resource that must generate the food required to feed a population that will grow from 6 billion in 2005 to 8 billion by 2030".

The following two quotations by Franklin Delano Roosevelt and naturalist Charles Kellogg respectively emphasise the importance of land resources:

- "The nation that destroys its soil destroys itself".
- "There can be no life without soil and no soil without life".

Despite the undisputable and fundamental importance of land resources to human well being, we sadly note continued trends in soil and land degradation as indicated by Sherr (1998) in Table 1.

Table 1: Percentage global estimates of soil degradation, by region and land use type

Region	Agricultural land (percent degraded)	Permanent pasture (percent degraded)	Forest and woodland (percent degraded)
Africa	65	31	19
Asia	38	20	27
South America	45	14	13
Central America	74	11	38
North America	26	11	1
Europe	25	35	26
Oceania	16	19	8
World	38	21	18

Source: Sherr, 1999:18

The above figures show that Central America, Africa, South America and Asia have the most degraded agricultural land. Sherr (1998) points out that land degradation will be a threat to developing countries' food security by 2020.

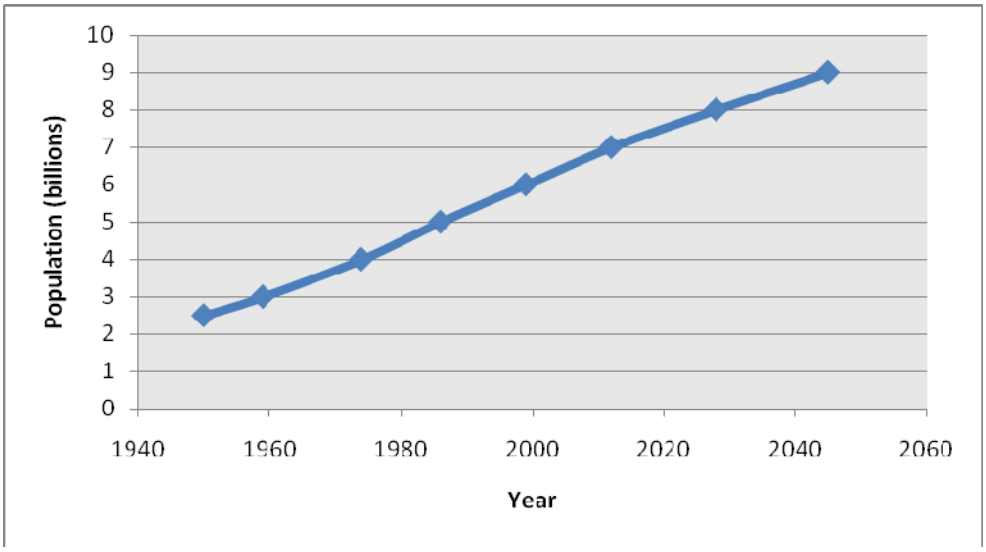
The Food and Agriculture Organisation (FAO) (1998) estimates that approximately five to seven million hectares of valuable prime agricultural land is degraded per year while the World Congress on Conservation Agriculture (2001) puts it at 10 million hectares. Forms of soil degradation include salting, water logging, compaction, pesticide contamination, decline in soil health and erosion. According to Oldeman (1994) the most severe degradation is a result of erosion, which accounts for soil losses of up to five to 10 tons per hectare in Africa, South America and North America and almost 30 tons per hectare annually in Asia. These rates of soil loss greatly exceed soil formation rates of approximately one ton per year. According to Gliessman (2009:29) "the cause-effect relationship between conventional agriculture and soil erosion is direct and unambiguous". He argues that the practices of conventional agriculture (intensive tillage, monoculture and short rotations) expose soil to wind and water erosion. Irrigation is also a direct cause of water erosion.

Soil resources sustain agricultural production which provides food and raw materials for the human economy. The practices of conventional agricultural result in most forms of soil degradation which decrease agricultural production. If the current rates of soil degradation continue food shortages will be inevitable. There is a need for agriculture practices which build, improve, restore and maintain soil health if sustained production for food security is to be realised.

2.3.5 Population growth and urbanisation

As indicated in Figure 4 below, world population increased from 3 billion in 1959 to 6 billion in 1999, a doubling that occurred over 40 years. The Census Bureau's latest projections imply that population growth will continue into the 21st century, although more slowly. The world population is projected to grow from 6 billion in 1999 to 9 billion by 2045, an increase of 50 percent that is expected to require 46 years.

Figure 4: World Population: 1950-2050



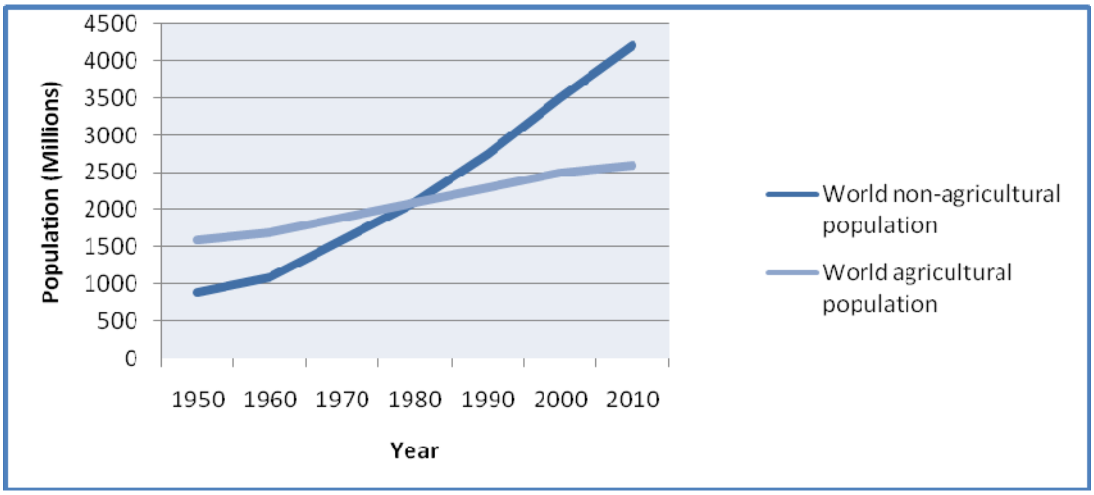
Source: U.S. Census Bureau, 2009.

The predictions by the U.S. Census Bureau confirm those by the United Nations that the world's population will grow to 8 billion by 2030, and at least 9 billion by 2050 (United Nations, 2006).

The NRC (2003) projects that 60 percent of the world's population will live in cities of less than a million people, 25 percent in cities of one to five million people, and about five percent in cities of six to 10 million people. It also predicts that by 2015 there will be 511 'million cities' (populations of around 1 million people). These predictions are almost consistent with Gliessman's (2007) indications that rural people working primarily in agriculture will abandon the land to urban areas and industrialised cities which will have an estimated 60 percent of the world's population by the year 2030. These trends are also supported by FAOSTAT (2005) as indicated in Figure 5: that there are now far more people in the world whose livelihoods are non agricultural than there are people who grow food, and this gap continues to widen over time. Swilling and

Annecke (unpublished) summarise these trends when they say that our future will be an urban one.

Figure 5: Number of people worldwide involved in agriculture and not involved in agriculture



Source: FAOSTAT, 2005

The challenge for agriculture is to be both sustainable and highly productive in order to feed the rising non-agricultural population in towns and cities (Gliessman, 2007; Chappell and Lavelle, 2009).

2.3.6 Inequalities and poverty

The Human Development Report (HDR) (1998) found that there are huge global inequalities in access to resources and consumption levels which increase poverty and food insecurity especially in developing nations. The HDR 1998 stated that the richest 20 percent of the world's population in developed countries account for 80 percent of private consumption expenditure, while the poorest 20 percent account for a mere 1.3 percent (UNDP, 1998:2). According to Swilling and Annecke (unpublished:3) "inequality is increasingly seen as a driver of many threats to social cohesion and a decent quality of life". Agriculture needs to focus on how it can be more equitable and improve livelihoods of the poor.

2.3.7 Water crisis

Water is the main limiting factor for agricultural food production in many regions and agriculture uses more than two thirds of water consumed globally (Gliessman, 2007); Postel and Vickers (2004) put it at 70 percent. Irrigation technology has significantly contributed to yield increases and cropped area with 18 percent of the cultivated area under irrigation (FAOSTAT, 2005) providing 40 percent of world food (Serageldin, 1995 and FAO, 2002). Postel and Vickers (2004) point out that irrigation has a considerable impact on regional hydrological systems.

The Global Environmental Outlook 4th report indicates that there is a global decline in the available water per capita globally and that water contamination is the greatest environmental cause of sickness globally (UNEP: 2007:4). The report indicates that if the present trends of water consumption and exploitation are maintained:

- 1.8 billion people will be living in regions of water scarcity by 2025.
- Two thirds of the world population will live under water stress conditions.
- Aquatic ecosystems will be negatively impacted, hampering the provision of their services due to the decline in quality and quantity of water resources.

Water extraction for irrigation purposes and other uses in agriculture is unsustainable as it exceeds replenishment rates by rainfall. Sustainable agricultural practices must aim to develop water use efficiency, harvesting, recycling and conservation strategies.

2.3.8 Section summary

This section reveals the key challenges to sustainable development, the global economy and human society, many of which are caused by and also affect agriculture. The predicted impacts of climate change will have a negative impact on agriculture. Ironically, agriculture significantly contributes to the emission of GHGs responsible for climate change and global warming phenomena. The development of the widely practiced conventional agriculture system is based on oil for energy to drive its process and for the production of essential inputs. However, the continuity and sustainability of this form of agriculture is threatened by the oil peak crisis. According to the MEA (2005) ecosystems generate goods and services essential for human life including agricultural production. Despite the crucial functions of ecosystems, the MEA notes that the manipulation of ecosystems in order to increase agricultural production to meet human needs has resulted in their degradation. It is virtually impossible for agricultural production to exist without land resources, of which the majority are degraded and the rates of deterioration are on the increase (Sherr, 1999). Gliesman (2007) links the practices of conventional agriculture to soil loss and degradation. He blames conventional agriculture for reducing genetic diversity into homogeneity for short term gains. Despite the fact that water is vital for life, we are moving towards water scarcity. It is important to note that agriculture uses 70 percent of fresh water resources while its rate of extraction from sources exceeds replenishment. The world population continues to grow and at the same time the majority is becoming non-agricultural. It is clear that we need sustainable food production systems and new agricultural approaches, which mitigate global environmental impacts and depletion of resources.

2.4 The concept and need for sustainable development

The finite global ecosystem is the source of all material inputs, which drive the infinite economic subsystem, and is the sink for all its wastes (Goodland & Daly, 1996:1011). Clayton and Radcliff (1996:1) and Goodland and Daly (1996:1008) state that economic systems determine the rate and outflow of energy and resources from the environment into patterns of human use and the rate and flow of wastes, energy and materials from human economic operations back to the environment. Agriculture, as part of the economic subsystem, contributes to the strain on the environment's regenerative and assimilative capacities.

The concept of sustainable development emanated from the need to integrate and balance environmental and economic concerns (Dresner, 2002:63). The Brundtland report, *Our Common Future* (WCED, 1987:1), states that "sustainable development is development that meets the needs of the present generations without compromising the ability of the future generations to meet their needs". Goodland and Daly (1996:1002) define sustainable development as "development without growth in throughput of matter and energy beyond regenerative and absorptive capacities". Development is progressive transformation of the economy and society leading to improved quality of life (Dresner, 2002:67; Bartelemus, 1994:1).

The sustainability concept is useful in indicating a set of issues on agriculture that are "conceived as the result of co-evolution of socioeconomic and natural systems" (Reijntes *et al.*,1992). This is supported by Altieri (2007) and Gliessman (1998) who acknowledge the role of the sustainability concept in driving changes to conventional agriculture systems to make them more environmentally, socially and economically viable. The development and adoption of sustainable agriculture systems aims to mitigate the deterioration of the quality and regenerative capacities of the global ecosystems believed to be a result of conventional agriculture practices.

Altieri (2007) points out that the dynamics of agricultural production have shifted from being just technical to become more complex; social, cultural, political, environmental and economic issues characterise this complexity in agricultural systems. He also argues that agricultural sustainability can be achieved by an in-depth understanding of the relationship between agriculture, the global environment and social systems. This argument is based on the principle that the development of agriculture systems is a result of complex interactions of a multitude of factors. Alternative agricultural systems, which aim to improve sustainability and productivity, have been developed to address the challenges created by conventional farming systems. "The main focus lies on the reduction or elimination of agrochemical inputs through changes in management to assure adequate plant nutrition and plant management respectively" (Altieri, 2007:3).

The Millennium Ecosystem Assessment (MEA) (2005) validates that the gains of agricultural productivity of the 20th century have resulted in substantial degradation to global ecosystems. Gliessman (2007:3) confirms that our system of food production has overdrawn and degraded the natural resources, which support agriculture – soil, water resources and the natural genetic diversity. The system also relies on non-renewable fossil fuels. Thus, Gliessman (2007:3) concludes, "our agricultural system is unsustainable – it cannot continue to produce enough food for the global population over the long term because it deteriorates the conditions that make agriculture possible". Matson *et al*. (1997); Tilman *et al.* (2002); Robertson and Swinton (2005) concede that the strain and degradation of global ecosystems by agriculture will continue to increase in the coming decades if appropriate action is not taken.

The concept of sustainability is useful in agriculture in trying to make practices of conventional agriculture more environmentally, socially and economically viable. Sustainability science recognises the regenerative and assimilative functions of the global ecosystems. It also notes that the capacity of the environment to carry these functions is almost or has been exceeded by human and economic activities to which agriculture contributes significantly. All these factors call for a paradigm shift from the most practiced modern agriculture system.

2.5 Practices of conventional agriculture

Section 2.3 revealed the key challenges to sustainable development referred to as the polycrisis and related it to agriculture while Section 2.4 introduced the sustainability concept. In this section, the main practices of conventional agriculture and how they contribute to the polycrisis are discussed. These are intensive tillage, monoculture, use of inorganic fertilisers, irrigation, chemical pest and disease control and use of hybrid seed. The aim of this discussion is to show how these practices contributes to the polycrisis and hinder sustainable development.

The main focus of conventional agriculture as defined by Gliessman (2007:3) is: "the maximisation of production goals and the maximisation of profit". Many argue (Xu, 2000:1; Badgely, 2006:86; Gliessman, 2007:3) that the development of conventional agriculture practices after the Second World War, popularly known as the 'Green Revolution', was done without a thorough evaluation of and regard for the unintended, long term consequences and their implications on the ecological balance and dynamics of agroecosystems.

According to Gliessman the framework and logic of conventional agriculture mimic industrial processes. He argues, "plants and animals assume the role of miniature factories" (2007:3). Output depends on input maximisation while productive efficiency is increased by genetic manipulation and the environment is highly regulated.

2.5.1 Intensive tillage

Conventional tillage systems are based on complete, deep and regular soil cultivation. The main objectives of soil cultivation are to achieve fine tilth, loosen soil structure, improve drainage and weed control (Gliessman, 2007:3). This is made possible by the regular and frequent use of fossil fuel driven heavy machines and equipment (Altieri, 2007:1; Kate, 2008:2; 2000:1; Badgely *et al*, 2006:86 and Bavec & Bavec, 2007:1). The repeated and inappropriate use of agricultural equipment results in land and soil degradation in a number of ways (Bavec & Bavec, 2007:1-2; Kate, 2008:2-3 and Sherr, 1999:14-15). Soil organic matter content is lost due to increased decomposition and absence of vegetation cover. Recurring traffic of machinery results in soil compaction. The subsequent loss of soil organic matter results in reduced soil health and loss of productivity (Abawi, *et al*., 2009:10). Rates of soil erosion by wind and air are exacerbated by intensive soil cultivation.

Intensive tillage systems rely much on cheap oil and this will be impossible with the advancement of the oil peak crisis when cheap oil is not available. Furthermore the repeated movement of tillage equipment used, complete loosening of soil and removal of vegetation cover result in soil health deterioration and degradation. This is unsustainable and will lead to reduced soil and crop productivity.

2.5.2 Monoculture

The adoption of the Green Revolution or conventional agriculture practices after the Second World War resulted in a specialised farming system. Gliessman (2007:4) refers to specialisation in crop agriculture as monoculture. This means that farmers grow a single crop on an extensive scale. He goes on to confirm that monoculture is closely linked to industrial agriculture where "labour inputs are minimised and technology based inputs are maximised in order to increase productive efficiency" (2007:4). Monoculture is compatible with other practices of conventional agriculture: it favours intensive tillage systems, chemical pest control, and specialised plant hybrids. The argument for monoculture is that it allows more efficient use of farm equipment, sowing, weed control, harvesting, and results in economies of scale on purchase of inputs like seed, fertiliser and pesticides (Gliessman, 2007:4).

Shiva (1995) opposes the myth that diversity results in reduced productivity, which led to the development and adoption of agricultural uniformity and monocultures. She argues that crop uniformity destroys genetic and biological diversity, which is the source and basis for breeding the uniform hybrid seeds or production of genetically modified organisms. The adoption of uniform crop varieties from multinational seed companies mainly planted as mono-crops has led to abandonment of diverse local varieties, thus contributing to loss of genetic diversity (Shiva, 2005; Kate, 2007). Also the creation of monoculture crop fields and plantations for industrial needs results in forest clearing and loss of biodiversity.

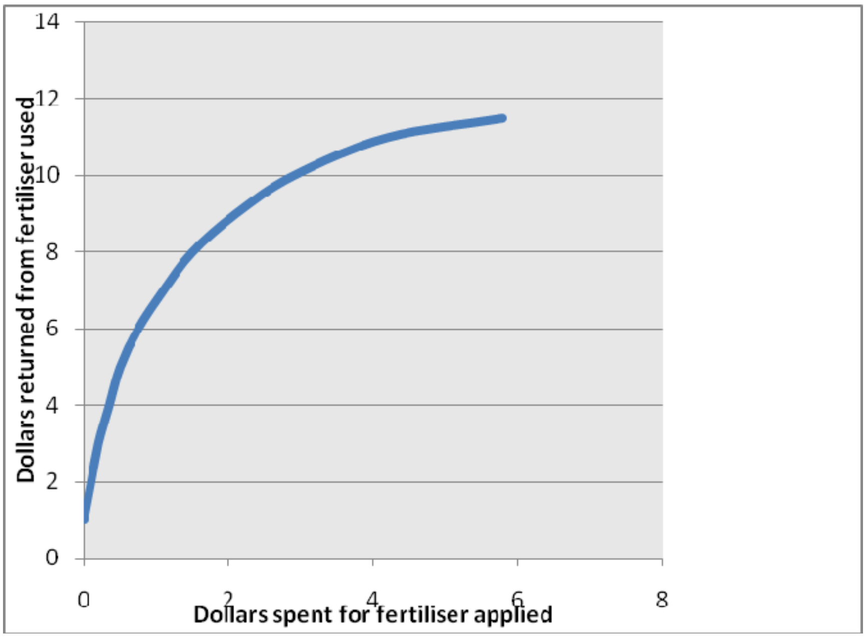
The practice of monoculture relies mainly on hybrid crops which can only be sustained by the use of pesticides and fertilisers made from cheap fossil fuel and are only effective with the correct amount of water necessitating irrigation which uses energy produced from the combustion of fossil oil (Shiva, 1995 and Gliessman, 2007). It is clear that agriculture systems need to increase crop diversity and mimic nature in order to reduce reliance on external inputs.

2.5.3 Use of inorganic fertiliser

The tremendous increase in grain yields in the second half of the 20th century is highly attributed to the intensive application of inorganic fertilisers, which was a result of the Green Revolution (Gliessman, 2007:4 and Kate, 2007:2). According to FAOSTAT (2005) the use of inorganic fertiliser worldwide increased tenfold during the period 1950 to 1992 and then moderated and had reached 141.6 million metric tonnes in the year 2002. Gliessman (2007:4) argues that the production of fertilisers is based on cheap fossil fuel and unsustainable nutrient mining.

However, Gliessman also admits that fertilisers are easy to apply uniformly and provides crops with readily available essential nutrients. Farmers have relied on the ability of fertilisers to meet plant nutrient needs in the short term and ignored soil health and the processes which maintain soil health in the long term (Gliessman, 2007:4). Many argue that the nutrient components are easily leached out of the soil root zone to other water bodies like rivers, lakes and streams resulting in eutrophication[5] and into groundwater reserves posing a health risk to consumers (Gliessman, 2007:4; Altieri, 2007:1; Kate, 2008:2; Badgely *et al*, 2006:6 and Bavec & Bavec, 2007:1). Gliessman (2007:4) argues that farmers do not have control over the economic cost of fertiliser as it is a variable cost and the fact that its price is based on the cost of petroleum. Shiyomi and Koizumi (2001) argue that the rate of crop yield increase with increasing agrochemical use has decelerated. This is furthered supported by the economics of fertiliser use, which shows diminishing returns as illustrated graphically by Edwards (1990) in Figure 6 below.

Figure 6: Diminishing returns on fertiliser use



Source (Edwards: 1990:10)

[5] Excessive growth of oxygen depleting plant and algal life.

The application of inorganic fertilisers is intended to feed the plant and not the soil. This results in loss of soil organic matter and soil health deterioration and ultimately soil degradation. Furthermore the inorganic fertilisers are produced from fossil fuel which is non-renewable and will become increasingly more expensive. Inorganic and nitrogenous fertilisers also contribute to release of nitrous oxide which is a GHG, thus contributing to global warming. Nitrates from these fertilisers are highly leachable and end up contaminating underground and surface water. Agriculture needs to reduce its dependence on these inputs.

2.5.4 Irrigation

Water is a major limiting factor to crop production. Conventional agricultural practices overcame this challenge with highly sophisticated irrigation technologies (Gliessman, 2007:4 and Kate, 2008:2). The adoption of irrigation technologies has resulted in increased cropped land and yields; even though irrigated land is only 18 percent of the total cropped area, it accounts for 40 percent of world food production (Serageldin, 1995 and FAO, 2002). FAOSTAT (2005) states that 44 hectares of irrigated land supports 1000 people globally. It is important to note that water for agricultural purposes accounts for 70 percent of total usage of fresh water (Sherr, 1999:14-15; Postel and Vickers, 2004 and Gliessman, 2007:4). The amount of water use in agriculture may have increased with the advent of inorganic fertiliser use which are only effective with the correct amounts of water which is supplemented by irrigation (Shiva, 1995 and Gliessman, 2007).

Gliessman (2007) asserts that the use of water in agriculture is unsustainable and states that:

- Groundwater extraction exceeds replenishment by rainfall.
- Over pumping causes land subsidence and saltwater intrusion along the coast.
- Water drawn from dams and rivers in urban areas for irrigation results in competition for water for human use.
- Construction of dams upstream to hold water has detrimental effects on the ecology of downstream rivers.
- Irrigation has a high likelihood to increase leaching of fertilisers.

- Irrigation can result in increased soil erosion rates.

Although irrigation has resulted in increased crop productivity, the drawing up of water from water sources is unsustainable. The rates of drawing up water exceed the rate of replenishment by rainfall. Techniques used for irrigation scheduling only take into account plant water use and not what is stored in the reservoirs. As water scarcity intensifies competition for water will also increase thus rendering agriculture based on irrigation. There is a need to implement strategies for water use efficiency, recycling, harvesting and conservation.

2.5.5 Chemical pest and weed control

Adoption of farming methods utilising high chemical pesticides (insecticide, fungicides and herbicides) and high yielding hybrid seed varieties in the post Second World War lead to significant increases in crop yields across the globe (Gliessman, 2007:4 and Kate, 2007:2). The use of these chemical agents presented an efficient way for farmers to deal with all unwanted organisms which threatened agricultural production. According to many, pesticide use has proved to be an unsustainable practice in modern agriculture (Gliessman, 2007:4; Altieri, 2007:1; Kate, 2008:2; Xu, 2000:1; Badgely *et al,* 2006:86; Bavec & Bavec, 2007:1). They argue that:

- Pesticides can reduce pest populations initially and result in a quick rebound or even greater numbers because they also kill natural pest predators.
- Overuse and misuse of pesticides result in the phenomenon of resistance[6].
- Pesticide resistance may force farmers to use even greater amounts and more dangerous pesticides which can promote greater resistance.

According to Pimental *et al.* (1991) and Pimental (2005) total crop losses to pests have stayed fairly constant despite increasing pesticide use. This is supported by Gliessman (2007) who states that farmers lose money due to the high costs of pesticides and also that they have profound effects on the environment and human health. Pesticides can find

[6] Pest populations continually exposed to pesticides are subjected to intense natural selection for pesticide resistance.

their way into water bodies through leaching and erosion "…where they enter the food chain, affecting animal populations at every level and often persisting for decades" (Gliessman, 2007:4).

Pesticides used for pests, disease and weed control are also made from cheap fossil oil. They support and enhance monocultures in conventional agriculture. Non-selective pesticides used indiscriminately kill all insect pests including beneficial microorganisms thus contributing to biodiversity loss and species extinction (Gliessman, 2007). The persistent use of these pesticides leads to pest resistance thus exacerbating pest and disease problems leading to the use of more toxic pests. Also the herbicides used only select the hybrid crops and kill all other vegetation species further eliminating agro-diversity. These pesticides and herbicides may leach into water bodies destroying aquatic life and posing a health hazard to humans, wildlife and livestock which drink the water. Agriculture needs to find less harmful methods of pest and disease control.

2.5.6 Hybrid and genetically modified seeds

The use of hybrid seeds has been critical in yield increases under modern agriculture (Kate, 2008:2). Gliessman (2007:5) supports this, stating that hybrid seeds, which combine two characteristics of different plants in the same species, can be more productive than non-hybrid varieties. He goes on to argue that this has been "one of the primary factors behind the yield increases achieved during the green revolution" (2007:5). However, he notes their disadvantage in that they require optimum conditions, including intensive application of inorganic fertilisers and chemical pesticides for them to express their full potential. Hybrid varieties also produce sterile seeds meaning that farmers have to buy seeds every season.

Millstone and Lang (2006:42-44) differentiate conventional plant breeding of hybrids from the more recent advances of genetic engineering which produces customised plant and animal varieties through the "ability of spliced genes from a variety of organisms into the target genome" (Gliessman, 2007:6). The latter results in organisms referred to as transgenic, genetically modified (GM) or genetically engineered (GE). According to

Millstone and Lang (2006:42-44), genetic manipulation in conventional breeding is through interacting genes of organisms from the same species or their close relatives. This restricts a shift of the gene pool and cross transfer of characteristics.

The development and production of genetically modified organisms has become an important issue in modern agricultural production. According to González-Cabrera *et al.* (2003), the area planted to GM crops has increased by approximately 40-fold from 1.7 million hectares to 67.7 million hectares between 1996 and 2003. They also mention that 55 percent of the world's soybean in 2003 was GM while for cotton it accounted for 21 percent. Despite the potential advantages offered by GMOs – reducing chemical pesticide use, irrigation and allowing production in saline conditions and increasing nutritional value (Gliessman, 2007:6), many have raised concerns about the adoption of related biotechnologies. Millstone and Lang (2006), Pretty (2007) and Shiva (2008) argue that these technologies are likely to result in:

- Migration of modified genes into other populations wild and domestic.
- Diminishing of biodiversity due to abandonment of traditional varieties.
- Farmers' dependence on transnational companies who owns the patents.

According to Makanya (2005:31), supported by Gliessman (2007:5-6), the production of GM crops is designed to suit the characteristics of conventional agriculture at the expense of alternative farming methods.

The use of hybrid seeds and GMOs promotes homogeneity and uniformity which is a further threat to species diversity. These uniform crops (monoculture) or animals are raised in extensive areas of land replacing other vegetation and animal species thus contributing to species extinction. Also their production is made possible with specific chemical pesticides and fertilisers and feeds and antibiotics for crops and animals respectively. In addition farmers abandon their local and indigenous varieties and breeds.

The adoption of GMOs promotes inequalities among farmers and agribusinesses. This is mainly because these GMOs are patented by the multinational companies which produce them and they also produce and sell the chemicals used in their production (Shiva, 1995).

Farmers are not allowed to reserve the seed and are forced to buy the chemicals from the multinationals. This makes the farmers reliant on these externally purchased inputs from the multinationals.

2.5.7 Section summary

This section outlined the common practices of conventional agriculture and detailed their contributions to the global polycrisis. Intensive tillage systems lead to soil degradation leading to reduced crop productivity and also depend on fossil fuel to operate the machines and equipment used. Monoculture is favoured in conventional agriculture due to its compatibility with other practices involved; however it contributes to biodiversity loss and species extinction. While the use of inorganic fertiliser has resulted in increased crop yields, its incremental use reaches diminishing returns. Fertilisers are unsustainable because their use often means the neglect of other practices of maintaining soil health and their production is based on cheap fossil fuels and contributes to the emission of GHGs. The use of irrigation increased yields, but is unsustainable because it draws out water more than the rate it can be replenished by rain. It also results in water pollution by leaching nitrates and toxic pesticide residues to water bodies used for livestock, wildlife and human consumption and increases soil erosion. The use of inorganic pesticides for pest and disease control has negative impacts outweighing the benefits as it leads to disease and pest resistance, loss of beneficial insects and poisoning of water bodies. Also their production is based on cheap oil and unsustainable nutrient mining. The use of hybrid crop varieties and GMOs has contributed significantly to increased productivity achieved with the adoption of the Green Revolution. However their disadvantages are that they require synchronisation with other unsustainable practices and conditions for conventional agriculture mentioned above and that they cause negligence of local varieties. Despite the potential agricultural benefits offered by GMOs, some argue that they have unknown implications on human health and can lead to extinction of biological diversity (Millstone and Lang, 2006; Pretty, 2007 and Shiva, 2008). Having examined the risks of conventional agriculture in terms of the sustainability polycrisis, the following section examines the main forms of alternative farming systems which exist.

2.6 Principles and forms of alternative or sustainable agriculture systems

This section gives a brief overview of some of the most widely practised forms of alternative agriculture. The list is not exhaustive but rather serves to highlight some of the key commonalities between these seemingly varied approaches. Section 2.7 goes on to describe the common practices and methodologies. Figure 7 gives a conceptual framework of the organisation of alternative agricultural systems.

Alternative agriculture is taken to be synonymous with sustainable agriculture (Chappelle and Lavelle, 2009:3). Lewandowski (1999:1) defined sustainable agriculture "as the management and utilisation of the agricultural ecosystem in a way that maintains its biological diversity, productivity, regeneration, capacity, vitality and ability to function, so that it can fulfil – today and in the future – significant ecological, economic and social functions at the local, national and global levels and does not harm other ecosystems." This is consistent with Neher (1992:3) who describes an alternative or sustainable agriculture system as one "that over the long term, enhances environmental quality and the resource base on which agriculture depends, provides for basic human food and fibre needs, is economically viable and enhances the quality of life of farmers and society as a whole". Sustainable agriculture must achieve indefinite food (crop and livestock) and fibre production at farm level while conserving and protecting the integrity of the agroecosystem and its natural resources. McIsaac and Edwards (1994, in Altieri 2007) point out that alternative agriculture practices should mitigate the negative impacts of conventional agriculture on the natural resource base. They also indicate that these systems take into account biophysical and socioeconomic factors as they influence agricultural productivity. This is supported by Altieri (2007) who states that the emphasis is on the long term effects of agricultural practices on soil properties, soil fertility, soil texture and structure, potential of hydrogen (pH), water holding capacity, infiltration rates and ecological and biological processes essential for crop and soil health, biodiversity, insect pests and predators, long term accessibility to inputs by farmers and sustainable utilisation and management of local resources to benefit local communities.

Figure 7: Conceptual framework of alternative or sustainable agriculture.

Alternative or Sustainable agriculture

↓

Forms

Agroecology, permaculture, organic farming, biodynamic farming, nature farming, traditional agriculture

↓

Aim

Indefinite agricultural production in an environmentally, socially and economically viable way

↓

Objectives

Diversification, adaptability, indefinite production, environmental viability, economic viability, socio-cultural acceptance and self sustenance

↓

Principles

Soil health management; Plant health management; Biodiversity and ecological balance

↓

Processes and methodologies

Cropping systems	Tillage systems	Organic amendments	Agroecosystems diversity
Crop rotations	Minimum tillage	Crop residues	Agrobiodiversity
Intercropping	Terracing	Manuring	Integrated pest management
Mulching	Live fences and barriers	Composting	Crop livestock interactions
Fallowing	Contour planting	Inoculations	
Cover cropping		Effective microorganisms	
Agro forestry			

Source: Created by Author.

2.6.1 Agroecology concept

Gliessman (2007:18) defines agroecology as "the application of ecological principles and concepts to the design and management of sustainable food systems." He reckons that this approach to agriculture is based on the integration of resource conserving methodologies of traditional agriculture with modern ecological knowledge and methods. This reinforces earlier views by Altieri (1989) that agroecology can achieve sustainability by critically analysing, evaluating and screening options for low input management in agroecosystems. The former argues that this approach has the potential for development of agricultural systems that are environmentally and economically sound, highly productive and socially acceptable. In support of this view Altieri (2007) explains that this is achieved by the holistic management of agroecosystems with human elements, environmental components and inter-relating them to ecological and biological processes (nutrient cycling, natural pest control and selection, competition and complementarity).

Altieri (2007) refines the aim of the ecological principles of agroecology referred to by Gliessman (2007) as to mimic natural ecosystems. This is achieved through a focus on cycling, increasing biomass production, efficient energy capture and use, soil and water conservation, and promoting biodiversity through mutual interactions.

2.6.2 Permaculture

Permaculture "is an approach to designing human settlements and perennial agriculture systems that mimic the relationships found in the natural ecologies" (Mollison, 1998:34). According to Collins and Qualset (1999), the integration of desirable traits of flora and fauna with components of natural environments enables permaculture designs to be economically, environmentally and socially viable while achieving sustainable agricultural productivity. According to the originator of permaculture Bill Mollison (1998:34), three sets of ethical values are considered:

- Care of the earth: life forms depend on global natural resources[7];
- Care of people: there is a need to meet human basic needs[8]

[7] The earth is a living entity which ensures continuity of living and non living systems.

[8] This is achieved through equal accessibility and sustainable utilisation of resources.

- Population and consumption limits: global ecosystems are finite[9].

Ultimately the design is based on ecological information to identify and design mutual relationships of whole system[10] components (Mollison, 1998). The result must achieve reduced emission of toxic wastes to the environment, reduced consumption of human labour and energy using internal inputs to produce high volume biomass in terms of food and raw materials (Mollison, 1998).

2.6.3 Organic farming

According to Lampkin, organic farming is "a production system which avoids or largely excludes the use of synthetically compounded fertilisers, pesticides, growth regulators and livestock feed additives. To the maximum extent feasible, organic farming systems rely on crop rotations, crop residues, animal manures, legumes, green manures, off-farm organic wastes, and aspects of biological pest control to maintain soil productivity and tilth, supply plant nutrients and to control insects, weeds, and other pests" (1999:5). This definition reinforces his earlier proposal (1994:468) that organic farming must integrate socio-economic and environmentally sustainable production systems and maximise utilisation of locally available renewable resources and manage natural ecological and biological processes which achieve acceptable agricultural outputs, suppress pests and diseases and provide maximum return to inputs. Dlamini (2007) summarises organic farming as farming without inorganic and synthetic fertilisers and pesticides. He further states that organic farming recognises the soil as living system. According to Dlamini (2007), organic farming has the potential to mitigate the global negative impacts of conventional agriculture.

2.6.4 Traditional agriculture

Dlamini (2007:20) defines traditional agriculture as "agricultural production where technologies being used depend completely on local resources and has developed a wide

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[9] Human activities must not exceed the earth's capacity to generate and regenerate natural resources and assimilation of wastes.

[10] A set of interacting physical and non physical components which require inputs to produce usable outputs.

range of site specific technologies embedded in the culture of the people in a certain area". This farming system is based on the indigenous agricultural knowledge of a defined community. Haverkort (1995) argues that this system uses knowledge, which is beyond techniques and methods of cultivation or animal husbandry to include different "kinds of insights, wisdom, perceptions, and practices related to people's resources and environments" (Haverkort, 1995:455).

According to Klee (1980), traditional farming focuses more on the long term sustainability of agroecosystems rather than solely on maximising yield and profit. Gliessman (2007:300) ascertains that these farming systems share common characteristics globally:

- Use of locally available and renewable resources and nutrient cycling (rather than depending on externally purchased inputs)
- Minimum environmental manipulation and impacts by adapting to local conditions
- Uses local crop varieties and at times incorporates wild plants and animals
- Maintains spatial and temporal diversity and continuity
- Production is targeted to meet local needs first
- Is based on the knowledge and culture of local people

2.6.5 Biodynamic farming

Another form of alternative agriculture is biodynamic farming, which can be seen as an advanced form of organic farming. According to Diver (1999) the ecological principals of biodynamic farming takes the farm as a whole[11]. This is through a holistic approach, which combines agroecosystem components for sustainability to address farm environmental, economic and social challenges.

There are other key concepts which make biodynamic farming a unique farming approach (Diver, 1992:2):

[11] A self contained organism with its own entity and individuality through crop and livestock integration, recycling of nutrients, maintenance of soil, crop and animal health where the farmer is part of the whole.

- The recognition that cosmic and terrestrial forces enhance processes of biological and ecological systems.
- The use of the science of anthroposophy to combine physical and higher non-physical realms which enrich the agroecosystem components with vital life force and enhance their adaptation to natural rhythms.
- The synchronisation of farm operations with the moon phases guided by the biodynamic calendar.
- The use of biodynamic preparations[12], sprayed on plants, soil and composts to stimulate plant growth and microbial activity, pest and disease control, and regulation of biological and ecological processes, which enhance soil health.

2.6.6 Nature farming

According to Xu *et al* (2000:2), Mokichi Okada developed nature farming more than half a century ago. This was after he conducted experiments which indicated that the practices of conventional agriculture were not compatible with nature nor the production of safe, quality, nutritious food without posing harm to the environment. As with other alternative farming systems, it shares some common principles and practices with organic farming. However, the distinction is drawn by:

- The non-tolerance on the use of inorganic and synthetic chemical fertilisers and pesticides
- Strict prohibition of the use of human and animal manure and other untreated human products
- Only uses composted crop residues for soil organic matter improvement and nutrient recycling

(Minamino, 1994:195).

According to Xu *et al* (2002), the principles of nature farming as set by Mokichi Okada in 1953 aim for:

- Production of safe and nutritious food

[12] Biodynamic preparations range from BD500-BD508. They are made from cow manure and fermented in soil during specific seasons.

- Affordability to farmers and consumers
- Sustainability and ease of implementation
- Conservation of natural resources
- Adequate supply of human food and material needs for the growing global population

2.7 Practices of alternative or sustainable agriculture

The last section highlighted that most alternative systems share common principles. This section highlights the practices that are common to alternative agriculture systems. These have been grouped into four main practices: cropping systems, organic amendments, tillage systems and agroecosystem diversity.

2.7.1 Cropping systems

The section will discuss the main cropping systems used in sustainable agriculture systems which include cover crops, green manures, crop rotations, intercropping, agroforestry and live fences.

Lu *et al* (2000) define cover crops as a cropping system which is used in sustainable agriculture agroecosystems for the management of weeds, pests, soil health and water use. Green manures differ from the former because they are mainly grown for the purpose of soil health improvement. They improve soil carbon and organic matter content when the nutrient rich foliage of green manure crops is ploughed down prior to seed production.

The inclusion of legumes as cover crops or green manures has the potential of reducing the need for inorganic nitrogen fertiliser due to their ability to fix free nitrogen from the atmosphere into usable plant nitrates (Badgely *et al.*, 2006 and Kate, 2008). They also further agree that these cropping systems have other advantages which include: increasing soil organic matter content, enhancing soil structure and texture, improving water holding capacity and infiltration and reducing soil erosion through wind and runoff. They also form part of sustainable weed, pest and disease management strategies by breaking lifecycles. This allows reduced dependence on chemical control of weeds, pests and diseases.

Crop rotation represents temporary crop diversification in a determined sequence of alternating crops, which do not belong to the same family and have different characteristics, over seasons (Altieri, 2007). Since crops of different taxonomic families are associated with different pests, diseases and weeds, rotations offers opportunities for their control through starvation or breaking life cycles (Bavec and Bavec, 2007).

Crop rotations offer opportunities to increase farm productivity without keeping lands fallow while deriving other benefits. These benefits include: nitrogen fixation when legumes are part of the rotation cycle and decreasing nitrogen mobility thus minimising the need for nitrogenous fertilisers.

According to Andrews and Kassam (1976) intercropping allows the growing of more than two crops of different taxonomic families on the same field at the same period using ecological principles to increase diversity, beneficial interactions and natural regulation mechanisms. It aims to increase farm productivity or output per unit area per unit time and the maximisation of available resources while benefiting from mutual and beneficial interactions (Sullivian, 2003). The other ecological advantages derived from planned intercrops include:

- Allelopathy[13] effects for weed control
- Soil fertility improvement through nitrogen fixation when legumes are used
- Increased diversity which plays a role in pest and disease management

(Bavec *et al.*, 2005).

Agroforestry is a sustainable land management system which involves the deliberate integration of woody perennials with crops and animals on the same land unit (Kamara *et al,* 1993). HDRA (1998) recognises that this approach allows for companion

[13] Production of biochemicals which affect the growth of other plants

relationships between trees, shrubs, crops and livestock. It uses agricultural and forest science to increase biodiversity, productivity and health of sustainability of agroecosystems (Gholz (1987).

By using varied cropping systems which better mimic nature, alternative agricultural systems overcome many of the negative impacts associated with monocultures.

2.7.2 Organic amendments

This section will discuss the use of organic amendments (composts, liquid manures or fertilisers, rhizobium inoculants effective microorganisms (EM) and crop residues) in sustainable farming systems.

The main types of composts used in sustainable farming systems include traditional composts, biodynamic composts and vermicomposts. They are important in restoring and maintaining soil health and productivity by improving soil carbon and organic matter content linked to the cation exchange capacity (CEC), pH and microbial activity which influence plant nutrient availability (Rosenberg, 2006 and Jack & Thies, 2006). Increases in soil carbon content enhance the capacity of soil for carbon sequestration. Vermicomposts and composts provides humic acids, plant growth hormones like auxins and indole acetic acid from the action of plant growth, promoting nitrogen fixation and convert mineral phosphate to plant phosphate (Jack and Thies, 2006), thus offering opportunities to reduce inorganic fertiliser use.

Liquid manures or fertilisers are produced by fermenting green plants rich in nitrogen in their photosynthetic pigments to leach out nitrogen to the solution and makes it readily available when applied through irrigation or as side dressing.

Cultures of rhizobium or bradyrihizobium are inoculated to legume[14] seeds to enhance nitrogen fixation. This results in availing nitrogen for the current and next crop and

[14] Legume plants are capable of forming symbiotic relationships with rhizobium or bradyrhizobium in their root nodules and fix atmospheric nitrogen into usable plant nitrates.

reduces the use of inorganic nitrogen fertiliser. Effective microorganisms (EM) are a culture of fermented lactic acid and phototropic bacteria, yeast and other beneficial microorganisms preserved at low pH without any genetic modification (Higa, 2001). They enhance breakdown of organic matter, production of organic acids and bioactive ingredients, energy and nutrient flows in agroecosystems and suppression of disease pathogens (Higa, 2001 and Rosenberg & Linders 2004).

The principle of not burning off crop residues in organic farming systems offers great potential for soil conservation through reduced rates of erosion from wind and water, nutrient recycling, water conservation by reducing evaporation and runoff while enhancing infiltration (Unger, 1991).

2.7.3 Tillage systems

This section will briefly discuss minimum tillage and the techniques of terracing and contouring as they are used in sustainable farming systems.

Minimum tillage is promoted in sustainable farming systems and involves only slightly opening the soil to allow sowing or planting without the use of conventional ploughing or tillage (Mupangwa *et al, 2007)*. The aim of minimum tillage is to restore and maintain soil health using crop residues as soil cover or mulch. This stimulates soil structure and texture by minimising repeated equipment movement, reduces raindrop impact on soil, reduces soil erosion due to wind and runoff and enhances soil water conservation through reduced evaporation and increased infiltration and water holding capacity of soil (Kate, 2007 and Mupangwa *et al.*, 2007). This technique relates to the use of crop residues discussed above.

The technique of terracing and contouring allows for the cultivation of steep slopes through levelling. It enhances utilisation and conservation of vulnerable landscapes through minimisation of erosion by runoff. According to the USDA (1998), terracing achieves this by reducing slope length into shorter segments and levelling of steps. The

USDA (1998) also highlights energy savings when water tanks are sited precisely on terraced land and irrigation is done by gravitating water downwards.

2.7.4 Agroecosystem diversity

This section will discuss how sustainable agriculture systems achieve agrobiodiversity through integrated pest management (IPM) and crop and livestock interactions.

It is considered by many (Altieri, 1994; Gliessman, 2007 and Bavec & Bavec, 2007) that the practices of crop rotations, cover crops, agroforestry and crop livestock interactions actively aim to promote agrobiodiversity. They reckon that biodiversity enhances sustainability and ecological balance through pest and disease regulation using natural enemies, beneficial mutual relationships among species, nutrient recycling and regulation of the hydrological cycle.

IPM uses complementary relationships of insects, crop ecology and agronomic practices for pest and disease control. Maintenance of biodiversity in sustainable agroecosystems enhances biological and natural pests and disease control through pest predators, starvation, natural enemies and breaking of life cycles (Altieri, 1994).

The integration of crop and livestock systems in sustainable agriculture systems provides for maximum and efficient utilisation of resources and nutrient recycling (Kate, 2007). Fallow fields can be used as grazing for livestock and livestock can be useful in bringing down green manures before they are ploughed into the soil. Also grazing livestock at high densities in fallow fields or fields under green manure can be used for *in situ* composting from their droppings and urine and mix them with soil when they trample over. Animals can also act as a biological control agent for pests for example ducks controlling population of snails in home gardens.

Conclusion

The principles and practices of alternative agriculture help in mitigating the causes and impacts of the polycrisis. Firstly the cropping systems increase diversity thus improving productivity and avoid biodiversity loss and species extinction. Through increasing agro-diversity the alternative agriculture practices employ natural pest and disease control and encourage the use of organic amendments and nutrient cycling to reduce the use of inorganic pesticides and fertilisers produced from fossil fuel. This also reduces environment pollution and water contamination. Cropping systems, tillage systems and use of organic amendments encourage the build up and maintenance of soil health and increase crop productivity which ensures sustainable food security. The minimum tillage concept advocated reduces the use of fossil fuel and mitigates soil deterioration. Water use efficiency and conservation is achieved through various practices like mulching, cover crops, terracing and contouring, minimum tillage.

2.7.5 Section summary

This section firstly looked at the various definitions of sustainable or alternative agriculture systems. There is consensus that the aim of these systems is to achieve indefinite production while preserving the environment and being economically viable and socially acceptable. The various forms of alternative agriculture systems (agroecology, permaculture, biodynamic, organic, traditional, nature farming) differ in some ways but generally share common principles and practices on soil and plant health, biodiversity and ecological balance. These are used to achieve the broad aim of sustainability and continued production and achieve this by mimicking natural ecosystems.

2.8 Chapter summary

This chapter gave an overview of the perspectives and current state of global agricultural systems (conventional and alternative farming systems). The global polycrisis was described and analysed to see which trends are affected by and influence agriculture. The practices of conventional farming were discussed in order to see how they contribute to the polycrisis while the practices of alternative agriculture revealed that they contribute to the mitigation of the polycrisis.

The information reviewed in this chapter gives insight into how we might critically analyse what agricultural sustainability must entail. Yield or output is normally considered the core indicator for agricultural sustainability (Gliessman, 2007 and Tisdell, 2007). This is misleading and I agree with Tisdell (2007) that yield is only one component to measure the performance or sustainability of agricultural systems. This is consistent with the proposal by Conway (1998) that the development and performance of agricultural systems must be holistic and take into account economic (yield and income returns), environmental and social consequences. Gliessman (2007) adds that agricultural sustainability must have an ecological basis to support a sustained yield[15].

Tisdell (2007) proposes that agricultural sustainability needs to be defined through a convincing scientific, socioeconomic and ecological enquiry that considers concepts and indicators related to agricultural sustainability. His emphasis is on the need for an objective, qualitative and quantitative assessment of short term and long term benefits versus the long term impacts of present and potential agricultural practices to determine overall sustainability. This is supported by Christen (1996:66-69) who raises the following questions: "…what constitutes sustainability of agriculture? Can it be achieved? If so, how can it be achieved?"

Christen (1996:80-86) and Gliessman (2007:17) agree that the concepts of agricultural sustainability must include the following factors, which are consistent with factors already discussed in this literature review:

- Mitigate environmental degradation and release wastes which do not exceed the assimilative capacity of the global ecosystems.
- Preserve, rebuild and maintain soil fertility and ecological health.
- Preserve and allow replenishment of aquifers to meet the needs of all forms of life and the environment.

[15] The condition of being able to harvest biomass from a system in perpetuity when the ability of the system to renew itself or being renewed is not compromised.

- Promote and achieve inter-generational and intra-generational equity through integration of natural resources within agroecosystems by substituting external inputs with nutrient recycling, resource conservation and enhancing the base of ecological knowledge.
- Regard and enhance succession of biological diversity both in the natural and artificial ecosystems.
- Promote equality and access to appropriate agricultural practices, preservation of local and traditional knowledge systems which allows control of local agricultural resources.
- Ensure food and nutrition security for all.

The above discussion and background information on global agricultural systems and their relation to the polycrisis, allows us to look at the case of *natuurboerdery* with more insight to determine how the practices can contribute to or mitigate the polycrisis as we search for the best practices for agricultural sustainability.

CHAPTER III: RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

The purpose of Chapter Three is to outline and justify the research design and methodology which was undertaken to answer the research questions of this study. The research design informed the methodology which encompasses multiple sources of data gathering and research instruments. Section 3.3.1 outlines my job description at ZZ2 as a student agricultural scientist and is supported by Figure 8 which shows the operational structure for ZZ2 *natuurboerdery*. This section also describes and explains the documents I developed as part of my role at ZZ2. Understanding my role and involvement at ZZ2 is important in understanding how I accessed information for the research findings. Section 3.5 details the data collection and analysis and goes on further to explain the presentation of findings and drawing up of conclusions. It also indicates the sources of evidence used and how literature and definitions of sustainable agriculture systems were used in developing the conceptual framework of *natuurboerdery* which set precedence to the presentation and description of the *natuurboerdery* farming approach. The delineation and limitations in section 3.7 explain what was not covered by this study and the reasons behind that. Section 3.8 presents the assumptions associated with the research.

3.2 Research Design

This thesis was conducted as a case study, using qualitative research methods for data gathering and analysis. A case study may be seen as a bounded system (Merriman, 1988), however this does not restrict it to one site or situation (Schumacher and McMillan, 1989). My approach to my case study research is supported by Nieuwenhuis (2009:75) who states that "the typical characteristics of case studies are to strive towards a comprehensive or holistic understanding of the interaction and relationships of participants or components in specific situations". In undertaking this research the ZZ2 *natuurboerdery* farming approach was viewed as a whole. This is to mean that focus was put on its interaction with the social, economic and ecological environments which it influences. This research is the first scholarship document on the *natuurboerdery* farming approach which makes it a vital source for developing the history, development and explanations of key principles and practices of this emerging farming system. The qualitative research approach which was undertaken was useful in collecting rich descriptive information and data which supported the overall aim of providing deeper understanding and information of the *natuurboerdery* farming approach (Nieuwenhuis, 2009:50). This enabled me to understand what *natuurboerdery* is, to construct meaningful information on the reasons why ZZ2 converted to this approach, the principles and practices of *natuurboerdery* and the associated changes and benefits realised after conversion as is presented in Chapter Four.

Despite the strength and suitability of case study research for my subject under investigation, I was aware that many have criticised this approach for depending on one case and being incapable of drawing general conclusions (Nieuwenhuis, 2009:76). My argument for choosing this research methodology is supported by Hamel *et al* (1993) who emphasise that case study research aims at gaining a greater insight and understanding of the dynamics of a specific situation. This was suitable as I did not intend to generalise my findings in any way.

In case study research the unit under investigation or analysis is a critical factor. In this research the unit under investigation was the *natuurboerdery* farming approach[16] as it was developed and adopted by all ZZ2 farms. This is supported by Nieuwenhuis (2009:75) who notes that case study research focuses on a system of action or on one or two concepts and issues that are fundamental to understanding the system being examined.

[16] This also covers research objectives:

i) To investigate the reasons and process of converting from conventional farming to *natuurboerdery* farming.

ii) To describe the principles and practices of *natuurboerdery* farming.

iii) To describe and explain the changes and benefits realised by converting to *natuurboerdery* farming approach.

I also made use of a literature review which is defined by Mouton (2001:179) as providing "an overview of scholarship in a certain discipline through an analysis of trends and debates". Specifically, I used a narrative literature review which synthesises individual studies in a narrative manner (Petticrew and Roberts, 2006). The purpose of my literature review was to establish the current perspectives and practices on global agriculture systems. This was important to provide background information before discussing the principles and practices of conventional and alternative or sustainable agriculture systems. An overview of the global polycrisis was presented by reviewing key issues and challenges to sustainable development as they relate to agriculture. This was critical to analyse how different agricultural systems contribute to and are affected by the polycrisis. Furthermore it created a platform for discussing the sustainability of *natuurboerdery* as a farming system which is presented in Chapter Five. This then necessitated defining agricultural sustainability and reviewing approaches used to developed and measure the sustainability of farming systems.

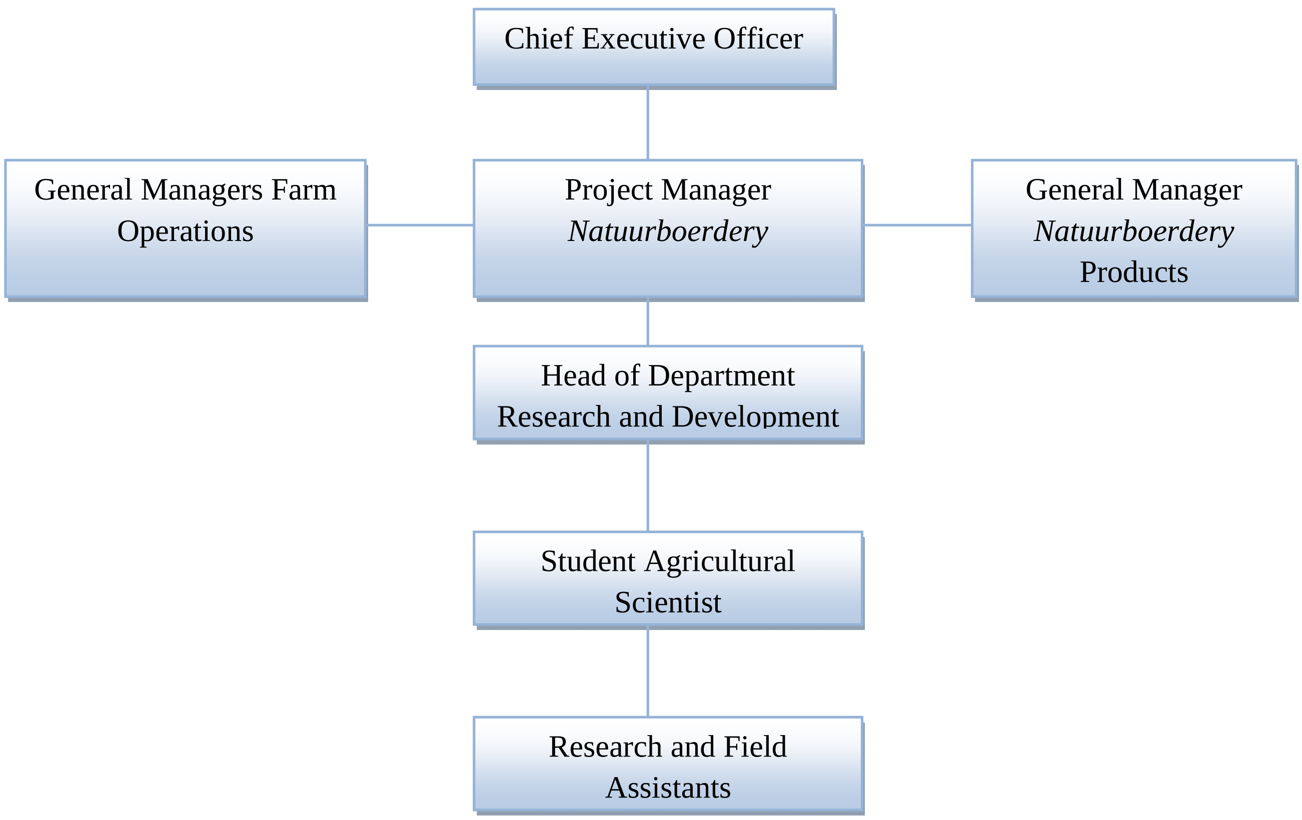
3.3 Methodology

By taking the research as a case study, the research methodology was based on use of multiple sources and techniques for data gathering (Yin, 1994). From the onset I determined the type of evidence to gather and the techniques for analysing collected data in order to answer the research questions and meet the objectives of the research. Data gathering was mostly qualitative but also included quantitative data for specific scenarios, like changes in soil carbon content, comparison of input use and cost of conventional and *natuurboerdery* farming.

3.3.1 Job description and role at ZZ2

I was attached from October 2009 up to July 2010 as a Student Agricultural Scientist at ZZ2 *Natuurboerdery* Centre under the Research and Development Unit (R & D) and reporting directly to the Head of Department (HOD) for R & D. The structure at ZZ2 reflecting my role and position is illustrated in Figure 8 below. The R & D department serves as the technical arm for the implementation of *natuurboerdery* farming approach for ZZ2. My main function was to provide technical assistance and support to the HOD for R & D in the all areas related to R & D for *natuurboerdery* (see Appendix N for R & D focus areas and aims). This involved mainly development of the *natuurboerdery* farm approach (monitoring of experimental trials and producing technical and journal articles at the end of each experimental trial) and information and data management (understudying the entire *natuurboerdery* farming approach, collecting and analysing agricultural data into usable information, documenting articles for publication on the *natuurboerdery* website and newsletter, *natuurboerdery* checklist and compliance criteria). Therefore my job was mainly centred on gathering and compiling information on *natuurboerdery* to come out with a logical and coherent description of the farming approach as the new farming system had not yet been described as a coherent whole. ZZ2 was very supportive of my research as they were eager to have *natuurboerdery* written up into a logical description.

Figure 8: ZZ2 *natuurboerdery* operational structure



My data collection was based on interviews, observations, participation and existing documents. These will be discussed in more detail in the following section.

3.4 Data gathering and research instruments

Data gathering in qualitative research uses a naturalistic approach in an attempt to understand the phenomenon under investigation. Hofstee (2006:115) describes research instruments as anything which can be used to obtain required data or evidence to be analysed. In qualitative research the researcher is a data gathering instrument where validity and reliability refers to research that is credible and trustworthy (Nieuwenhuis, 2009:80). Lincoln and Guba (1985: 991) include credibility, applicability, dependability and confirmability as key to trustworthiness. The two (1985:316) claim that: "Since there can be no validity without reliability, a demonstration of the former [validity] is sufficient to establish the latter [reliability]". Multiple methods of data collection were used to allow data gathered to be cross-checked for validity. The multiple methods of data collection used for this research included documents, observations, interviews and photographs (Yin, 1994:4; Nieuwenhuis, 2009:81-92 and Hofstee, 2006:115-116). These are discussed in detail in the following section.

3.4.1 Documents

Documents refer to any written materials for communication purposes (Nieuwenhuis, 2009:82 and Mouton 2001:99). For this research, a primary source of data included unpublished documents, administrative documents, company reports, letters, magazine articles, research reports, research articles, posters, minutes of meetings and PowerPoint presentations. Most of the reports have been produced by professional staff at ZZ2 who have been involved in the development of the *natuurboerdery* farming approach. A lot of these sources can be described as grey literature defined as "information produced on all levels of government, academics, business and industry in electronic or print formats not controlled by commercial publishing" (Paola and Sandra, 2003:1). The authors also further state that this body of materials are not found easily through conventional channels such as publishers but is frequently original and usually recent. Due to my position at ZZ2 I had access to many documents which are not in the public domain.

In selecting the documents to use as data sources I was always cautious to evaluate the accuracy and authenticity of the information before incorporating them as part of my data. The criteria used for choosing documents as data sources followed suggestions by Nieuwenhuis (2009: 83) and the following was first verified:

- Nature of the document (primary or secondary source, official or unofficial).
- Time of publication (this is important because the phenomenon under investigation (*natuurboerdery*) evolved over time).
- The purpose or intent and the context which it was produced for.
- The points and arguments put forward and their relationship to my study.
- The research methodology used to produce the document (if it is empirical).
- Empirical data (based on original research).

In support of crystallisation of data explained in section 3.5, the data obtained from the documents was corroborated with the evidence gathered from other sources (Maree, 2009:83). I was always cautious and guarded against selectivity, unfair treatment of documents and misinterpretation of author's arguments and selective treatment of data to suit my argument (Nieuwenhuis, 2009:83).

3.4.2 Observations

According to Nieuwenhuis (2009: 83) observation is a systematic process where one records patterns and occurrences of objects and participants without questioning. In this regard I observed events as they occurred in the natural setting and enabled me to gain a deeper understanding of the principles and practices of *natuurboerdery* (Nieuwenhuis, 2009:84). Also, as an intern student at ZZ2 under *Natuurboerdery* Research and Development, I learnt most of the principles and practices of *natuurboerdery* by participating and by being immersed in the actual research situation I was investigating. Through observation I learnt about *natuurboerdery* through personal experience and reflection and thus understood it in the same way as those involved in its development and adoption.

Types of observation

Nieuwenhuis (2009:84) describes four types of observation used in qualitative research.

Complete Observer: The researcher does not participate in the situation under investigation. He/she simply observe from a distance to get an "etic or outsider" perspective (2009:85). Its limitation is that the researcher is not immersed in the situation and therefore does not really understand what she/he observes.

Observer as Participant: The researcher gets into the situation under investigation only as an observer. She/he focuses on patterns or behaviours to understand the assumptions and values of the phenomenon and attempts to make sense of the social dynamics. The researcher remains uninvolved without influencing the dynamics.

Participant as Observer: The researcher is a participant in the investigation. She/he interacts with participants to design and develop intervention strategies and may even try to alter the situation. The researcher becomes immersed in the setting to gain an "emic and insider" perspective (2009:85).

Complete participant: The researcher is totally immersed in the setting. Participants may not even know that they are under observation. The limitations arise on ethical grounds, when participants do not know that they are being observed.

My situation was mostly participant as observer however at times observer as participant or complete participant. As an intern in R & D, I was engaged with all staff at all levels and was involved with all aspects of *natuurboerdery*. This allowed me to get an inside perspective and deeper understanding of the whole system.

I was also highly involved and responsible for the development of *natuurboerdery* documents described below. This explains also my recruitment which required someone capable of writing up the whole story of *natuurboerdery*. My experience in writing research assignments and case studies under the Bachelor of Philosophy programme was crucial and necessary. Being involved in such developments, it becomes unavoidable that I to some extent had influence in the dynamics and setting of *natuurboerdery* (participant as observer).

***Natuurboerdery* checklist and compliance criteria:** This document was developed following precedence of other documents like the Woolworths Farming for the Future

(WFF), Global Good Agricultural Practice, and International Federation of Organic Agriculture Movement Guidelines for Organic Standards and Certification. A team of four comprising the HOD R & D, General Manager *Natuurboerdery* Products, Environmental and Safety Officer and Student Agricultural Scientist (myself) was tasked with producing the whole document. The rest had hands on experience of the practices of *natuurboerdery* and I had knowledge on sustainable agriculture systems and sustainable development. Firstly I conducted a preliminary discussion on the *natuurboerdery* farming approach with the General Manger *Natuurboerdery* Products (Johann Noffke), who rose to that position from being a Farm Manager and had vast experience on the way ZZ2 farmed. From the insight gained from that discussion, plus my own observations and reading documents mentioned above, I developed a set of questions for the *natuurboerdery* checklist and compliance criteria described in Chapter Four and shown in full in Appendix H. As a team we would then meet regularly to review the questions, from this I gained a good understanding of the whole *natuurboerdery* farming approach.

Technical and journal articles: In the R & D Unit we conducted experiments on products and farming methods used or to be incorporated in the *natuurboerdery* farming approach. I was the team leader for research and field assistants and did the experimental designs, monitoring of field trial or experiment layouts, supervision of data collection, statistical data analysis and write ups of technical reports for use by ZZ2 farm managers and journal articles for scientific publications including posters for display. This again enhanced my understanding of the *natuurboerdery* farming approach.

Website and newsletter articles: I was instrumental in the introduction of the *natuurboerdery* newsletter which I contributed articles to and edited other articles from staff on *natuurboerdery* events and progress. I also contributed summaries which were posted on the *natuurboerdery* website in liaison with the HOD and *Natuurboerdery* Projects Manager and wrote scripts for the advertisement of the *natuurboerdery* farming approach in national media.

R & D strategic plan: I was tasked by the HOD to develop the *Natuurboerdery* R & D strategic plan document (in a way that would influence the sustainability of the *natuurboerdery* farming approach) using the company’s strategic plan as the baseline. To do this I drew on the knowledge I had gained at ZZ2 and my knowledge of agricultural sustainability and sustainable development from my Bachelor of Philosophy and previous professional experience as an agronomist. This document was then discussed by ZZ2 management and was adopted for implementation and directing R & D activities.

None of the documents I developed, aside from the *natuurboerdery* checklist and compliance criteria which is listed in Appendix H, were incorporated in this thesis in their original form. Rather they were useful to me in gaining a deeper understanding and clearer perspective of the whole *natuurboerdery* farming approach. By sharing the processes I was engaged in at ZZ2, I hope to make the source of many of my findings clearer too.

As a big organisation not all staff members were aware that I was investigating the *natuurboerdery* farming approach. At times my informal discussions with staff brought in some credible information about *natuurboerdery* which was included in this research. However this was not a formally organised method of data collection and the participants may not know that they were providing information (complete participant). The practices of *natuurboerdery* as developed and adopted by ZZ2 were difficult for me to influence for the period I was on attachment. Given this situation most information was generated mainly as observer as participant. I used triangulation and crystallisation of observed data and data from other sources to make sense of what I observed.

3.4.3 Interviews

Interviews were used to get ideas, beliefs, views, opinions, understandings and experiences of ZZ2 staff on *natuurboerdery* farming approach. As stated by Nieuwenhuis (2009:87) use of qualitative interviews enabled me and the rest of the world to see the concept of *natuurboerdery* "in the eyes of the interviewee" which provided a valuable source of descriptive data. For me to get rich descriptive data to answer my research questions and objectives, I:

- Chose interviewees who have witnessed and were involved in the development and adoption of *natuurboerdery* and also those who are influenced and affected by the same

- Explained to the interviewees the importance of my work and the value of their contribution in this study (Maree, 2009: 16).

Table 2 below indicates the interviewees, their positions and dates when the interviews were conducted and the lists of questions for each interviewee are indicated from Appendix A to G.

Table 2: Names and job description of interviewees

Job title and role	Name of interviewee	Appendix	Date of interview
Tommie van Zyl	Chief Executive Officer[17]	B	30 June 2010
Johhan Noffke	General Manager *Natuurboerdery* Products[18]	C	21 June 2010
Piet Prinsloo	*Natuurboerdery* Project Manager[19]	D	18 June 2010
Bertus Venter	Agronomist[20]	E	22 June 2010
Geoff Miller	Compost and FPEs Manager[21]	F	19 June 2010
Anonymous	Ordinary Worker[22]	G	02 July 2010

In addition to the interviewees in the above table 2, I regularly had informal interviews or disccussions with Bombiti Nzanza, the HOD for R & D, ZZ2 farm managers, agronomists, technical and general employees. I was also part of the *natuurboerdery*

[17] Day to day running and management of the whole company.

[18] Responsible for the production and utilisation of *natuurboerdery* products like FPEs, compost, compost tea and other natural products. He has been at ZZ2 for more than 22 years and has vast knowledge on ZZ2 farming practices and experience.

[19] Responsible for the implementation of the *natuurboerdery* farming approach on ZZ2 farms and activities of the R & D and ZZ2 Laboratories

[20] Technical backstopping of farmers in crop production.

[21] General production of *natuurboerdery* products mainly compost, compost teas and FPEs.

[22] A casual worker on the farm with more than 15 years at ZZ2.

taskforce and attended meetings on issues pertaining to the development and implementation of *natuurboerdery* farming approach on all ZZ2 farms.

Two types of interviews (open-ended and semi-structured) described by Nieuwenhuis (2009:87) were used to collect convincing data and to have a deep and clear understanding of *natuurboerdery*.

Open-ended interviews: These were spread over the period I was on my internship at ZZ2. I had great and free opportunity to discuss with staff at all levels. I had to explore my views and understanding of sustainable agriculture and sustainable development and link it to *natuurboerdery* which enabled me to critically review the *natuurboerdery* farming approach I was investigating. Information obtained from the various informants was verified with data from other sources. This helped to ensure authenticity of data collected and validity of the research.

Semi-structured interviews: Preset questions were used to define the line of inquiry and to corroborate data which emerged from other sources (Maree 2009: 87). I had to carefully probe, explore and clarify answers given during the interviews.

3.4.4 Photographs

During the research process I took photographs of different activities and scenarios. These were important for my own recall, to give convincing evidence of what takes place in *natuurboerdery* and to illustrate explanations of some of the findings.

3.4.5 Conclusion

The above four sources of evidence were used in this work; as stated by Tellis (1997:7), no single source can be considered to be the best among others; they are rather complementary or can work in tandem. For this reason I used multiple sources of evidence which were discussed in Setion 3.4.

3.5 Data collection and analysis

In my data collection I was guided by three principles of data collection as stated by Yin (1994: 4). These principles are as follows:

i) Use of multiple sources of evidence: In this regard I had to go beyond triangulation to crystallisation as suggested by Richardson (2000:934). Yin (1994:4) argues that triangulation searches converging findings from different sources which increases validity. Richardson (2000:934) argues that triangulation is based on the assumption of a fixed point or object that can be triangulated. The argument is based on the recognition that this world is "far more than three sides". She goes on to reinforce the argument that the "concept of crystallisation will enable us to shift from seeing phenomenon as fixed, rigid, two dimensional object towards the idea of a crystal, which allows for any infinite variety of shapes, substance, transmutations, dimensions and angles of approach" (2000:934).

Therefore the concept of crystallisation allowed for a complex and deeper understanding of the *natuurboerdery* farming approach. "Crystals grow, change and alter, but are not amorphous" (Richardson, 2000:934). This is supported by Nieuwenhuis (2006:81) who says that the emergent reality is not a result of measurements but "…emerges from the various data gathering techniques and data analyses employed and represents our own reinterpreted understanding of the phenomenon". My findings were those which crystallise from the data collected from different sources collected by different methods to add to trustworthiness. This is confirmed by Nieuwenhuis (2006:81) that the crystallised reality is credible to the readers of our collected and analysed data and enables them to see the emerging pattern.

ii) Creation of a case study database: I used the suggestion by Hofstee (2006:56) that planning in primary research is essential. I created a database of all the information collected and observed which I used for final report writing as a reference source. This database contained notes of observed information, documents gathered, tabular numeric data from archives, and narratives from interviews, which were open-ended answers to the research questions.

iii) Maintaining a chain of evidence: My aim was to continuously link between initial research questions and the case study procedure and the circumstances of the evidence I was collecting (Yin: 1994:4). I was guided by the fact that in qualitative studies data collection and analysis are not separate processes. According to Nieuwenhuis (2006:81) it is an ongoing, cyclical and iterative (non-linear) process. This enabled me to employ the criterion of saturation of data[23].

"Data analysis consists of examining, categorising, tabulating, or otherwise recombining the evidence to address the initial propositions of a study" (Yin, 1994:21). There is consensus that data analysis for case studies is one of the least developed aspects in case study research methodology (Yin, 1994 and Tellis, 1997:11). To overcome this challenge in-depth data analysis involved the use of appropriate techniques. This included mind mapping to reduce data and categorise it into themes, practices, trends and relationships for easier understanding. The data was interpreted by extracting meaning and integrating data from various sources so as to build knowledge and understanding of *natuurboerdery* in scholarly and practical ways which enabled the drawing of conclusions from findings and giving recommendations (Nachmias and Nachmias, 1996:294; Brynard and Hanekom, 1997:48-55; and Mouton, 2001:108-109). The actual process is further explained in the following section.

3.5.1 Presentation of findings, conclusions and recommendations

The main aim of this research was to provide a deep understanding, and clear description of the whole *natuurboerdery* farming approach. The findings and conclusions were presented and drawn out respectively with this in mind and informed by literature on sustainable agriculture and farming systems. As such Chapter Four presents the whole of *natuurboerdery* as a distinguished farming system.

Ikerd (1993:1) suggests that a farming system is "an overall approach to farming reflecting goals, abilities, resources and circumstances pertinent to the farm operations - all of which result in decisions concerning the composition and operation of these human made systems". Smithers *et al.*, (2002) add that farming systems are largely defined by their main inputs, practices and products which include pest, disease and nutrient

[23] The point where no new ideas and insights are brought to the fore.

management, crop selection, land cultivation, utilisation and allocation where the farmer is the focal point and decision maker. Many authors (Allen and Starr, 1982; Izacs and Swift, 1994; Weber, 1996) agree and conclude that farming systems are comprised of subsystems at smaller scales of aggregation and exist as part of larger systems in a hierarchical fashion.

Based on the above theories or definitions I adopted the definition of *natuurboerdery*[24] and its aim as coined by ZZ2. I also maintained the five health aspects[25] or subsystems developed by Nzanza (2009) which are incorporated into the *natuurboerdery* farming approach. Based on my observations, interviews, understanding of agricultural systems, knowledge and experience from developing the *natuurboerdery* checklist and compliance criteria I had to figure out, group and fit the farming practices, techniques and methodologies into their respective health aspects or subsystems to come up with the conceptual framework of the *natuurboerdery* farming approach indicated in Chapter Four. I then used this framework to describe the practices of *natuurboerdery* farming approach to meet research objective two[26].

Prior to defining *natuurboerdery* and describing its associated practices a brief overview or ZZ2 company profile was provided as prologue to enhance understanding of the discussions and descriptions which follow. This was extracted and refined from the company website. After this it was necessary to first discuss the reasons and route of ZZ2's conversion from conventional agriculture to *natuurboerdery* farming approach to answer research objective one[27] and followed by the definition of *natuurboerdery* and its associated practices. The former was compiled based on an unpublished document by van Zyl *et al* and PowerPoint presentations derived there from and also interviews with three

[24] An approach to commercial farming that aims to harness the laws and energies of natural ecosystems for health and sustainable crop production without sacrificing the benefits of technology and science.

[25] Agroecosystem health, soil health, plant health, food and human health.

[26] To describe the principles and practices of *natuurboerdery* farming.

[27] To investigate the reasons and processes of converting from conventional farming to *natuurboerdery* farming.

key sources (namely Tommie van Zyl, Johhan Noffke and Piet Prinsloo as indicated in Appendix B to C) and informal discussions and interviews with long serving ZZ2 farmers. Lastly, changes due to *natuurboerdery* were presented to meet objective three[28] and these were grouped into technical and strategic changes, ecological and environmental changes, social changes and benefits and economic and production benefits and changes. This was important to ascertain the sustainability of *natuurboerdery* as suggested by Harrington (1992) that comprehensive sustainable agriculture systems must include ecological, social, economic and ethical dimensions. This was mainly informed by interviews from the above named key informants.

Conclusions and recommendations were drawn up from my own understanding of agricultural sustainability and sustainable development and supported by the literature review in Chapter Two. This was also based on constructive and critical analysis and also using induction[29] and deduction[30] as described by Anneke (2008).

3.6 Ethical procedures

An ethical clearance form was signed in line with Stellenbosch University academic requirements. On my interview for my internship I clearly indicated my intention to do academic research on the *natuurboerdery* farming approach. This was most welcome with the interview panel and had the blessing of ZZ2 Chief Executive Officer CEO. However the objectives, research methodology, presentation of findings, conclusions and recommendations were not influenced by ZZ2 as a company or its staff. Rather it is a reflection of my own understanding of the whole *natuurboerdery* farming approach.

[28] To describe and explain the changes and benefits realised by converting to *natuurboerdery* farming approach.

[29] Induction is the process of reasoning in which the conclusion of an argument is very likely to be true, but not certain, given the premises. It is to ascribe properties or relations to types based on limited observations of particular tokens or to formulate laws based on limited observations of recurring phenomenal patterns.

[30] Deduction is the process of reaching a conclusion that is guaranteed to follow, if the evidence provided is true and the reasoning used to reach the conclusion is correct. The conclusion is based only on the evidence previously provided; it does not contain new information about the subject.

During interviews with staff anonymity was maintained on issues deemed to be sensitive. Before conducting interviews, I explained to the interviewees my intentions and importance of the interviewees contribution.

3.7 Delineation and limitations

As stated in section 1.5 this research aimed to provide a description of the development of *natuurboerdery* and its principles and practices. It must be noted that ZZ2 is a large company carrying out operations in three provinces of South Africa, data was only collected on selected farms in Limpopo province and mainly on tomato and avocado production. My speciality is in crop production and therefore livestock and wildlife activities were not detailed.

It was going to be interesting to measure or evaluate the sustainability of *natuurboerdery*. However this thesis did not attempt to explicitly measure this because the development of sustainability indicators and a matrix for the above purpose was seen to be time consuming and requiring in depth studies of the whole process. Given that the time period permitted for this research was one year, it was not possible to undertake such a procedure in the given time. Rather, I have included a brief discussion of *natuurboerdery's* sustainability in the final chapter, using the polycrisis and the discussion on the unsustainable practices of conventional agriculture from the literature review as the reference points.

This thesis did not directly compare *natuurboerdery* farming with organic or conventional farming. A detailed description of *natuurboerdery* was seen to be adequate to address the research problem. The other reason was that this removed bias in developing and describing the principles of *natuurboerdery*. After providing a detailed description of the *natuurboerdery* farming approach in this thesis independent work can then be carried out to determine the main differences between *natuurboerdery* and other farming systems as suggested under areas for further research in section 5.5.

I was limited in describing the economic changes as a result of conversion to *natuurboerdery*, which lack the actual monetary figures on the decrease of costs and increase in profits. ZZ2 did not want to disclose this information as it is a private company. However I used ZZ2's land records to determine the inputs used during conventional farming and those now used for *natuurboerdery*. After compiling all the inputs used for the two systems, I then used current agriculture commodity budgets by the Department of Agriculture (DA) (2010) to determine the current costs for the respective inputs specifically pesticides and fertilisers.

This research did not prove or experiment on the results or changes occurring due to the adoption of *natuurboerdery* (relying instead on my observations and interviews with ZZ2 staff). Undertaking experimental trials of this nature would have been expensive, required much time and may require more than one season to prove. The major limitation in carrying out this research was the absence of previous written academic work on *natuurboerdery* and this may also explain the importance of this thesis. This thesis created a background for future research work on the *natuurboerdery* farming approach as recommended in section 5.5.

> This thesis has two versions: one for the public and the other one which will be under embargo. The version under embargo contains section 5.4 which is a SWOT analysis with a critical analysis of *natuurboerdery,* while the public version does not contain section 5.4. I felt it necessary to keep section 5.4 private because, during the period of research, I was fully employed by ZZ2 as a Student Agricultural Scientist and was involved in nearly all aspects of *natuurboerdery*. As an employee, I considered criticism of the company to be against my personal and professional ethics, as I did not want to negatively affect the reputation of the company. However it must be noted that the criticism is based on my own understanding and anyone can choose to differ with my opinions.

3.8 Underlying assumptions

The reliability of the results and conclusions drawn were mostly affected by the source of data. Therefore the validity of this work is based on the following assumptions:

- All sources of information (company documents, records and interviewees) give a true reflection of the aspect under investigation.
- This study was conducted independently and professionally without favour or prejudice of the subject under investigation.
- The researcher's subjectivity cannot be eliminated. The researcher was taken as an instrument in data gathering. My involvement and immersion in the changing real world situation was essential in this qualitative research to record the changing events in the real life context (sometimes before, during and after the change occurs) (Maree, 2009:79).

3.9 Chapter summary

This research was undertaken as a case study and the chosen methodology qualifies as qualitative research. The use of a case study research design and qualitative research methodology allowed a holistic description of the development, adoption, principles and practices and changes which occurred due to the adoption of the *natuurboerdery* approach. The fact that I was attached at ZZ2 for ten months between 2009 and 2010 enabled effective data gathering. The use of multiple sources of information and techniques for data gathering adequately addressed the research questions and objectives. The analysis plan aimed to generate usable and meaningful information of the *natuurboerdery* farming approach. Due to the extensive nature of ZZ2 operations focusing on operations in Limpopo was feasible as I was stationed in that locality. Selective emphasis on crop production activities was done because of my experience and in depth knowledge in the subject. The focus on outlining an in depth description of *natuurboerdery* farming approach was meant to provide background information for further research like developing a sustainability matrix for measuring the sustainability of *natuurboerdery* and generating information which can be used to compare the former with other existing farming systems (conventional and alternative agriculture).

CHAPTER IV: FINDINGS AND DISCUSSION

4.1 Introduction

This chapter presents research findings based on the research objectives and to answer the associated research questions. An overview of ZZ2, its company profile, areas of operation and products is first presented in Section 4.2 to provide a background for the discussion of research findings that follow. The information for this overview has been extracted mainly from the company website.

The research findings are presented from Section 4.3 to 4.6 in order to draw conclusions and make recommendations in Chapter Five. Section 4.3 describes the reasons for and process of conversion from conventional farming to the *natuurboerdery* farming approach. It also highlights the challenges encountered during the conversion to and implementation of *natuurboerdery*. It concludes by defining *natuurboerdery* as a farming system in order to provide a background for the discussion of its practices in Section 4.4. The practices of *natuurboerdery* are discussed in relation to the five principals or health aspects (agroecosystem health, soil health, plant health, food health and human health) promoted in *natuurboerdery*. This is followed by Section 4.5 which discusses the changes and benefits due to the adoption of the *natuurboerdery* farming approach. In the last two Sections (4.4 and 4.5) the practices, changes and benefits due to *natuurdoerdery* are explicitly linked to how they contribute to and mitigate the global polycrisis and the negative impacts of conventional farming discussed in Chapter Two.

4.2 An overview of ZZ2

ZZ2 is a privately owned agricultural company registered as Bertie van Zyl (Pty) Ltd in South Africa. The name ZZ2 originated after the Anglo-Boer War in 1902 when farmers were required to have a registered number to brand their cattle. Burtie van Zyl, grandfather of Bertie van Zyl and the founder of the ZZ2 farming enterprise, registered the brand ZZ2 in 1903 and it has evolved to represent all ZZ2's products (ZZ2, 2010). ZZ2 carries out agricultural operations in three provinces namely Limpopo (Mooketsi, Politsi, Polookwane, Waterpoort, Hourtbosdorp, Pondrift, Vredendal and Musina), Western Cape (Ceres, Vredendal and Riebeeck-West) and Eastern Cape (Langkloof) (ZZ2, 2010) as shown in Figure 9. It is important to note that in all these areas ZZ2 owns more than one farm. These ZZ2 farms operate in a near autonomous system, decisions are made on the farm by the general manager, farm manager, and project managers[31] depending on the prevailing situation in order to achieve company production targets.

Figure 9: Location of ZZ2 operations

ZZ2 produces diverse agricultural produce (tomatoes, onions, avocados, apples, pears, beef and game) at a massive commercial level as indicated in Table 3. All crop and livestock production activities are carried out based on *natuurboerdery* farming approach. Tomatoes are produced in Mooketsi, Polokwane, Waterpoort, Musina, Pondrift, Vredendal and Riebeeck-West. Tomatoes are produced all year round, mainly for the local market (approximately 40 percent of local market share) and limited exports to Reunion, Sychelles, Dubai and Oman (ZZ2, 2010). Avocado production under extensive

[31] This comprises the senior management staff of ZZ2 farms and they are normally referred to as 'farmers', this term will be adopted in this section. They make decisions at farm level.

orchards is concentrated in Mooketsi valley, Politsi and Hourtbosdorp, where seven different varieties are produced. ZZ2 is the only onion producer with year-round production of onions in the country, during winter the limpopo lite onion is produced in the northern areas and during summer the cape brown onion is produced in the southern areas (ZZ2, 2010). A total of 32 different varieties of apples, pears and stone fruits are produced for almost half the year on farms in Ceres, Riebeeck-West and Langkloof for local and export market. ZZ2 also carries out wildlife and livestock activities which are integrated with crop production on all its farms (ZZ2, 2010).

Table 3: Products and production statistics for ZZ2

Product	Area under production hectares	Production tones per annum
Tomatoes	1 600	160 000
Onions	500	30 000
Avocados	400	3 000
Apples and pears	350	12 000
Beef and game	60000	

Source: van Zyl *et al*., unpublished

4.2.1 Core values

The core values of ZZ2 are described in terms of its:

- Vision: aims to be the benchmark of success in agriculture, which, as a living, open system, creates value for all its stakeholders
- Mission: to deliver high quality primary agricultural products and services … practices which optimises resources, based on *natuurboerdery* farming approach and are ethical, environmentally friendly and sustainable… and to serve clients who seek value
- Ethical norms: prudence, justice, fortitude and temperance

(ZZ2, 2010).

4.3 Converting from conventional farming to natuurboerdery farming approach

4.3.1 Introduction

This section gives an account of the reasons behind converting from conventional farming to the *natuurboerdery* farming approach and the process or path followed during the conversion period, including the challenges encountered and ends by defining *natuurboerdery*. The evidence presented in this section was mainly obtained from a key document *(ZZ2's* Natuurboerdery *system for improving soil health)* co-authored by ZZ2 technical staff (van Zyl, Prinsloo, Pieterse, Morad-Khan, Nzanza, and Hern) and the information was analysed for consistency with evidence obtained from interviews with key informants (Tommie van Zyl, Piet Prinsloo and Johann Noffke) and general discussions and informal interviews with other long-serving ZZ2 farm managers.

4.3.2 Reasons for converting to *natuurboerdery*

Soil health deterioration and decreasing production

There was a declining trend in yield from the late 1980s despite having reached the optimum soil chemical nutrient requirements for tomato production (van Zyl *et al.*, unpublished). This was supported by Noffke (2010) who claims that at Bangani farm in Mooketsi, yield from Sekelbos land declined from 120 tonnes per hectare to as low as 65 tonnes per hectare between 1998 and 2000 despite nutrient levels attained being almost optimum for tomato production. ZZ2 also noticed a significant loss of soil carbon, which in turn affected soil microbial life leading to soil health deterioration and land degradation and the soils could no longer sustain targeted economic production (Venter, 2010).

The deterioration in soil health was mainly attributed to the intensive use of inorganic fertilisers and pesticides associated with conventional agriculture (van Zyl *et al.*, unpublished). Van Zyl (2010) and Prinsloo (2010) agree that soil feeding was neglected at the expense of plant feeding. This is supported by a team of soil health specialists, Abawi *et al.* (2007), who state that soil carbon and organic matter influence almost all other soil properties important for maintaining a good soil health. They further state that these have a direct link to soil microbial, soil pH and cation exchange capacity (CEC) which in turn determines the availability of soil nutrients for plant growth. According to Prinsloo (2010) at this point ZZ2 recognised the importance of soil health in supporting sustainability in agricultural production.

Soil borne diseases and pest problems

According to Noffke (2010) the last decade of the 20th century was marked by an increased and high prevalence of soil borne diseases especially *Verticilium Wilt* and *Fusarium Oxsyporium* and soil-borne root nematodes in tomato production for ZZ2. Noffke (2010) and van Zyl (2010) agree that there was also evidence of increasing pest populations particularly whiteflies, *lyriomyza* flies and semi-loopers. They further state that both pests and diseases were becoming impossible to control with inorganic pesticides. The inability of pesticides to control pests and diseases was highly linked to resistance[32]. van Zyl (2010) cites an event at Ammondale Farm in Polokwane where Nemacur[33] failed completely to control root-feeding nematodes and the explanation given by the manufacturer was that of microbial breakdown[34] of Nemacur.

Increased production costs

The prevailing situations of pest and disease problems and decreasing yields influenced the use of more pesticides and fertilisers while yields continued to decrease (Noffke, 2010 and Venter, 2010). This was supported by van Zyl (2010) that. while more quantities of chemical inputs were needed, their cost on the market was continuously increasing and fuel prices were rising, which also influences the price of fertilisers and pesticides. He adds that a point was reached where the cost of inputs to sustain targeted production increased to uneconomic levels, putting ZZ2 into a difficult financial position.

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[32] A heritable change in the sensitivity of a pest population that is reflected in the repeated failure of a product to achieve the expected level of control when used according to the label recommendation for that pest species (IRAC, 2008).

[33] A highly toxic organophosphate and inorganic nematicide used for the control of soil nematodes.

[34] Some chemical compounds are broken down and stimulated by the action of certain microorganisms.

Customer demands and environmental concerns

According to Prinsloo (2010) and van Zyl *et al.*, (unpublished) ZZ2 became aware of the dynamics in customer preferences and that green consumerism is on the increase whereby customers now prefer food which has been produced in ethically and socially acceptable ways. They add on that customers also demand high quality food with appealing taste, nutrient density and extended shelf life. ZZ2's motto is "food health is our promise; healthy soils our passion" and aims to leave a legacy that saves the future generations free from hunger (van Zyl *et al.,* unpublished). In other words ZZ2 became aware of the sustainability concept and the environmental impacts associated with the practice of conventional agriculture.

4.3.3 Section Summary

The conversion of ZZ2 to *natuurboerdery* farming approach was a result of the negative impacts of conventional methods of farming which resulted in persistent soil borne disease and recurring pest problems, soil health deterioration and decreasing yields and increased production costs. ZZ2 needed a farming system with less negative environmental impacts while sustaining economic yields and also meeting the demands of the customers or consumers. In short the conversion was a result of the unsustainability of conventional farming practices.

4.3.4 The conversion process

Between 1999 and 2000 ZZ2 began the process of converting from a predominantly conventional and inorganic chemical agriculture system on all its products (tomatoes, onions, avocados, and apples) to a more ecologically-balanced farming system based on use of both inorganic and organic inputs (van Zyl, 2010 and Noffke, 2010). ZZ2 CEO Tommie van Zyl and *Natuurboerdery* Project Manager Piet Prinsloo named this farming approach *natuurboerdery* in 2000 because they believed that it was to be based on and mimic natural processes and ecosystems. They then defined it specifically as "an approach to commercial farming that aims to harness the laws and energies of natural ecosystems for health and sustainable crop production without sacrificing the benefits of technology and science" (ZZ2, 2010).

From my time at ZZ2 I came to realise that the conversion to this farming approach is not complete and did not occur overnight but rather has evolved over the years. It was a process of smaller technical changes and adjustments over time which later came to represent an entire approach or system of farming.

Brief overview of ZZ2 during conventional farming

According to Noffke (2010) the period of conventional farming was solely based on the use of inorganic chemical inputs:

i) Plant nutrient management was only through inorganic fertiliser application determined by soil chemical analysis for macro nutrients and micro elements taking into account crop requirements and crop growth stage.

ii) Pest and disease management was through use of the most toxic and efficient pesticide sprays without paying much attention to pest economic threshold levels and effect on the environment or produce.

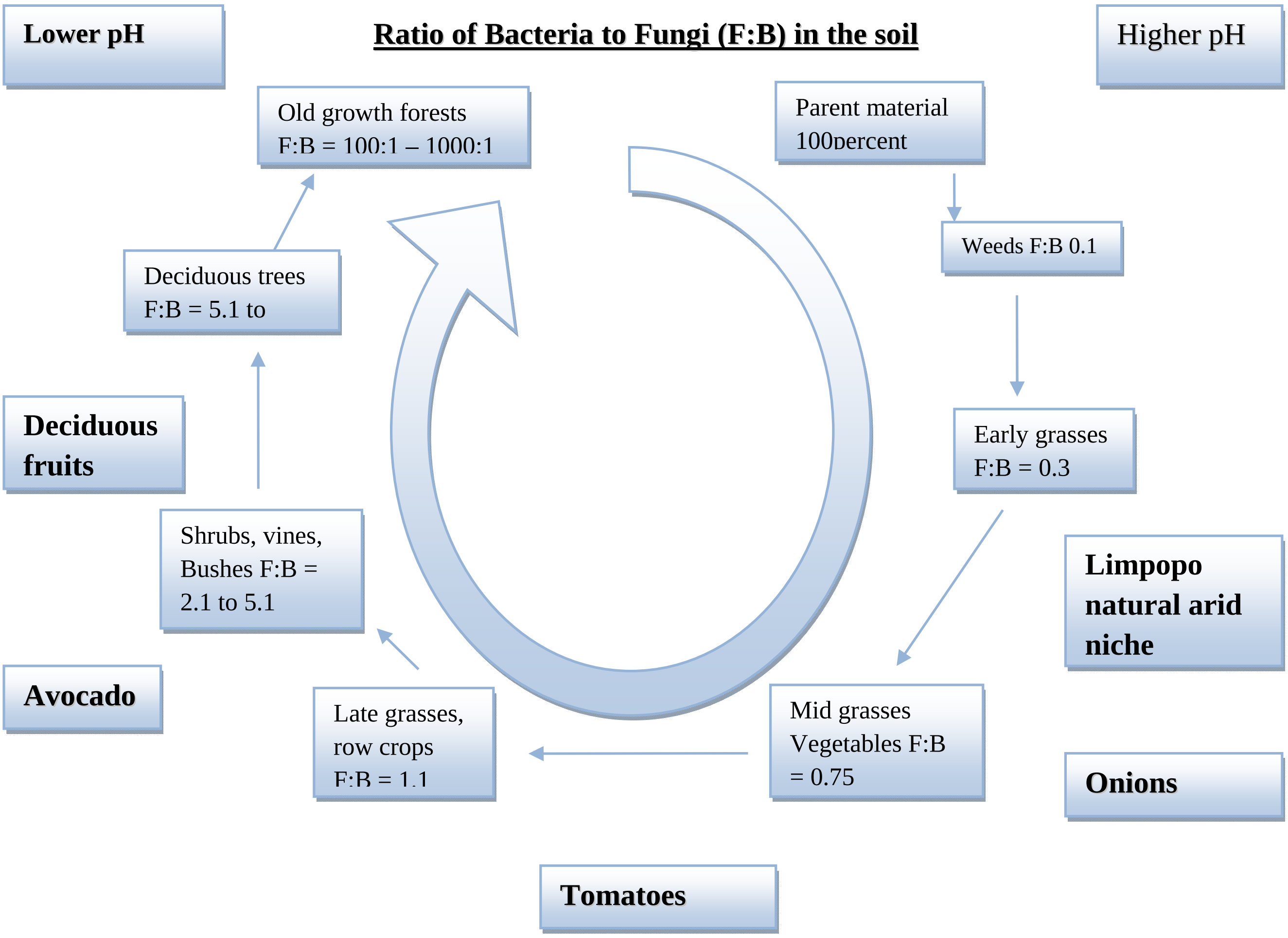
The above is supported by van Zyl (2010) who states that during the period of conventional farming they (ZZ2) understood very well the use of crop chemicals which made them good friends of Hiefer Chemicals Private Limited. Prinsloo (2010) adds that the emphasis was on feeding the plant and the soil was conceived to be only important for providing structural support to the plant. Nutrient cycling and other factors which influence nutrient availability to the plant were nonexistent resulting in loss of soil carbon, organic matter, microbial life and deterioration in soil health (Nzanza, 2010). These factors directly influence soil pH and CEC which determine plant nutrient availability (Abawi *et al.*, 2007).

Conversion strategies and stages

The conversion strategies and stages were synchronised to ensure that they address the reasons for converting from conventional farming.

According to van Zyl (2010) ZZ2 was introduced to the use of fluvic and humic acids rich in carbon for soil feeding and EM to increase soil microbial population of beneficial microorganisms in 1999 by a microbiologist, EM and fermented plant extracts (FPEs) expert, Professor Koos Prinsloo (Emrosa, South Africa). They also acknowledge that Professor Koos Prinsloo linked ZZ2 to a compost tea expert, Dr Elaine Ingaham, who brought in the production and use of compost and compost tea to build soil carbon and balance soil microbial life. She also introduced ZZ2 to the fungi to bacteria ratio and the succession wheel (indicated in Figure 10) which links each crop to a specific niche with its own optimum ratio of fungi to bacteria. For example, onions thrive in a bacterial dominated soil while avocados prefer a fungal dominated soil (Ingaham in van Zyl *et al.,* unpublished). ZZ2's experience showed that bacterial dominated soils will have a higher pH whereas fungal dominated soils will have a low pH (van Zyl *et al.,* unpublished)

Figure 10: The succession wheel (relationship between vegetation stage and fungal to bacterial ratio in the soil)



Source: Ingaham in van Zyl *et al.*, unpublished.

Based on the information and knowledge from the two experts, the focus shifted to feeding the soil with an aim of achieving a soil carbon content of three percent so as to increase nutrient availability to plants and to increase and balance soil microbial population (fungi : bacterial ratio) (van Zyl, 2010 and Prinsloo, 2010). They concur that soil health management was incorporated as a key component of the *natuurboerdery* farming system. They further state that the strategy was to improve soil health using organic materials: fluvic and humic acids, composts, manure, compost tea and EM. In 2008 a team from ZZ2 R & D attended a workshop on soil health at Cornell University.

According to Nzanza (2009) this was a significant event which led to adoption of the Cornell Soil Health Indicators (CSHI) as a guiding instrument for soil health management in the *natuurboerdery* farming approach. Other strategies to improve and build soil health introduced include use of microbial inoculants; mycorrhizal fungi and trichoderma; organic amendments; vermicomposts and biochar; minimum tillage for land preparation and fallowing and cover crops as cropping systems. The flow chart in Figure 11 shows the transitional stages in soil nutrient and health management at ZZ2 and the soil health management approach is discussed in more detail in later sections.

Figure11: Timeline for the introduction of different nutritional components at ZZ2

Mineral elements		Carbon Content and microbes		Soil health management	
Inorganic fertilisers		Organic amendments		Improvement	Building
Macro-elements	Micro-elements	Carbon	Microbes	Compost	Biochar
Nitrogen (N)	Iron (Fe)	Fluvic acid	Bacteria : Fungi	Manure	Cover crops
Phosphorous (P)	Zinc (Zn)	Humic acid	Protozoa	Vermicompost	Fallowing
Potassium (K)	Boron (Bo)	Compost	Nematodes	Compost tea	Minimum tillage
Calcium (Ca)	Silica (Si)	Manure		EM	
Magnesium (Mg)	Cobalt (Co)	EM		Mycorrhiza	
Sulphur (S)	Copper (Cu)	Compost tea			
1998		1999		2008	

Source: Modified from van Zyl *et al.*, (unpublished)

In the past, to cope with persistent soil borne root nematodes, pests and diseases pressures ZZ2 had to:

- Increase crop rotation cycles for periods extending to 10 years and land available was a limiting factor to meet production targets to sustain the company. This resulted in ZZ2 acquiring more land and clearing it for production purposes which contributed to land degradation, biodiversity loss and species extinction through habitat loss.

- Another strategy to cope with these outbreaks was to rely on heavy use of chemical pesticide use.

(Noffke, 2010).

Noffke (2010) and Prinsloo (2010) admit that the above strategies did not work and were unsustainable. They further state that chemicals used were harmful to both pests and beneficial insects, with harmful pests building resistance to pesticides. According to van Zyl *et al.,* (unpublished:2) this made ZZ2 listen to the words of Carl B. Huffaker, a professor in entomology and ecology, who said that, “when you kill off the natural enemies of a pest, we inherit their work”. This motivated ZZ2 to seek alternative and environmentally-friendly ways for managing pests and diseases (Prinsloo, 2010). He further states that an integrated pest and disease management programme was then introduced. This includes scouting for and monitoring of pests, use of threshold levels, FPEs, natural products, biological pest predators and reduced use of inorganic chemical pesticides. The approach to pest and disease management is discussed in more detail in later sections.

To meet customer demands the *natuurboerdery* approach includes: food health (production of highly nutritious fruits, zero chemical residues and longer shelf life) and human health (workers’ health and a healthy environment) (Nzanza, 2010 and Prinsloo, 2010).

To explain these new technologies, practices or strategies demonstration plots or trials were set on all farms and managed by the farmers themselves (Noffke, 2010). He also states that some farms which adopted the practices at the onset were also good examples and convinced others to adopt the approach. Also farmers came up with new ideas and experimented on them and shared their successes with others. There is a *natuurboerdery* taskforce which reviews challenges, successes, disseminates information and coordinates the implementation of the *natuurboerdery* farming approach.

According to Prinsloo (2010), van Zyl (2010) and Noffke (2010) ZZ2 did not turn to organic production completely but chose to develop and adopt their *natuurboerdery* approach which incorporates organic materials with reduced inorganic fertilisers and pesticides. They state that turning organic completely was going to reduce productivity or yields by between 40 to 60 percent and this would not be economically sustainable for ZZ2.

Conversion challenges

According to Noffke (2010) and van Zyl (2010), ZZ2 believes in any open system[35] and did not force farmers to convert to *natuurboerdery*, thus a paradigm shift was not easy. They say that it was difficult to instil a mindset change on all at one time as some farmers had fears of the unknown and there was a tendency of holding on to the system which they know.

Noffke (2010) explains that *natuurboerdery* works with living systems or organisms (soil, EM, microbial life and insect pest predators) yet only a fraction is known about their behaviour and mechanisms. He gives an example when a certain wasp *(trichograma)* imported from America was introduced as a predator of red spider mites, aphids and red bollworm eggs. This failed to work as the wasp failed to adapt to the hot climate of the Mooketsi Valley. The strategy now is to propagate locally adapted insect pest predators by creating breeding zones which are not sprayed inorganically or organically such that they will thrive as their food (i.e. pests) will be available.

I have observed that the control of insect pests (whiteflies, thrips and aphids) and soil borne diseases (verticilium wilt and oxysporum) to below economic threshold levels is still a constraint. The problem is worsened by the lack of readily available effective biological or natural control agents to keep the populations or incidences at acceptable levels without incorporating inorganic chemical control. However success has been registered on the control of soil nematodes using EM lantana with total elimination of

[35] It is important to note that farmers are allowed to use any strategy they believe will enable them to achieve their targets

nematicides. The challenge on EM lantana is its registration as an organic pesticide, the reason being that little is known in South Africa on EM and products derived from it. According to Nzanza (2010a) this is compounded by the fact that agricultural research had previously evolved around chemical control and little work has been done on natural and organic control options.

Soil borne diseases particularly *verticilium wilt* and *fusarium wilt* are still a problem on most farms and research is in progress to find an organic control strategy using disease suppressive compost. Dr Adele McLeod from Stellenbosch University and research fellow with ZZ2 on plant pathology is working closely with Dr Michael Raviv from Volcano Institute, Ministry of Agriculture in Israel and the *natuurboerdery* R & D in the implementation of this programme.

The initial production of compost tea was done using equipment imported from America at a cost of R500 000 in the year 2000 (Noffke, 2010; van Zyl, 2010 and Prinsloo, 2010). Unfortunately this did not work properly, it produced a vortex instead of a bubble. Noffke (2010) explains that a vortex does not oxygenate the water and compost tea mixture to levels which can support aerobic bacteria needed for aerobic fermentation for the production process. He further states that this was replaced with locally-manufactured equipment and recycling old tanks, which was at a much lower cost.

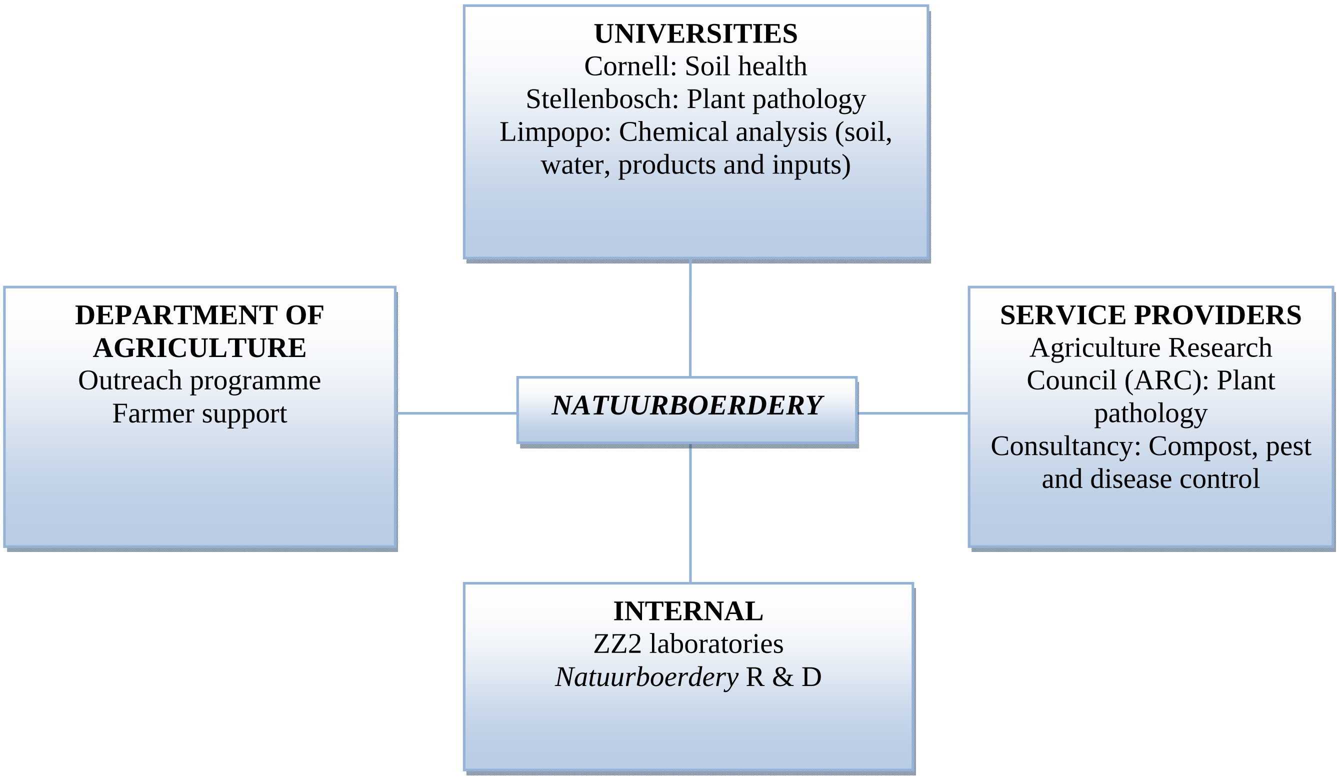
Operations for soil preparation are the same as those for conventional agriculture. Currently only about five percent of cropped area is under minimum tillage, although the target is an annual increment of 18 percent (Nzanza, 2009). The challenge has been finding the right equipment for minimum tillage so that it is compatible with other operations. ZZ2 technical and R & D staff and agronomists are working closely with a local engineering company (Radium Engineering Pty Ltd) to design a minimum tillage machine which can do four operations[36] in one run. If this is successful the target will be to go 100 percent on minimum tillage which will result in 75 percent cost savings on soil preparation through less use of tractors (Nzanza, 2010a and Noffke, 2010).

[36]Clear crop residues, mark planting lines, apply compost and break clods.

4.3.5 Information base for natuurboerdery

Information on *natuurboerdery* is gathered in a number of ways. According to Noffke (2010) the most important thing is that *natuurboerdery* does not try and reinvent the wheel, it borrows from other systems which have proven to be sustainable. The internet plays a significant role for providing information on research and farmers' experience from elsewhere. ZZ2 also has a broad network with agricultural institutions to address challenges and opportunities for *natuurboerdery* as indicated in the Figure 12 below.

Figure 12: *Natuurboerdery* network



Source: Author, 2010.

ZZ2 has a strong R & D department which carries out on-farm research to test new products and techniques before they can be adopted by farmers (See also Appendix N for R & D focus areas). ZZ2 Laboratories at the Aquaculture Centre at the University of Limpopo carry out tests and analysis such as soil health tests, leaf, root and fruit chemical analysis, mycorrhiza root colonisation, quality tests for FPEs, compost and compost teas (see also Appendix O for details on tests conducted). Where the laboratory does not have capacity it subcontracts specialist laboratories to do the work. The services provided are extended to outside clients who are not ZZ2 farmers for business purposes and to promote sustainable agriculture methods.

Consultants are also engaged in their areas of expertise which fit into the *natuurboerdery* farming approach: compost specialist Dr Michael Raviv (Volcano Institute, Ministry of Agriculture, Israel), EM and FPEs expert Professor Koos Prinsloo (Emrosa, South Africa) and specialist in plant pathology and soil borne diseases, Dr Adele Mcleod (University of Stellenbosch, South Africa).

4.3.6 Section summary

The conversion from highly intensive inorganic chemical agriculture to *natuurboerdery* has been, and continues to be, a gradual process. Mainly it first focused on improving soil health by improving soil carbon content which influences factors which affect plant nutrient availability. This was through the introduction of organic soil amendments such as fluvic and humic acids, compost and manure. Compost teas and EM are used to increase and balance soil microbes especially fungi to bacteria ratio. Cover crops, fallowing, minimum tillage and use of biochar, *mycorrhiza* and *trichoderma* inoculations are also used for soil health building. Thus the focus shifted from feeding the plant to feeding the soil. The Cornell Soil Health Model has been adopted to guide soil health management and includes soil health monitoring. An integrated pest and disease management programme which uses FPEs, natural products, biological pest predators and reduced inorganic chemical pesticides is in place.

Several challenges were encountered during the transition period and strategies were devised to counter these. The first challenge was to instil a mind set change in ZZ2 farmers who were used to the intensive inorganic chemical agriculture. The other challenge is working with living organisms when there is little information and knowledge on their characteristics and mode of action. Pest and disease management in *natuurboerdery* is curtailed by the unavailability of effective organic and natural control methods. Disease suppressive compost for soil borne diseases and pathogens is under investigation for inclusion in the *natuurboerdery* practices. Also ZZ2 is working with a local engineering company to design a machine for minimum tillage compatible with its operations.

4.4 What is natuurboerdery?

ZZ2 developed and adopted its own unique farming approach, *natuurboerdery*, and defined it as "an approach to commercial farming that aims to harness the laws and energies of natural ecosystems for health and sustainable crop production without sacrificing the benefits of technology and science" (ZZ2, 2010). The overall aim is to maintain ecological balance through minimising environmental impacts, restoration, conservation and sustainable utilisation of natural resources and biodiversity while achieving economic yield and improving the quality of life for workers, surrounding community and consumers which must lead to overall sustainability.

4.5 Practices of natuurboerdery

Section 4.3 discussed the reasons for converting to *natuurboerdery* and the challenges of the initial process of converting. This was followed by the definition and a brief description of the *natuurboerdery* farming system. The main aim of this section is to show the findings for answering research objective ii: to describe the principles and practices of *natuurboerdery*. This section will start by stating the five health aspects of *natuurboerdery* developed by Nzanza (2009) which can be regarded as the guiding principles on which the whole approach is based. As described in Chapter Three, I used these to develop the overall conceptual framework by arranging the different practices into their relevant group, shown in Figure 13.

It is important to note that this section used evidence provided by all sources and data gathering instruments discussed in Section 3.4. It is also a reflection of my personal understanding and experience of *natuurboerdery* as a farming system.

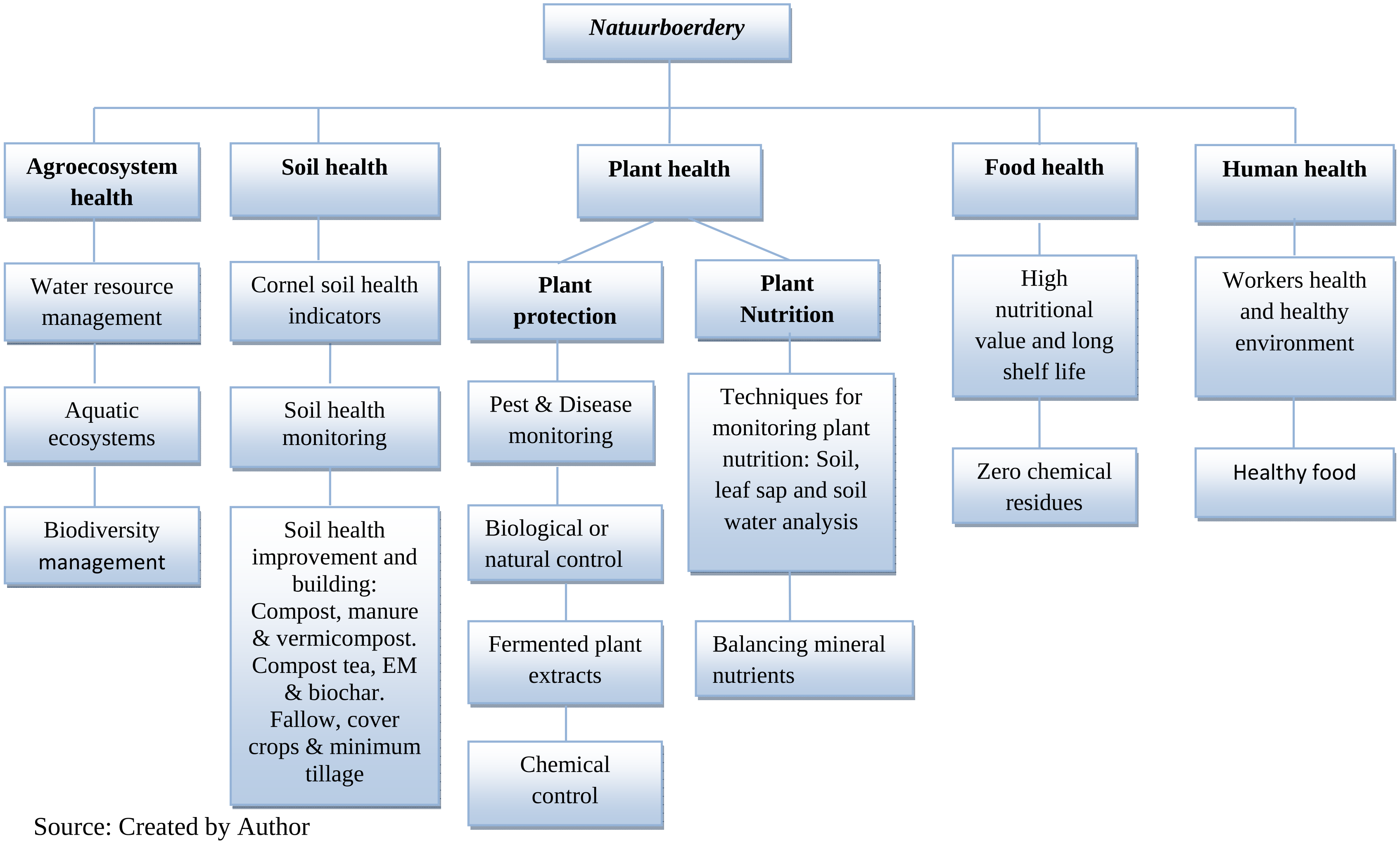
The farming practices of *natuurboerdery* incorporate five fundamental health aspects to achieve increased and sustainable agricultural productivity while maintaining environmental and ecosystem integrity. The five fundamental health aspects are:

- Soil health
- Plant health
- Agroecosystem health
- Food health
- Human health

(Nzanza, 2009).

The health aspects of *natuurboerdery* are connected to achieve the aim of ecological balance and human health for sustainability. The key to *natuurboerdery* is the soft and integrated approach which minimises environmental and ecological damage while maintaining sustained productivity (Nzanza & Taurayi, 2010a). The five health aspects of *natuurboerdery* and their practices are illustrated as the conceptual framework of *natuurboerdery* farming approach in Figure 13.

Figure 13: Conceptual framework of the *natuurboerdery* farming approach



Source: Created by Author

4.5.1 Agroecosystem health

This section describes the practices and management approach to agroecosystems in *natuurboerdery* which are important in maintaining ecological balance and biodiversity. The main components or systems described are water resource management, aquatic ecosystems and biodiversity management. These are further divided into their main sub-components or subsystems. The management guidelines for aquatic ecosystems were gathered during the discussion meetings for the development of *natuurboerdery* checklist and compliance criteria which is shown on Appendix H and furthermore they are in line with those described for Global GAP[37].

Water resource management

According to Noffke (2010) *natuurboerdery* recognises the scarcity and importance of water in agricultural production and has introduced water management programmes to ensure use efficiency and conservation of water resources whereby volumes of available ground water are strictly monitored and managed. He explains that firstly the volume of permissible water extraction is governed by and categorised into three zones: green, yellow and red where extraction is limited and not allowed to pass the yellow zone as indicated in Figure 14 below. He further states that the planting programmes are designed to match available water resources. This helps to increase or decrease hectarage considering other factors. The third factor is to ensure water use efficiency by firstly determining the soil water holding capacity. This helps to know how much water will be available to the plant and how much to apply, also based on climatic conditions and plant growth stage. This forms the basis of irrigation scheduling which is further enhanced the use of irrigation equipment (tensiometers, moisture probe meters, weather stations and irrigation profile holes[38]). Water quality is also improved by the use of ozone[39] which enriches it with oxygen.

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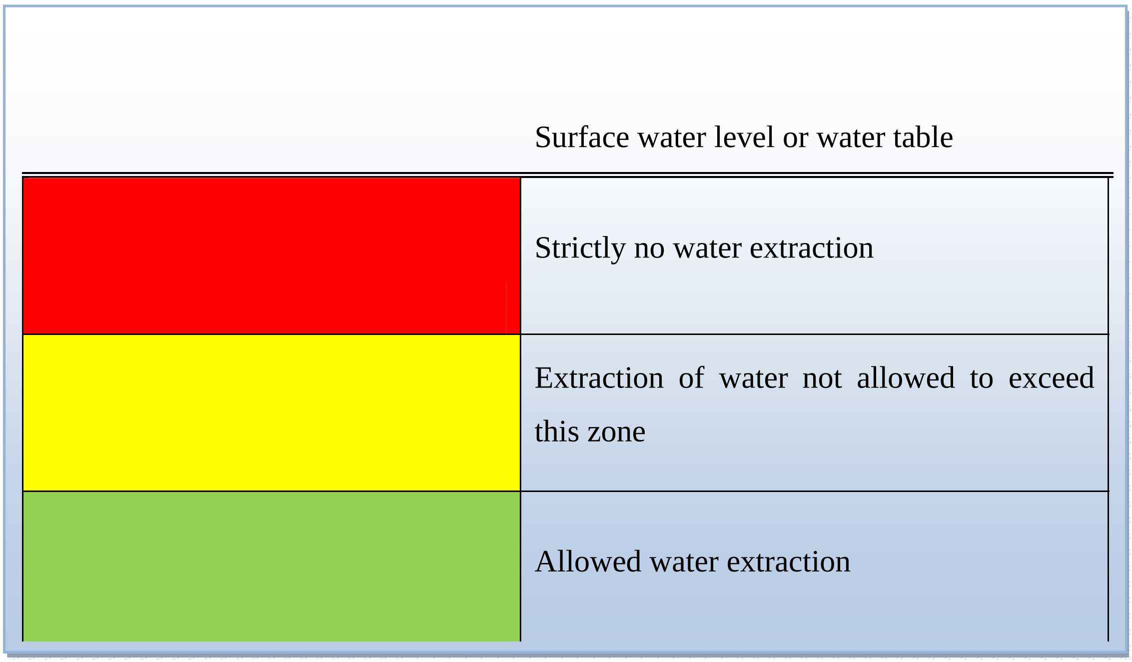
[37] Global Good Agricultural Practice

[38] Small holes or pits dug in the cropped field to just below the rooting zone to monitor downward movement and availability of water applied through irrigation.

[39] Enriching oxygen water levels through electrolysis

Figure 14: Zoning of available and permissible water extraction



Source: Created by author, 2010

Acquatic ecosystems

Taurayi *et al.* (unpublished) discuss the importance of respecting and including the significance of aquatic ecosystems (wetlands, rivers and dams) in the *natuurboerdery* farming approach to provide and maintain ecological balance, environmental integrity and other important ecological functions and set the management programmes and guidelines for the respective ecosystems discussed below.

i) Wetland management programme

Wetlands have a number of important ecological functions. They reduce the impacts of flooding by acting as sponges and slowly release water after rains whilst recharging the groundwater and protecting downstream riverbanks from erosion. Also wetlands serve as an important habitat for diverse species of flora and fauna. The *natuurboerdery* protocol stipulates that wetlands must be identified and delineated on the farm map during winter periods as some wetlands may not be identifiable during summer. The wetland management programme must use the following guidelines:

- Buffer areas adjacent to wetlands of unused land are maintained free from alien species with a width of between 25-75m.
- Free water flow in and out of wetlands is maintained at all times.
- Controlling and monitoring of pollution sources like seepage from compost heaps, cleaning of EM and compost tea production areas and waste water from packhouses.
- Clearing of invasive alien species but not disturbing soil integrity.
- Monitoring degradation and erosion of wetlands.

ii) River management programme

Rivers and river banks provide habitat for several plant and animal species which purify water and also offer several ecological functions like ecological corridors, delivering water to downstream areas, preventing erosion and feeding ground water sources. The management guidelines at ZZ2 farms are as follows:

- All water use and activities must be authorised by the Department of Water Affairs.
- Controlling of alien species including water plants in the river and its banks.
- River bank and catchment areas are kept intact and rehabilitated when degraded. The integrity of river ecosystems is influenced by the presence of natural vegetation over banks or catchments areas. The vegetation stabilises the riverbank, filters pollutants and maintains natural water temperature, contributes organic matter for supporting aquatic life and buffer adjacent land uses.
- River banks are gently sloped and planted with indigenous vegetation to minimise erosion and maintain water quality.
- Buffer strips of natural vegetation are maintained at 30-40m with a width of 10m. This is done to prevent leaching of fertilisers and pesticides.
- Enough water is maintained in the rivers by monitoring water abstraction.

iii) Management of farm dams

Farm dams are important for storing and supplying water for irrigation to enable year-round production. They also enhance the aesthetic beauty and diversity of the farm by attracting a wide range of birds and insects. Farm dams are also stocked with indigenous and threatened fish species and the levels are continuously monitored for conservation thus minimising species extinction. The management guidelines for dams include clearing alien vegetation and planting indigenous shrubs on dam shores, maintain indigenous water lilies and weed beds to protect the predatory birds like fish eagles, buffers strips of 10-30m comprising indigenous vegetation are maintained between dams and farm lands.

Biodiversity management

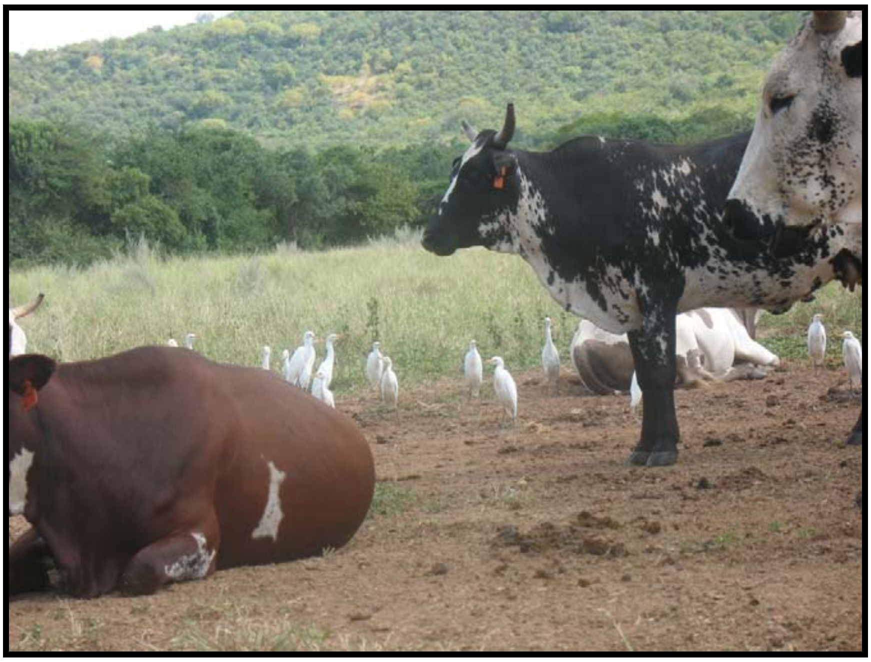
Three systems or management approaches used in *natuurboerdery* to promote biodiversity include integration of livestock and cropping systems, clearing of alien species and land management. It is important to note that livestock and cropping systems were regarded as different and independent entities during the period of conventional farming (Noffke, 2010).

i) Integration of livestock and cropping systems

The *natuurboerdery* farming approach integrates cropping systems with livestock production and wildlife to enhance agrobiodiversity and maintain ecological balance. The main livestock includes with two breeds of cattle (pinsgaurer and nguni) and goats. The wildlife component includes a range of animal species from the biggest animals to the smallest (elephants and hippopotamus to rabbits and squirrels).

Livestock forms a very important component of *natuurboerdery* and is mainly grazed on natural grass which is provided by fallow lands thus increasing sustainable land utilisation and productivity. The grazing system can be described as ‘free range’ that is to mean that livestock are not locked up in kraals or restricted areas. As the cattle freely roam the grazing lands they drop their dung around which is then spread by the dung beetles improving soil health and also increasing biodiversity. Diversity also comes in the form of stock birds which feed or control ticks which parasitise on cattle spreading diseases as shown in the photograph, Figure 15.

Figure 15: Integration of livestock and cropping systems



Goats have also been incorporated into *natuurboerdery* systems, mainly for the purposes of grazing on invasive alien species (sickle bush). In a way they increase agrobiodiversity by acting as a biological control agent. As the goats are locked up during the night for protection their night droppings provide biomass for compost making.

Wildlife protection and conservation in *natuurboerdery* farming systems provides a way of increasing biodiversity and minimising species extinction and this is enhanced by the protection of vegetation in conservancies. In addition conservancies have economic and social significance by providing tourist facilities and activities like hunting and shooting, bird viewing and also protecting heritage sites with cultural and aesthetic value.

ii) Clearing alien species

ZZ2 recognises the negative environmental impacts due to invasive alien species which include direct habitat destruction, increasing the risk and intensity of wildfires and reducing surface and subsurface water. The *natuurboerdery* protocol at each farm includes an alien species control programme. The plan includes a map showing the alien species density and indicating the dominant alien species in each area. Clearing starts with young and less dense trees to prevent build up of seed banks.

At ZZ2 farms the main identified alien species are sickle bush and lantana camara. Their clearing (including using goats as mentioned above) leads to positive development as they are used to make products which are used as production inputs (biochar and EM lantana). The other alien species being cleared are the blue gum and black wattle around watershed areas. These are used for timber and the clearing has resulted in increased available water and annual flow of natural springs.

iii) Land management

Due to increased productivity and ability to rehabilitate degraded lands by the *natuurboerdery* farming approach, ZZ2 does not clear new land for agriculture purposes unnecessarily. Environmental impact assessments (EIAs) are conducted for all agricultural activities when a new or virgin land is to be opened. This also serves to protect threatened flora and fauna.

Section summary

The availability of ground water for irrigation is monitored and managed by zoning systems which guards against depletion. Water efficiency is ensured by planting hectarage equivalent to available water and use of irrigation and scientific equipment to determine crop water needs and for irrigation scheduling. The integration of crop and livestock systems and clearing of alien species contribute to agro-biodiversity and allow proliferation of indigenous vegetation. Aquatic ecosystems are managed to preserve their integrity and conserve biodiversity. Ecosystem damage is prevented by carrying out EIAs on all proposed agricultural activities.

4.5.2 Soil health

This section details the soil health management approach which is a key component of *natuurboerdery*. It begins with a description of selected Cornell Soil Health Indicators (CSHI) in Table 3 followed by the soil health monitoring strategy. Lastly it discusses the strategies used for soil health improvement and building which include the use of organic soil amendments (compost, manure and vermicompost), soil inoculants (compost tea, EM and biochar) and cropping systems (fallowing, cover crops and minimum tillage).

Cornell soil health indicators

ZZ2 has adopted the soil health concept based on the CSHI as described in Table 4, and is key in *natuurboerdery*. According to Abawi *et al.* (2007) these indicators are important in sustainable crop production as they determine soil productivity, they relate and respond to management practices and they are simple and cost effective. They also describe soil health as the integration and optimisation of biological, chemical and physical factors of soil which influence farm profitability and sustainability.

Table 4: Description of Cornell soil health indicators

Soil Properties	Indicators
Physical	***Aggregate stability:*** measures the extent of resistance from falling apart of soil aggregates when wetted and hit by raindrops.
	Available water holding capacity: reflects the amount of available water for plant use stored in a disturbed soil. It is the difference between water stored at field capacity and at wilting point.
	Subsurface or Surface hardness: is a measure of the maximum resistance (in psi) encountered in the soil at the depth 0 to 6 inch and 6 to 18 inch depth using a field penetrometer.
Biological	***Organic matter:*** material derived from living organisms including plants and animals including living and non living as well as decomposed humus.
	Active carbon: is a measure of food available for soil microbial community. It is a leading indicator of soil heath which responds quicker than total organic matter content to changes in crop and soil management.
	Potentially mineralisable nitrogen: an important measure of soil biological activity and an indicator of the amount of nitrogen that is rapidly available to the plant when nitrogen is converted from an organic form to an inorganic form by soil microbes.
	Root health rating: is a measure of the quality and function of the roots as indicated by size, colour, texture, and absence of symptoms and damage by root pathogens such as *Fusarium, Pythium, Rhizoctonia and Thielaviopsis*. Low ratings (1 to 3) indicate healthy roots due to absence of pathogens at damaging levels or being suppressed by soil beneficial organisms in the soil.
Chemical	***Soil chemical composition:*** measures soil pH levels, plant nutrients and toxic elements and consist of the following P, K, Mg, Na, CEC, C, Cu, B, Fe, Mn and Zn.

Source: Abawi *et al.*, 2007:16

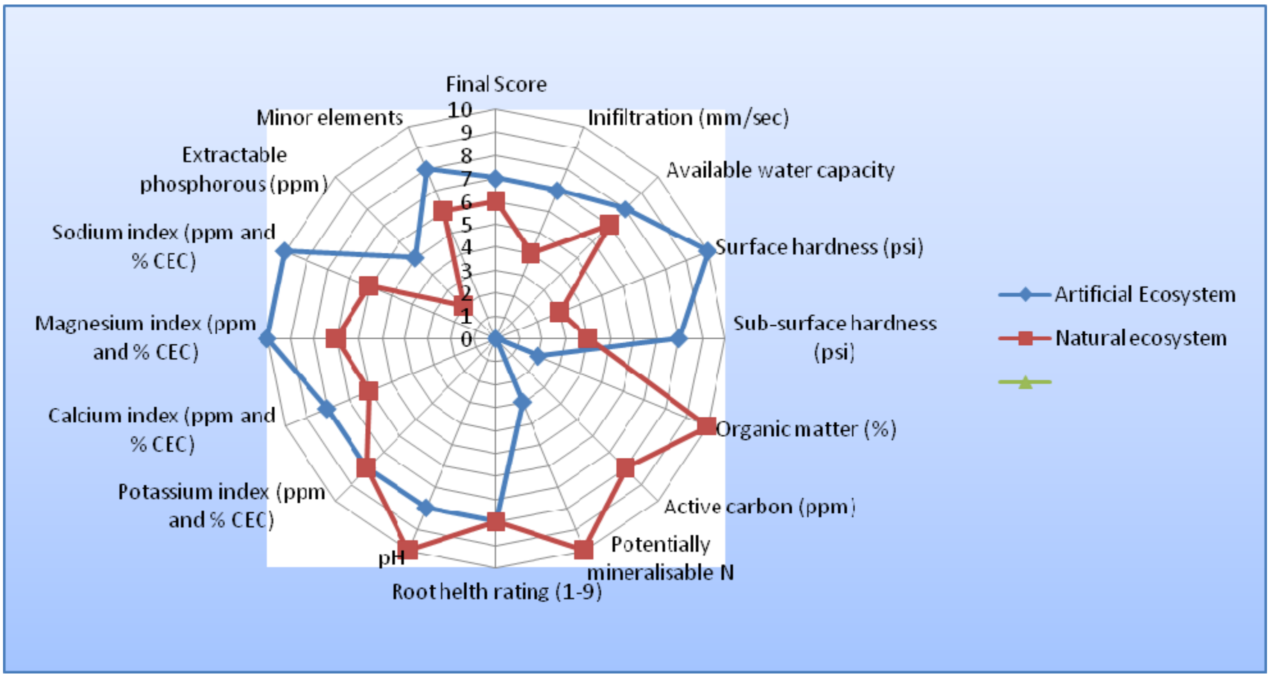
Soil health monitoring

Long term soil health monitoring is carried out at all ZZ2 farms[40] and is divided into three different categories: comparison of artificial and natural ecosystems, pair side comparison of sorghum cover crop land and natural grass (fallow) land and effects of tillage system and cover crop type on soil health where each land has a block for soil health monitoring (Taurayi and Nzanza, 2010b). Figure 16 compares soil health indicators for Roma Land at Vreedsam farm in

[40] ZZ2 farms are divided into lands which are further divided to blocks with specific soil characteristics and have similar management practices.

Mooketsi (artificial ecosystem) and its adjacent natural ecosystem. The scores for the soil health indicators show that the artificial ecosystem performs better in the physical and chemical indicators while the natural ecosystem is better in biological indicators. The information obtained from these indicators is that the management practices must take into account practices for improving the biological indicators for its artificial ecosystems. This is because *natuurboerdery* uses natural ecosystems as reference points for sustainable soil health and productivity (Taurayi and Nzanza, 2010b).

Figure 16: Comparison of soil health indicators on ZZ2 lands (artificial ecosystem versus natural ecosystem)



Source: Taurayi and Nzanza, 2010b

According to Taurayi and Nzanza (2010b) the *natuurboerdery* farming approach uses soil health monitoring to provide information on soil health status and is important for increasing farm productivity, sustainability and directing research and farm management activities. The management of soils is based on the assessment of soil health status over time as it provides:

- Information on the impacts of specific practices on soil health and strategies which can effectively address shortfalls in soil health management

- Reassurance that cropping systems are sustainable and soil health indicators are heading in the right direction
- A baseline reference from which improvement in soil conditions can be evaluated, thus providing the means to establish an early warning system for what needs to be addressed (Taurayi and Nzanza, 2010b).

Soil health improvement and building

i) Compost and manure

ZZ2 produces different types of compost (plant feeding, disease suppressive and soil feeding compost) using locally available and renewable raw materials indicated in the Table 5 below.

Table 5: Compost types and recipes

Soil Feeding Compost		**Plant Feeding Compost**		**Disease Suppressive Compost**	
Material	**Quantity**	**Material**	**Quantity**	**Material**	**Quantity**
Grass	$43.75m^3$	Grass	$214.5m^3$	Tomato crop residues	$40m^3$
Cattle manure	$19m^3$	Cattle manure	$128m^3$	Cattle manure	$118.5m^3$
Chicken manure	$6m^3$	Chicken manure	$15m^3$	Chicken manure	$15m^3$
Pine chips	$5m^3$	Macademia husk	$6m^3$	Basalt	$10m^3$
Blue gum chips	$5m^3$	Basalt	$10m^3$	--	--
Saw dust	$10m^3$	--	--	--	--

Source: Miller, 2010

Depending on the type of compost to be produced, bale grass (soil feeding) or tomato crop residues (disease and plant feeding) are laid on the ground and followed by the application of manure, (cattle then chicken) and then wood chips or sawdust and then basalt. Each compost row is referred to be 'three high' meaning that there will be three layers (the bottom, middle and upper layers) (Miller, 2010). The compost rows also receive small amounts of compost from the mother heap[41] and EM to enrich microbial life for the decomposition process (Miller, 2010 and Noffke, 2010). Basalt and lime can be added depending on the type of soil to be applied with the compost.

After placing the raw materials in layers, the compost batch is turned with a compost turner and water is applied simultaneously. This stimulates the decomposition process due to microbial activity coupled with an increase in the compost pile temperature (thermophilic phase). Temperature and moisture content are measured on a daily basis with a temperature and moisture meter respectively. Temperatures are not allowed to exceed 65 degrees celscius as temperatures above this tend to destroy beneficial microorganisms, resulting in reduced decomposition rates and produces compost with high ash content which is undesirable and also results in loss of nitrogen due to volatilisation of ammonia (Raviv, 2010). Raviv further states that high temperatures not exceeding 65 degrees Celsius are sufficient to destroy weed seeds and disease pathogens while beneficial microbes will survive.

If temperatures exceed 65 degrees Celsius the compost pile is turned coupled with water application to correct temperatures and to maintain moisture content of 30 percent – 40 percent. This process is repeated until the compost matures at around 18 weeks and the temperature drops and becomes constant at around 30 degrees celsius. When the compost is mature samples are sent to ZZ2 laboratories for quality control. It is analysed for nutrient content, heavy metals and microbial populations. The photographs on Figure 17 how the laying of the raw materials, compost turning with a compost turner and the mature compost batch.

Nzanza (2010) and Noffke (2010) agree that the application of compost is key in building soil health and is considered to be the backbone of the *natuurboerdery* farming approach. They explain that compost provides nutrients required for plant growth and have replaced the use of inorganic pre-plant fertilisers[42] in *natuurboerdery*. They are also aware that it increases soil

[41] This refers to a mature compost preserved because of its best qualities for inoculating the new compost rows.

[42] This is normally referred to as basal fertilisers, they are applied just before or at planting.

organic matter which in turn has a bearing on many soil health properties like carbon content, CEC, pH, nutrient availability, microbial population for availing and recycling nutrients and also that the carbon content is linked to the sink capacity for carbon sequestration as stated by Abawi *et al.* (2007).

The compost is applied on the planting ridges and incorporated into the soil by a compost applicator. The three types of composts described in Table 5 are applied to specific soils and for specific reasons as follows:

Soil feeding compost: Applied to soils with a very low carbon and organic matter content.

Plant feeding compost: Applied to soils which have reached carbon content of three percent specifically for maintaining the carbon content and to provide plant nutrients.

Disease suppressive compost: Research is underway to determine its efficacy in suppressing soil borne diseases specifically *Verticilium wilt* and *Fusarium oxysporium.*

Compost quality assessment is done to meet farmer's needs of improving soil health and sustainability of farming. Therefore the quality tests measures key performance indicators for composts which are used to derive a compost quality score and measure the following:

- Functionality (the ability of compost to supply plant available nitrogen).
- Degree of decomposition (size fractioning)
- Nutrient content and availability (EC and pH)
- Phytotoxity (mono and dicotyledon seed germination)
- Human health (*E. coli)*
- Compost chemistry (analysis for available and total macro and micro elements: (N, P, K, Mg, Na, Ca, Cu, B, Mn and Zn)
- Heavy metals (Cd, Cr, Hg, As and Pb)

(Malherbe, 2010)

Figure 17: Compost batches at ZZ2 compost site a) laying raw material b) turning compost with a compost turner and c) mature compost batch

a)

b)

c)

ZZ2 produces a special type of manure which they call BH 50:50 from chicken and cattle manure (Miller, 2010). The two raw materials are mixed in equal proportions and left to cure for 12 weeks, to destroy weed seeds and pathogens. Temperatures and moisture content are monitored and maintained in the same way as for compost making. Manure is used in combination with compost as a preplant fertiliser to correct soils with low P and Ca levels. The other advantages of manure are similar to those of compost.

ii) Vermicompost

ZZ2 R & D has conducted research on vermicompost so that it can be incorporated in soil health and plant nutrition programmes on *natuurboerdery*. The trials indicate that vermicompost used in combination with compost offers opportunities to reduce the side dressing application of inorganic fertiliser by 50 percent while maintaining the same yields (Taurayi and Nzanza, 2010c). They also state that results show that vermicompost improves plant nutrition particularly sap NO^{-}_{3} and K^{+} and maintains pH at near 7 which is near optimum for all plant species.

Due to this milestone achievement vermicompost will be incorporated in *natuurboerdery* protocols as a component for preplant fertiliser applications in combination with manure and compost.

iii) Compost tea

ZZ2 produces its own compost tea from the compost mother heap. The brewing process uses 40kg compost from the compost mother heap, 1kg brown sugar, 1kg Seagrow, 1kg humate and 1 litre Afrikelp mixed in 1000 litres water. To avoid contamination of the tea the brewing area is kept clean and cleaned with soap. The water is first oxygenated by bubbling air through for 24 hours before adding the ingredients. When the ingredients are added aerobic tea is produced by continually bubbling air for 72 hours and the tea is used within 6 hours because it is perishable. The photograph in Figure 18 show the bubbles produced by compost tea due to the continuous bubbling of air during the production process. The tea is applied on a weekly basis at 50 or 100 litres per hectare through drip irrigation or as foliar spray in fields under production to improve soil microbial life, increase nutrient availability or for control of leaf or fruit diseases. For example foliar applications of compost tea have shown to be effective in replacing the use of copper oxychloride to prevent fungal infections in avocado production (Pieterse, 2010).

Figure 18: Production of compost tea at ZZ2 *natuurboerdery* centre

ZZ2 experience has indicated that if incorrect procedures are followed for compost tea production, substandard tea will be produced (Miller, 2010). This will act as a source or carrier for pathogens for human health and plant diseases. ZZ2 measures total coliforms of *E. coli* and SFI tests as described in Appendix O to determine compost tea quality (Malherbe, 2010).

iv) Effective microorganisms

The EM used at ZZ2 is obtained from Effective Microorganisms South Africa (EMROSA) in Midrand. It is the same technology as developed by Professor Teruo Higa at the University of the Ryukyu in Okinawa, Japan. EM contains photosynthetic bacteria, lactic acid bacteria and yeasts and other unknown beneficial microbes.

Figure 19: EM production at ZZ2 *natuurboerdery* centre

EM is used in its original state as stock EM, EM Verleng (25 litres molasses, 46 litres stock EM, and 50kg brown sugar in 1000 litres water) or as EM silica (250kg non toxic silica, 400 litres EM Verleng in 1000 litres water) fermented anaerobically for 24hours in sealed plastic tanks shown in Figure 19. EM is used to balance beneficial microorganisms in the agroecosystem and to improve soil health for sustainable crop production. A balanced microbial population in the soil improves nutrient availability critical for plant growth and to balance and cycle nutrients for sustainable production.

The EM is applied through drip irrigation to enrich the soil microbial population or as a foliar spray for control of leaf diseases. It is also used to extract active insecticidal ingredients of herbal plants in the production of FPEs used for plant protection to be discussed under the plant health section.

Although ZZ2 uses EM from a recognised South African supplier it has identified the need to verify the quality of stock and extended EM (EM verleng and EM silica) and related products

(FPEs) to protect its use from anomalies which can arise during production (Miller, 2010). The quality tests are based on ZZ2's long term usage and experience of EM and are done by microscopical evaluation of samples and quantification of the typical constituents of original EM (Malherbe, 2010).

vi) Biochar43

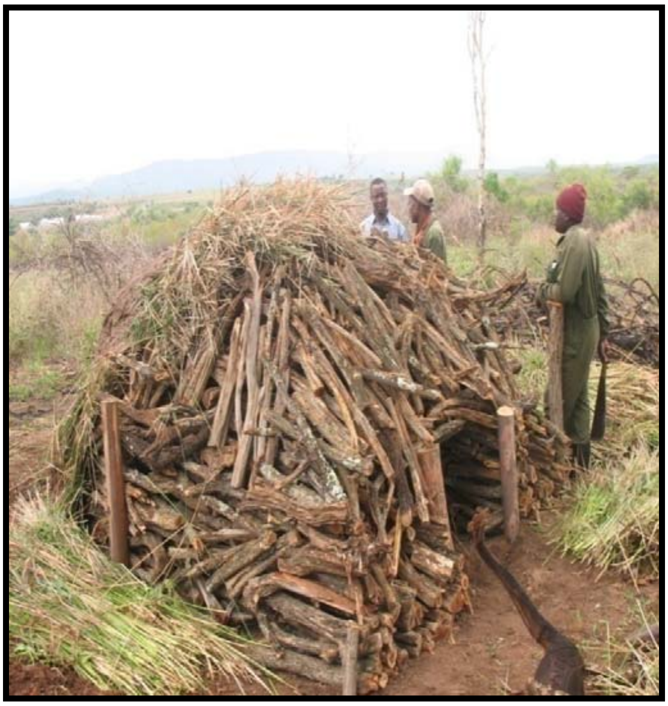
ZZ2 R & D have started to produce biochar from cleared sickle bush. It is made by burning cleared sickle bush biomass in kilns at very low temperatures and in the absence of oxygen. The photographs in Figure 20 show the invasive sickle bush and the biochar kiln before lighting. The biochar is first ground into fine granules of approximately 2mm in diameter and then broadcast into the fields by hand onto the planting stations. In its initial trials to investigate the potential to incorporate biochar into soil health building programmes of *natuurboerdery* there are indications that biochar has great potential to influence plant growth and root symbioses with mycorrhizal fungi (Taurayi and Nzanza, 2010d). Other trials elsewhere indicate that biochar additions can change soil physical and chemical properties which can lead to increased soil nutrient availability, concentration of nutrients in plant tissues and enhanced root colonisation by mycorrhizal fungi (Drew *et al.*, 2006). Biochar also increases soil carbon thus contributing to soil carbon sequestration and can also be used for rehabilitating degraded lands (Glaser and Woods, 2004).

[43] The charred by product of pyrolysis of plant biomass and contains many poly-aromatic (cyclic) hydrocarbons with oxygen and hydrogen functional groups. It is almost similar to charcoal but is used for the purposes of rehabilitating degraded soils.

Figure 20: Production of biochar at ZZ2 from sickle bush a) land invaded by sickle bush b) biochar kiln before lighting

a)

b)



vii) Cover cropping and fallowing

Once a field completes its production cycle under *natuurboerdery* it is either put under cover crops or is left fallow. After production, crop residues are baled for use in compost making, poles, twines and other production materials are also removed. The field is then ploughed to remove ridges and to bury remaining residues. This is then followed by discing to level the field and to create a good texture.

If the field is to be left under fallow it is left in that state to allow natural grass to grow as shown in Figure 21. If it is to be put under cover crop a specific crop, either sorghum or a legume like cowpea or bean plant, is planted to address a specific need like breaking disease or pest life cycles or to enrich the soil nitrogen levels (Noffke, 2010). He also further states that fallowing and cover cropping is important in the *natuurboerdery* farming system as it allows the integration of livestock with cropping systems and is a way to improve agrobiodiversity in space and time as shown in Figure 22.

Figure 21: Fallow field (natural grass)

Figure 22: Integration of livestock and cropping systems

Cover crops and fallow fields also provide biomass for making compost which enhances nutrient cycling. These cultivation systems are also used for soil health building as it allows improvement of soil structure and texture, drainage, organic matter content and carbon content when the biomass is ploughed down (Abawi *et al.*, 2007). According to Noffke (2010) it improves soil microbial life since no inorganic chemicals are used during these periods.

viii) Minimum tillage

Noffke (2010) and Nzanza (2010) agree that *natuurboerdery* recognises minimum tillage as the most sustainable method for soil preparation as it enhances soil health through:

- Improving soil structure and texture
- Increasing water penetration and soil water holding capacity
- Increasing organic matter content
- Improving soil microbial life and
- Protection of the soil from erosion

At ZZ2 avocado production uses 100 percent minimum tillage for land preparations where only the planting stations are tilled. The interow spaces maintain a grass cover which is only maintained by slashing as shown in Figure 23.

Figure 23: Permanent grass cover on minimum tillage in avocado production

Currently five percent of the total cropped area for tomato production is under minimum tillage. The incremental target for each farm is 18 percent per annum. Figure 24 shows a tomato field under minimum tillage at BHB farm in Mooketsi.

Figure 24: Tomatoes under minimum tillage

ix) Mulching

According to Nzanza (2010) *natuurboerdery* recognises the importance of mulches in improving several soil health properties as stated by (Abawi *et al.*, 2007):

- Provide plant nutrients and improve soil structure when they decompose
- Provide habitat for microorganisms thus increasing diversity
- Reduce runoff thus increasing water penetration
- Reduce soil surface temperatures which limits evaporation and maintains soil moisture, reducing the frequency of irrigation and saving water and energy

ZZ2 R & D is carrying trials to select the best type of mulch which will improve soil health and contribute to water and energy savings for avocado production. The three organic mulches under investigation are grass, raw chip and composted chip as indicated in the Figure 25 below.

Figure 25: Research on mulch types in avocado production

Section summary

Natuurboerdery uses the Cornell Soil Health approach which integrates biological, chemical and physical components as they affect crop and overall sustainability. The management approach is categorised into soil health monitoring, improvement and building. In monitoring pair side comparisons are done on different cover crop lands, artificial and natural lands where natural lands are used as reference points. This is important on providing information on decision making and taking corrective measures.

Soil health improvement and building aims for long term soil health status of lands. It is done in two ways: use of organic amendments, compost, manure, vermicompost, biochar, effective microorganisms and compost teas all produced on the farm using locally available and renewable resources and cropping systems which make use of fallowing, cover cropping, minimum tillage and mulching.

4.5.3 Plant health

This section will discuss plant health management under *natuurboerdery* which is split into two categories: plant protection and plant nutrition. The broad aim is to reduce the build up of pest and disease resistance by reducing the dependence on inorganic chemical pesticides through an integrated pest and disease management approach. Plant health is to be maintained through increasing microbial diversity, reducing the use of synthetic fertiliser by increasing on farm nutrient cycling and making use of measurements and analysis of plant nutrient components (soil, soil water and leaf sap analysis). The plant health management approach is a precursor to human health, food health and agroecosystem health.

Plant protection

This section will first discuss the goal of the plant protection programme. It is then followed by a discussion of the main strategies or techniques used for pest and disease management and these are pest and disease monitoring techniques, biological or natural control, FPEs and chemical control.

According to Noffke (2010) Prinsloo (2010) and Venter (2010) the goal for plant protection in *natuurboerdery* is to reduce the use of inorganic synthetic pesticides with the aim of reducing insect and disease resistance, health risk to spray operators, contamination of food and the environment. This is achieved by a pest and disease management approach which integrates biological, chemical and natural control and can be defined as integrated pest management (IPM), integrated disease management and integrated weed management. Prinsloo (2010) adds that the aim is to manage pest[44] populations rather than eradicate them and to do this in a way that has minimal impacts on the agroecosystem and the environment.

Pest and disease monitoring techniques

i) Scouting

Scouting for pests and disease is done on a daily basis by a team of trained scouts to monitor the pests and diseases on the crops and in the lands and to plan pesticide spray programmes accordingly. They also check nutrient balances of plants and microbe balance in the soil and

[44] The definition of pest is broad and is used to describe insects, diseases and weeds.

check quality of fruit. The scouting procedure involves counting of pests on pheromone and other traps, careful examination of individual plants and counting any harmful and beneficial insects and diseases. The information is then recorded on a scouting form which is translated to a summary form. This information is discussed at weekly meetings and is used for decision making to ensure plant health.

ii) Pheromones and traps

The use of traps is important in monitoring tomato pests in *natuurboerdery*. The traps used at ZZ2 contain sex pheromones or plant volatile lures that are males of specific female tomato pests of economic importance which are shown in Appendix I.

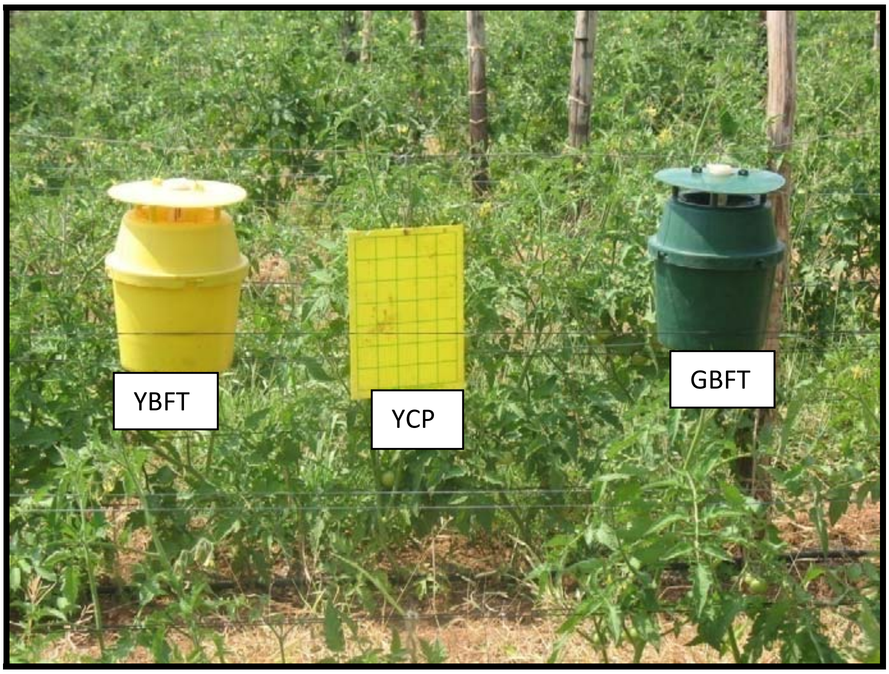
Sex pheromones are species specific and are used for potato tuber moth and the Yellow Bucket Funnel Trap (YBFT) used contains P.T.M. Pherolure (sex pheromone) to attract male moths on a weekly basis and baited with a volatile toxicant DDVP (2,2 Dichlorovinyl dimethyl phosphate) which kills all the potato tuber moth males entering these traps (Booysen *et al.,* 2010).

Booysen *et al.* (2010) state that plant volatiles used are not 100 percent species specific and normally attract a range of different *Lepidoptera* moth species. The Green Bucket Funnel Traps (GBFT) used contain the T.V. Pherolure consisting of five plant volatiles which attract mainly African bollworm and tomato semi-looper in a ratio of 70 percent female and 30 percent male moths and is baited with DDVP (2,2 Dichlorovinyl dimethyl phosphate) which kills all moths entering these traps (Booysen *et al.*, 2010).

For white flies, thrips, tomato leaf miner and aphids, the Yellow Card Plastic (YCP) is used. It is made from a special plastic which releases a very specific wavelength attracting the mentioned insects and has a standard grid design which enhances easy counting (Booysen *et al.,* 2010). An adhesive paint Flytac[45] is used in combination with the Yellow Card Plastic to ensure that insects making contact with the card get stuck until the cards are cleaned (Booysen *et al.,* 2010). Figure 26 is a photograph showing the placement of YBFT, YCP and GBFT in a tomato field and is described in detail in Appendix J.

[45] A solvent-free, non-toxic, non-flammable water-based paste which becomes sticky when dry.

Figure 26: Trapping devices for tomato pests from left YBFT, YCP and GBFT



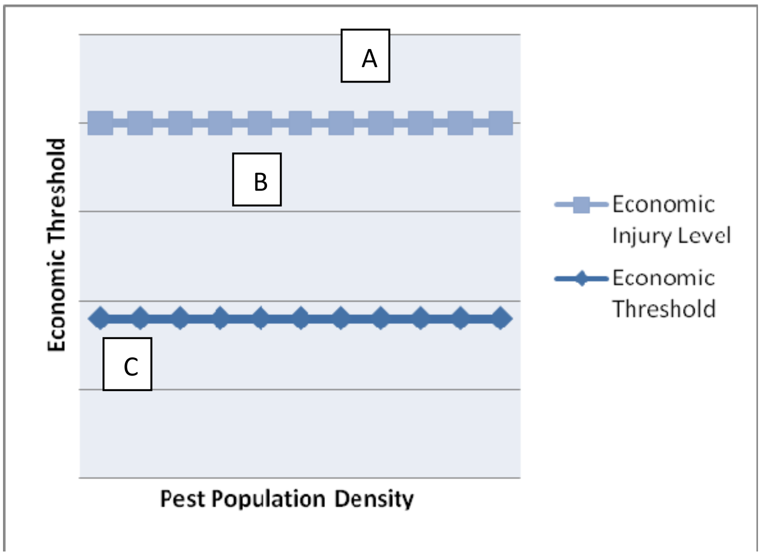
iii) Indicator plants

Indicator plants (egg plant) are planted at the beginning of tomato rows produced under *natuurboerdery* for the purposes of pest and disease monitoring. These plants are highly susceptible to insect pests and diseases and indicate the presence of pests and diseases first before they attack tomatoes in the field (Venter, 2010). In other words, they give a warning for the presence of diseases and pests which allows for an early control programme to be implemented.

iv) Use of threshold values

According to Venter pest and disease control is implemented if their intensity exceeds the economic injury levels (EIL) which involves a cost to benefit analysis of the control option.

Figure 27: Economic injury level and threshold



Source: Created by Author, 2010

Each pest has its own economic threshold to determine the need for control. Pest and disease control in *natuurboerdery* farming uses this concept of threshold values as indicated in Figure 27 above. At point A pest population exceeds the EIL. This means that the cost of pest damage is higher than the cost of control and warrants control measures to be implemented. Under such situations *natuurboerdery* uses the most effective control strategy to bring the pest population below EIL. At point B the pest population is below EIL but above the economic threshold (ET) which calls for initiation of control measures to prevent populations from exceeding EIL. At point C the pest population is below ET which is accepted and no control measures are implemented but monitoring continues.

v) Biological or natural control

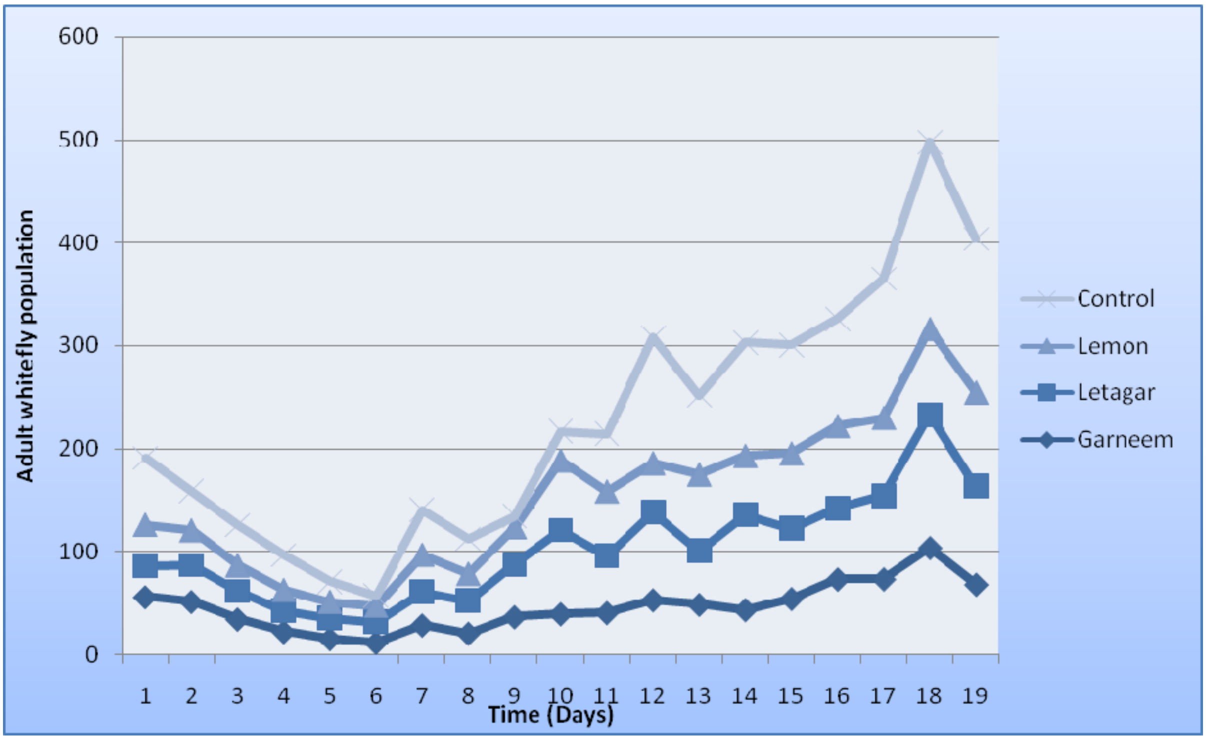
ZZ2 uses biological agents for pest and disease control. Insect pest predators are used to control insect pests: copidosoma for bollworm eggs, trichograma and encarsia wasp for whitefly eggs and digyphylus for aphids. Venter (2010) explains that the first introduction of a *trichograma* species (for whitefly control) imported from America failed to adapt to the hot environment of Mooketsi Valley and ZZ2 switched to an indigenous species which adapted easily and is proving to be effective. The encarsia wasp is very effective and efficient as it multiples fast and can move extensive distances searching for the whitefly eggs which it parasitises on.

In the production of cherry tomatoes at Gomoto farm in Mooketsi, ZZ2 uses an entirely biological or natural control programme based on organic products supplied by Dagutaku and its own FPEs. However if these fail to suppress pests to accepted levels, inorganic chemical control is effected. For example an aphid outbreak in April 2010 in one of the lands could not be controlled by this programme, and chemical control with dimethoate was brought in. When the pest populations were brought below ET, biological and natural control was reverted back to in order to rebuild on the microbial life which could have been destroyed by the inorganic chemical.

vi) Fermented plant extracts

According to Venter (2010) FPEs from herbal plants with insecticidal properties are used to reduce the overreliance on inorganic pesticides in *natuurboerdery*. The herbal plants are obtained from the ZZ2 herbal garden at BHB farm and lantana which is cleared from around the farms. The FPEs are produced at ZZ2 by anaerobic fermentation of whole or parts of the herbs mixed with EM and other additives (e.g. molasses, brown sugar and aloe vera) as indicated in the table of Appendix K. The addition of EM is used for the extraction of the active insecticide ingredients and to enrich the population of beneficial microorganisms (Noffke, 2010 and Nzanza, 2010). These FPEs are key to the *natuurboerdery* plant protection, for example EM lantana has been effective in controlling soil borne nematodes resulting in the elimination of inorganic nematicides. Also the neem plant, which is widely recognised for its insecticidal properties, has shown effectiveness against whiteflies and keeping the populations below the ZZ2 accepted levels (Taurayi and Nzanza, 2010e). For example the results of a trial to investigate the effect of FPEs on whitefly population in a tomato field (Figure 28) show that garneem kept the adult whitefly below 50 up to day 15 which is within the threshold level and ZZ2 standards (Taurayi and Nzanza, 2010e).

Figure 28: The effect of EM neem on whitefly adults' populations

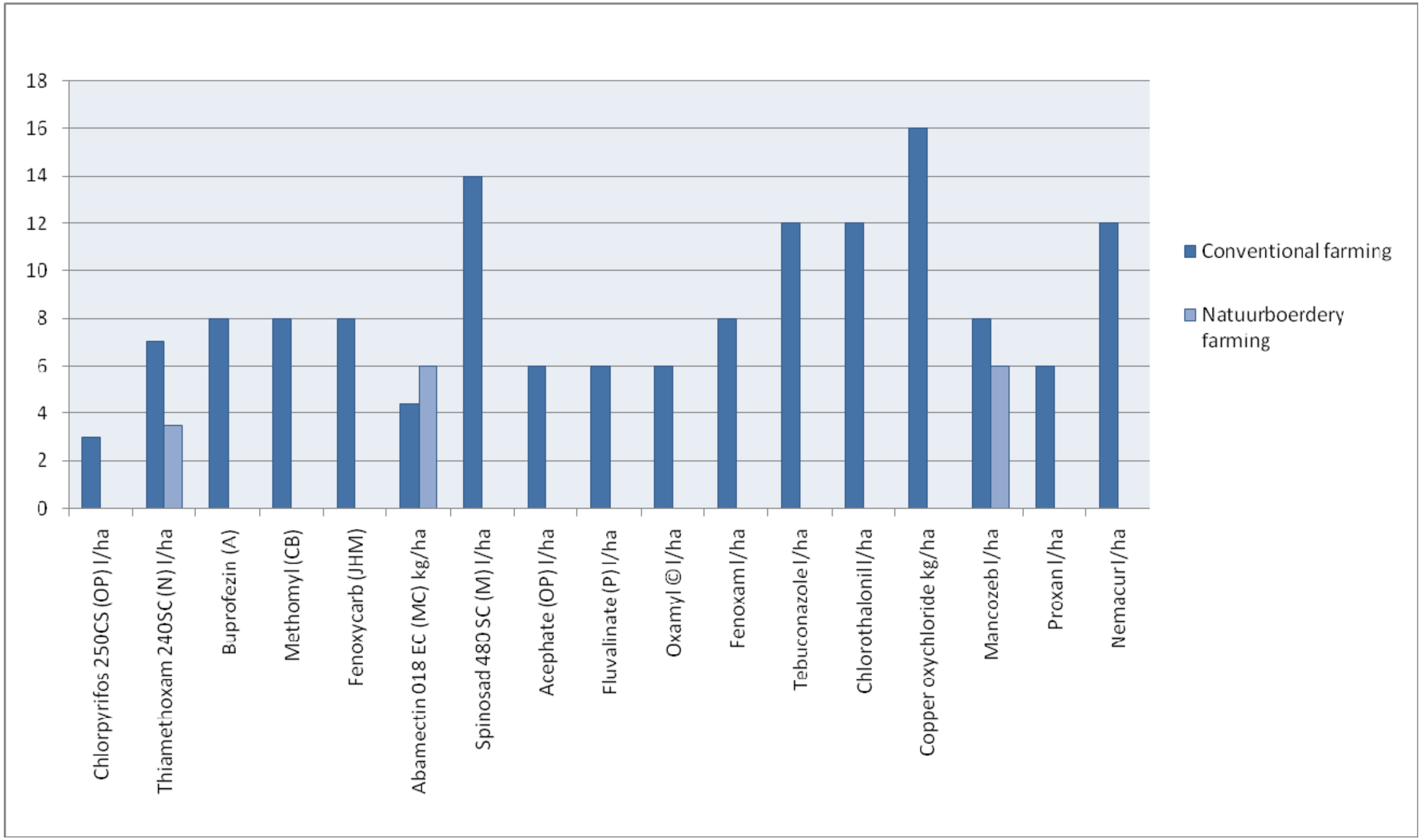


Source: Taurayi and Nzanza, unpublished

vii) Chemical control

Venter (2010) and Noffke (2010) confirm that the plant protection control programme for *natuurboerdery* against pest and diseases does not exclude the use of inorganic pesticides. They clarify that this option is used as a last resort if all other control options fail. However the rule in *natuurboerdery* is to start with the least toxic chemical pesticide until control is achieved and each farm must show evidence of year-on-year reduction of the use of inorganic pesticides. It is also interesting to note that there has been a significant reduction in the use of chemical pesticides (in terms of volumes and numbers) for the control of pests and diseases. This is evident from archive land records at BHB farm in Mooketsi for Kariba land, they indicate that a total of 17 inorganic pesticides were used during conventional farming while only three were used under *natuurboerdery* for a single tomato growing season as shown in Figure 29. Please note that this graph also clearly indicates that a significantly lower total volume was applied under *natuurboerdery*.

Figure 29: Comparison of inorganic pesticide use in *natuurboerdery* and conventional farming



Source: Created from land records data for Kariba land at BHB farm in Mooketsi

Plant nutrition

This section will describe and explain the plant nutrition programme for *natuurboerdery*, by first outlining a brief overview of the aim and practices involved. This is then followed by a description of the techniques used for monitoring plant nutrition and lastly how balancing mineral nutrients is achieved.

According to Venter (2010) plant nutrition in *natuurboerdery* aims to balance mineral nutrients in the soil for plant growth while enhancing soil microbial life. It is important to note that the nutrition programme uses both organic and inorganic fertilisers. This is through pre-plant or basal fertiliser applications[46] which are purely based on organic amendments (compost, manure, vermicompost, EM and compost teas) as discussed in Section 4.5.2 (under improving and building soil health) and side dressing and foliar sprays[47] using inorganic fertlisers and natural or organic products.

Venter (2010) points out that *natuurboerdery* recognises the importance of mineral ions and acidity levels for optimum plant growth and soil microbial life. He further emphasises that the application of side dressing fertilisers or foliar sprays to balance soil and plant nutrients during plant growth is based on weekly soil water and leaf sap analysis as discussed in the following section. These analyses are done at the on-farm laboratories (as indicated in Figure 28) to support decision making on the quantity, type and timing of side dressing fertilisers and foliar applications (Venter, 2010). The components of soil water and sap analysis conducted are discussed in the following section.

Techniques for monitoring plant nutrition

Soil water analysis

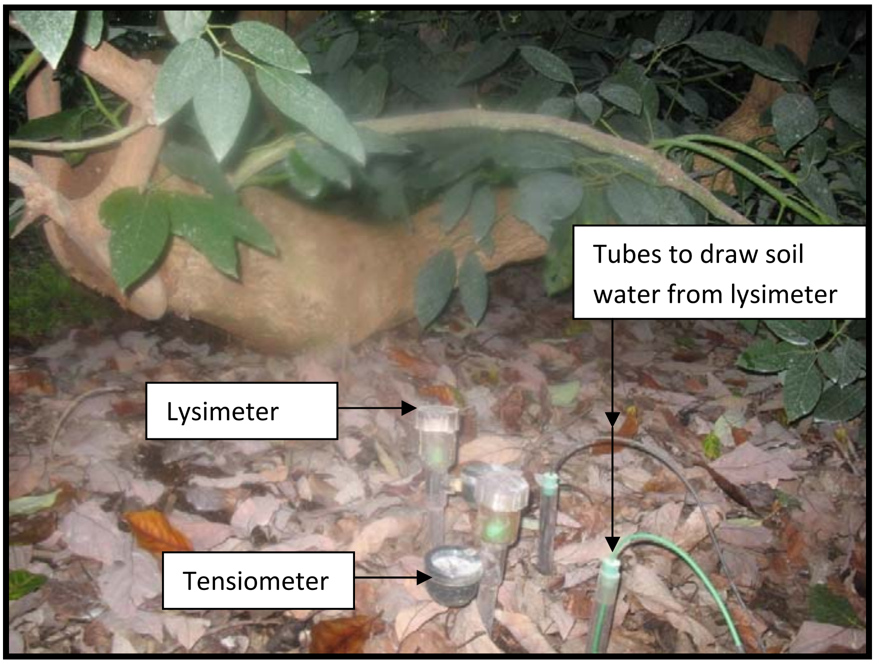
To collect samples for soil water analysis a pair of lysimeters are inserted into the soil alongside tensiometers as shown in Figure 30, to measure water tension at different depths in a way that mimics the plant root system. Water is drawn from the lysimeter using a syringe and is used to

[46] Applied just before planting or at planting.

[47] Applied during the crop growth period

measure soil water pH and electrical conductivity (EC) using cardy meters (compact pH and EC meter as shown in Figure 31).

Figure 30: Lysimeter and tensiometer



Soil water pH and EC

Optimum soil pH and EC are crucial for nutrient availability, plant growth and microbial life. According to Venter (2010) extreme pH ranges result in reduced microbial life and locking up of nutrients while high EC or salty conditions dehydrate soil microbes and low EC immobilise ions for plant growth and soil microbial life. He gives the following guidelines for pH and EC:

- Optimum soil water pH should be around 6.4 and is achieved by providing the required minerals in their right concentrations.
- Optimum EC[48] range must be between 2 – 12 S/m[49] i.e. EC must not fall below 2 S/m during the growth period and EC above 12 S/m as it inhibits growth.
- EC must be raised to 6 S/m during the reproductive stage (flowering and fruiting).

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[48] EC is adjusted by varying the concentration of inorganic fertiliser and water mixture to be applied through drip irrigation

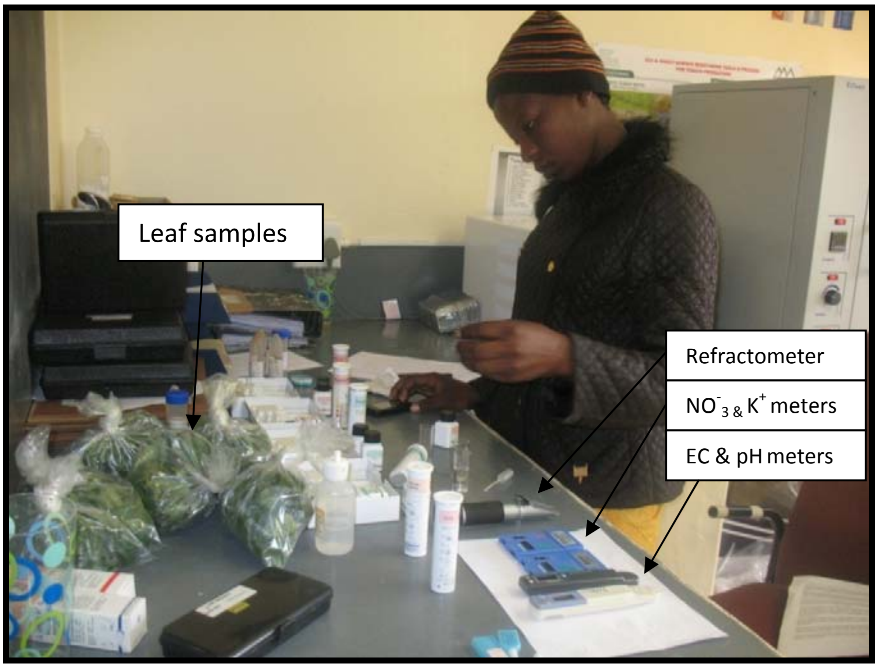
[49] Unit for measuring EC is Siemens per metre

Tensiometers are used to measure the tension by which the soil holds on to its water. If the soil is very wet suction is low and if it is very dry suction will be high and this information is used for irrigation scheduling (Venter, 2010).

Leaf sap analysis

The procedure of leaf sap analysis involves collection of leaf samples from the youngest and fully developed leaves which are crushed to the point of juice extraction using a garlic sap extractor. The sap is used to analyse different nutrient components using different tools shown in Figure 31. The information aids decision making for plant nutrient management and their importance is detailed below.

Figure 31: Sap analysis at *natuurboerdery* centre



i) Brix levels

The refractometer is used to measure dissolved solids referred to as the brix levels which reflects sugar levels in the plant, how well the plant is photosynthesising, mineral nutrient levels in the plant and plant health. According to Venter (2010) the goal is to achieve brix levels of 12 and above although each plant has its own optimum. He further explains the importance of brix levels as follows:

- High brix levels have high sugar and nutrient content levels and produce a healthy, high-yielding plant with high quality produce. This means extended shelf life, better taste and nutrient density with a lower nitrate and water content
- High brix levels confer insect and disease tolerance
- Crops with high brix levels have a lower freezing point associated with frost tolerance
- Brix levels also indicate soil fertility since it is influenced by phosphate and calcium levels. Soils producing high brix plants will also have less weed pressure, as broad leaf weeds and sour grasses grow prolifically in soils lacking calcium and phosphate

Factors influencing brix levels

Noffke (2010) and Venter (2010) mention that when interpreting brix levels it is important to always bear in mind that it is affected by certain climatic conditions as follows:

- Storms – results in lower brix levels as plants translocate sugars to the roots when anticipating periods of drought.
- Droughts – high brix levels as the water content is low and the plant juices are concentrated.
- Overcast or cloudy weather – brix levels drop due to lower rates of photosynthesis.
- Variation of brix levels during the crop cycle from the top to the bottom of the plant is a result of soil nutrient imbalance especially phosphate to potassium ratio.
- Brix levels vary during the day because plants translocate sugars to the roots at night and early morning and return them to the leaves during the day.

ii) Sap EC

The plant sap EC meter is used to indicate the level of ion uptake by the plant. According to Khan (2009) and Venter (2010) low EC results in nutrient unavailability while high EC results in nutrient elements not being complexed correctly and can be a result of excess nitrate ions. They give an ideal range for plant sap EC of between 2 – 12S/m.

iii) Sap pH

Plant sap pH is measured with a pH meter, Khan (2009) and Venter (2010) mention that its measurement helps to determine:

- Breakdown of carbohydrates by enzymes for plant growth and health
- Risk potential for insect and disease attack (fungal, viral and bacterial)
- Nutrient imbalance in the plant
- Fruit quality and shelf life

They also indicate that:

- The optimum plant sap pH for all species is 6.4
- A pH above the optimum is mainly a result of an imbalance of the anions of nitrogen, phosphorous and sulphur
- At pH 8 the probability of insect attack is high
- Low pH is a result of imbalances of calcium, magnesium, potassium and sodium cations and is associated with a high likelihood of fungal attack

According to Khan (2009) a single component of plant sap cannot give an accurate indication of plant nutrient status. She emphasises the need for combined interpretation of plant sap brix levels, pH and EC and gives some guidelines as described in Table 6.

Table 6: Interpretation of combined plant sap brix levels, pH and EC

Brix level	EC	pH	Interpretation
High	Optimum	Optimum	Good, balanced nutrient levels and microbial life.
Low	Low	Low	Missing ions, probably due to lack of microbial life. Carrier elements (N and P) may be lacking and also Na and K. Soil structure indicates the ratio of Ca to Mg.
Low	Low	High	Lack of carrier (N and P) elements possibly due to reduced microbial activity. Also phosphates, acetates and organic acids may be missing.
Low	High	Low	Incomplete complexing of ions probably due to reduced microbial activity or excess of acid producing elements sulphur or other metals. This also indicates lack of Ca, Mg, K and Na.
Low	High	High	Incomplete complexing of ions probably due to lack of microbial activity. Nitrate ions may be in excess levels while phosphates, sulphates and magnesium may be deficient.

Source: Khan, 2009.

iv) Nitrate ions (NO3-)

The plant sap nitrogen meter is used to measure nitrate ions which indicates plant usable nitrogen. Khan (2010), Noffke (2010) and Venter (2010) emphasise that plant nitrogen must be measured to ensure that it is availed to the plant in the right quantities at the right time for optimum yields because excess or deficient nitrogen during the crop cycle limits crop yield potential.

v) Potassium ions (K^+)

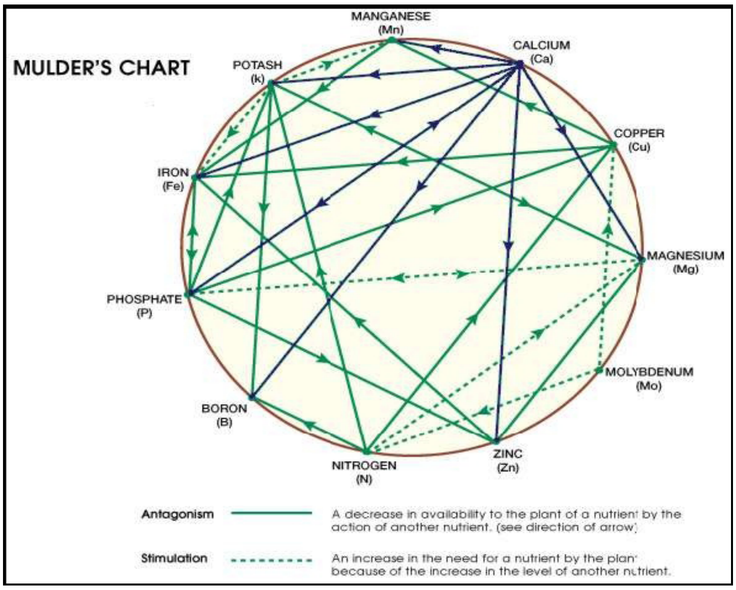
The plant sap potassium meter is used to measure potassium ions. Khan (2009), Noffke (2010) and Venter (2010) are aware that potassium is a precursor for the reproductive growth stage (flowering and fruiting).

Soil water and plant sap analysis is used to monitor plant health and indicate nutrient status (excess or deficient) for corrective action to be taken. This allows the agronomist to design a nutrient management programme which balances plant nutrients by knowing the exact amount, type and method of nutrient application in a cost effective and sustainable way. This is supported by Venter (2010), who says that this system reduced the application of synthetic fertiliser and resulted in cost savings of up to R6 000 per hectare in 2010 for tomato production. He also says it results in improved food health (shelf life taste and reduced contamination). The following section will describe the approach to balancing mineral nutrients based on the results of soil water and plant sap analysis.

Balancing mineral nutrients

The holistic approach to plant nutrient management discussed above allows nutrient balancing with a positive effect on soil microbial life. The balancing of mineral nutrients is based on measurements of cations and anions of soil water and leaf sap and follow the Mulder's chart as shown in Figure 32 (Venter, 2010). This balance is achieved through foliar applications and side dressing of both inorganic and organic fertilisers combined with natural products to be discussed in the next sections. According to Venter (2010) the Mulder's chart shows the relationship and effects of the levels of plant nutrients on one another which is related to their function in plant health.

Figure 32: Mulder's chart



Source: Khan, 2009

i) Foliar sprays

Noffke (2010) emphasises that foliar feeding is not used to replace soil health management but as a means to bypass problems in the soil such as mineral lock ups in the soil root zone, leaching of nutrients in light soils or nutrient competition. Venter (2010) adds that they are also applied as a means to:

- Boost yields
- Build brix levels which are monitored by the use of a refractometer
- Initiate reproductive growth after vegetative growth
- Correct major nutrient deficiencies
- Remove plant stress due to moisture stress, frost, water logging, pest and disease attack.

Noffke (2010) and Venter (2010) indicate that when applying foliar feeding the following factors are adhered to in order to achieve maximum efficiency:

- Smaller droplets are preferred and achieved by using a boom spray with misting or fogging nozzles which produce cone shaped spray patterns and results in less amount of actual feed used
- Complete plant cover is aimed without allowing the spray to puddle from the leaves

- The pH of the liquid solution must be between 6 and 7 unless other specific responses are targeted
- The EC for the liquid solution must be between 12 – 20S/m on the conductivity meter, less than 12 results in no response and greater than 20 S/m can burn the plant foliage.
- The operations are done during the night or early morning periods when relative humidity is high, stomata openings are open, temperatures are low to avoid evaporation of the fine solution sprays. No sprays are carried out when there is a likelihood of rain or heavy dews to avoid washing off of sprays

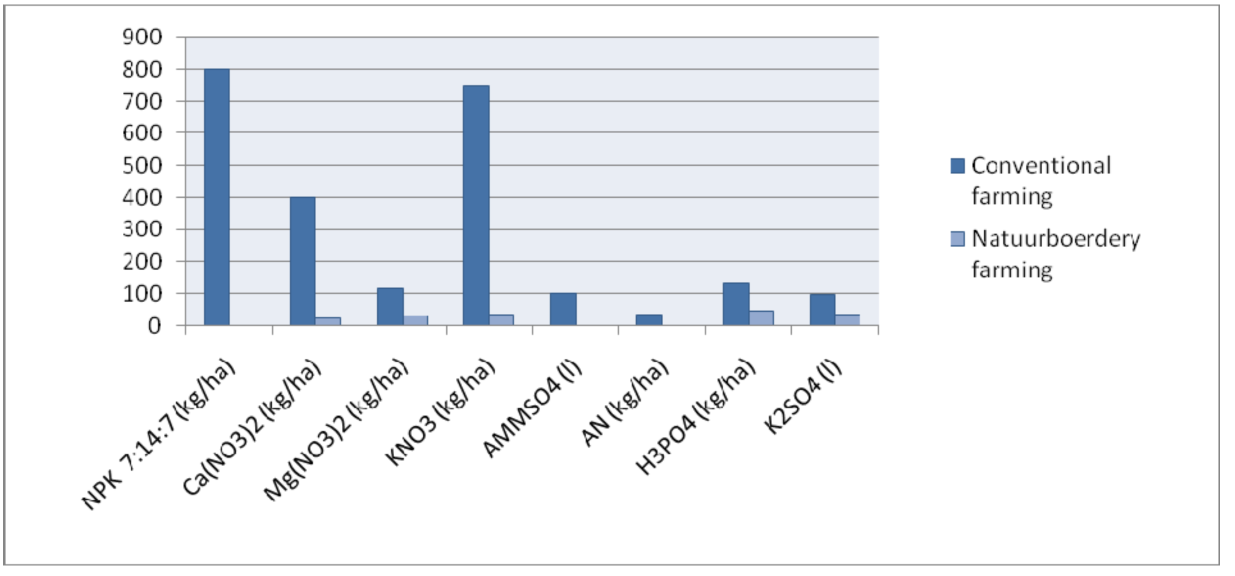
ii) Side dressing

Side dressing of inorganic fertilisers and organic or natural products is not fixed but dependent on plant needs and nutrient deficiencies revealed by soil water and leaf sap analysis during the crop growth cycle (Venter, 2010). Side dressing is done for the management of sodium and magnesium elements in the case of heavy soils or to avail nutrients in light soils (Venter, 2010). It is also done to obtain a quick response like increasing crop vigour, raising brix levels and to increase yield quantity and quality.

To increase brix levels phosphate and calcium fertilisers combined with Afrikelp are used; to increase flowering and fruit set potassium fertilisers are used and to increase growth and plant health nitrogenous and phosphate fertilisers are used. Humic and fluvic acids are included in all fertigation programmes with the aim of obtaining luxury levels of Ca, Mg, P and B in all leaf tests (Venter, 2010).

It is important to note that the *natuurboerdery* farming approach has resulted in less inorganic fertilisers as compared to the period of conventional farming at ZZ2. This is supported by comparison in Figure 33 which shows that during conventional farming a total of eight different inorganic fertilisers amounting to 2230.07 kilograms and 196.55 litres was applied, while *natuurboerdery* uses 135 kilograms and 35 litres per hectare in a single tomato growing season at Ammondale farm, Krai land in Polokwane. This is also consistent with the comparison of plant nutrition programme in Appendix M, for conventional farming period and *natuurboerdery* farming at Vreedsam farm, Chembere land in Mooketsi. It indicates that *natuurboerdery* uses more natural or organic products than inorganic fertilisers.

Figure 33: Comparison of inorganic fertiliser use in *natuurboerdery* and conventional farming for tomatoes



Source: Created form ZZ2 Land Records 1995-2010. Ammondale farm, Krai land

Section summary

Natuurboerdery plant health consists of plant nutrition and protection and aims to reduce the use of inorganic fertilisers and pesticides while maintaining plant health.

Plant protection uses a holistic approach which involves pest and disease monitoring and management. Monitoring involves scouting, use of indicator plants and pest trapping devices. *Natuurboerdery* manages pests and diseases rather than control which is dominant in conventional systems. This involves the use of threshold levels to determine control. The control methods involves biological using pest predators, natural using FPEs, compost teas, organic pesticides and disease suppressive compost for soil borne disease pathogens and inorganic chemical control which starts with the least toxic chemical when necessary.

Decisions on plant nutrient management are based on soil, soil water and leaf sap analysis for mineral ions, pH, EC and brix levels. It is based on plant needs and nutrient balancing through the application of preplant organic amendments as described under soil health building and improvement, side dressing, inorganic fertilisers application and foliar application of natural and organic amendments.

4.5.4 Food health

According to Prinsloo (2010) *natuurboerdery* promotes food health by producing healthy, quality and nutrient dense food with extended shelf life and zero chemical residues. This section will discuss the strategies used to promote food health.

High nutritional value and long shelf life

Prinsloo (2010) explains that, to satisfy customer needs and demands, ZZ2 aims to produce nutrient dense fruit with extended shelf life. The strategies and techniques for soil health and plant health discussed before are a way of achieving this. In a survey to compare the quality of tomatoes produced under different farming practices, Taurayi and Nzanza (2010f) found that tomatoes produced under *natuurboerdery* farming practice have a longer shelf life of 21 days compared to 7 days for those produced under conventional systems. The motto at ZZ2 is "healthy soils our passion and food health our promise" (ZZ2, 2010). A phytochemical food health model has been developed to check on the quality and nutritious content of tomato fruits as indicated in Table 7.

Table 7: Food health model

Criteria	Food health Indicator	Process or Function
Physical	Colour Firmness Flavour Texture Aroma	Colour, size and appearance to satisfy customer needs and choice
Phytochemical	Lycopene Beta carotene Ascorbic acid Vitamin E Total phenolics Flavonoids	Powerful anti-oxidant Precursor of Vitamin A Antioxidant activity Antioxidant activity Antioxidant activity Antioxidant activity
Mineral	Brix Calcium	Shelf life

Source: Nzanza, 2009

Zero chemical residues and contamination

Food produced under *natuurboerdery* must have zero chemical residues, this is achieved by a soft approach to plant protection which favours the use of organic or natural products and preferential use of least toxic pesticides (Nzanza, 2009). If a chemical pesticide is used during harvesting the waiting window period is strictly observed (Taurayi *et al.*, unpublished). As a quality control measure samples are taken at random and on an unnotified basis at harvesting farms by the Marketing and R & D departments and sent for analysis of chemical residues. Managerial staff of farms found not to be obeying the rules are charged for an act of misconduct.

According to Nzanza (2010) some filler materials for fertilisers may contain heavy metals like copper, mercury, cadium, lead, and arsenic which may contaminate produce. To avoid contamination from fertilisers, suppliers must have recent results for the chemical analysis of the fertilisers or foliar sprays before the product is accepted for use on ZZ2 farms (Taurayi *et al.*, unpublished).

According to Miller (2010) and Noffke (2010) compost and compost teas can be a source or carrier of food pathogens. This is supported by Malherbe (2010) who confirms that ZZ2 quality control checks (compost batches and compost teas) for food pathogens particularly *Salmonella, Campylobacter, Escherichia coli, Cryptosporidium, Toxoplasma, Cyclospora* and the result must be zero at verotoxin level. Also in the fields there are ablution facilities with running water and workers are taught to wash their hands after using the facilities to avoid contaminating produce with their hands.

Section summary

The *natuurboerdery* farming approach aims to produce high quality and nutritious food with zero chemical residues and a longer shelf life. This is achieved by the production practices of soil health and plant health management. Also the products or inputs and the output or produce go under analysis to determine chemical residues (heavy metals) and human pathogens before they are used or sent for the market respectively. The food health model is used to assess quality and nutrient status.

4.5.5 Human health

According to Noffke (2010) and Prinsloo (2010) *natuurboerdery* recognises the importance of human health and its contribution to overall farm productivity and sustainability. They also state that the activities of *natuurboerdery* must promote human health by prioritising workers' health, creating a healthy environment and producing healthy food as discussed below.

Workers' and environmental health

Noffke (2010) supports that the soft approach to disease and pest management uses organic and least toxic chemicals which protects the health of the workers handling the products and those who do the spray operations. At ZZ2 workers' health is also ensured by providing safe accommodation and sanitation facilities and each compound has a caretaker who does the ground maintenance. Each farm is serviced by a qualified state-registered nurse and medical doctor who visit farms every Friday and women go for reproductive health sessions once every month.

The use of these products also contribute to environmental stability as most of them are biodegradable thus contributing to environmental health. This also protects the health of the community due to absence of water pollution from leaching of pesticides and nitrates from fertilisers.

Healthy food

The food health model described Table 6 is used as a guiding tool to check on the quality, nutrient status, chemical residues and contamination levels as a means to promote promotes human health.

Section summary

Human health is promoted by producing health food and creating a healthy environment for worker's and the surrounding community. This is achieved by the other four health aspects and their associated practises.

4.6 Changes and benefits due to adoption of natuurboerdery farming

4.6.1 Introduction

This section gives an overview of changes which have occurred as a result of converting from conventional agriculture to the *natuurboerdery* farming approach. The changes are grouped in four main categories starting with strategic and technical changes, ecological and environmental changes, social changes and lastly economic changes.

4.6.2 Strategic and technical changes

This section gives a brief description of the changes in the production practices and the introduction of the *natuurboerdery* checklist and compliance criteria.

Production practices

Since the conversion to *natuurboerdery,* ZZ2 has adopted a number of products and techniques which were not used during the period of conventional farming. These are used to support the key practices of *natuurboerdery* as discussed earlier. In brief this includes the use and production of organic soil amendments (compost, manure, compost tea, FPEs, EM products, vermicompost and biochar), cover cropping, fallowing and minimum tillage, soil water and leaf sap analysis, water use efficiency and management of agroecosystems and the use of a food health model and indicators as described under the practices of *natuurboerdery*.

Natuurboerdery checklist and compliance criteria

The conversion to *natuurboerdery* helped all ZZ2 farms to attain Global GAP[50] accreditation (van Zyl, 2010). In addition all farms supplying their products to Woolworths undergo Woolworths' Farming for the Future (WFF) assessment. ZZ2 has introduced the *natuurboerdery* checklist and compliance criteria to monitor, improve and assess the implementation of *natuurboerdery* practices on its farms. This also enhances its farms' chances of retaining their GGAP accreditation and to qualify to supply Woolworths. The checklist is sort of an internal audit and includes all components of WFF and GGAP and adds on other *natuurboerdery* practices. The components of the checklist are categorised into seven major sections and subsections with various compliance criteria and standards as shown in Appendix H.

[50] Global Good Agricultural Practice

4.6.3 Ecological and environmental changes

This section will describe and explain ecological and environmental changes which may have resulted from the conversion to *natuurboerdery* farming approach and this includes increases in soil carbon and organic matter content, reduction of weed species, clearing of alien species and increases in water availability and quality.

Increase in soil carbon and organic matter content

Soil carbon and organic matter content has significantly increased across ZZ2 farms as shown in Table 8. Soil carbon started at an average low content of 0.3 to 0.8 percent and has increased to approximately 1.5 percent on some of the tomato lands and 7 percent[51] on avocado lands. This represents an increase of 80 percent to 85 percent respectively. According to Noffke (2010) this is mainly attributed to the use of organic soil amendments which include compost, manure, EM and compost teas and cropping systems of fallowing and cover crops. He also cites that the target for *natuurboerdery* is to attain 3 to 5 percent carbon content on all cultivated lands. The increase in soil carbon signifies improvement in soil health as it is directly linked to soil organic matter content and influences other important soil properties like CEC and pH which all influence nutrient availability for plant growth (Abawi *et al.*, 2007).

Table 8: Changes in soil carbon content

Farm/land name	**Carbon Content (percentage)**		
	1999	**2005**	**2010**
Esme 4/Mopani	0.3	0.7	1.5
Vreedsam/Roma	0.1	0.58	1.3
Morgenson/Politsi	0.8	4.5	7

Source: ZZ2 Land records at Esme 4, Vreedsam and Morgenson

Reduction in weed species

ZZ2 lands have experienced a significant reduction of weed species and a marked return of quality natural grass common in natural ecosystems (Noffke, 2010). According to Noffke this

[51] This figure might appear high because soil samples are taken under the crop canopy area and the trees continuously drop their leaves which increase soil carbon content as the leaves decay.

was due to normalisation of soil microbial life and activity, in this case a change from bacterial-dominated soil to a soil with balanced fungal: bacterial ratio which suppresses growth and development of weed species. This in turn has two benefits for the *natuurboerdery* farming system: the grass provides biomass for the production of composts thereby enhancing nutrient recycling and it allows the integration of livestock with cropping systems when it is used for animal grazing when the land is in fallow.

Clearing of alien species

The clearing of alien species has provided mutually beneficial changes for ecosystems, the *natuurboerdery* farming system and the community:

- ZZ2 is engaged in the clearing of invasive sickle bush on its conservancies and uses it as biomass for the production of biochar and firewood for the local community. This is allowing the regrowth of natural grazing grass for wildlife
- The clearing of alien species (blue gum and black wattle) around water catchment areas has resulted in the return of natural springs which had dried up and now have all year round water flow and also increased available surface and underground water (Noffke, 2010)
- The invasive noxious weed *Lantana camara* is being cleared from around the farms and is used for the production of EM lantana which is used for controlling soil nematodes resulting in the elimination of nematicides

Increased water availability and quality

According to Noffke (2010) and Prinsloo (2010) the adoption of techniques which ensure conservation and water use efficiency has resulted in increased available surface and ground water for irrigation and domestic use by 30 percent. Irrigation scheduling is now strictly adhered to and is enhanced by the use of scientific calculations and equipment like digitised weather stations, use of irrigation profile holes, tensiometers and moisture probe meters on all farms and lands under production. Noffke (2010) points out that the reduction in the use of chemical pesticides and fertilisers also results in reduced pollution[52] of water bodies and serving aquatic life.

4.6.4 Social changes

This section will discuss the social programmes introduced (community outreach programme, *natuurboerdery* learning centre and agriculture scholarship) by ZZ2 when it adopted *natuurboerdery* farming and also how *natuurboerdery* affects the quality of life for its workers, community and customers or consumers.

Community outreach programmes

To ensure accessibility of information on sustainable agriculture practices ZZ2 is involved in an outreach programme for small scale farmers and schools by providing technical and extension support through its agronomists and in some situations providing organic inputs like compost, FPEs and compost tea. A good example is Stephen Mohale, a small scale farmer with about 300 hectares, and former farm supervisor on one of the farms now owned by ZZ2. He quit his job to venture into small scale farming with the use of chemicals and after an appreciation of the *natuurboerdery* farming approach he approached ZZ2 for advice (Mohale, 2010). Now ZZ2 provides agronomic advice to him through its agronomists and also provided a graduate trainee to help him in farm management three days a week and assist with tillage and irrigation equipment, compost, FPEs and other organic inputs.

ZZ2 has also initiated an extensive programme for building soil health for horticultural crops and food security for communities in Limpopo province. The focus is on small scale and communal farmers, currently 50 farmers and 10 trainers of trainers. This programme is being run in conjunction with the Department of Agriculture, University of Limpopo and Cornell University from America. The programme involves provision of initial inputs, technical support and capacity building.

[52] This is as a result of reduced leaching of nitrates which cause euthrophication and also leaching of chemical toxins.

Another programme to benefit the community is the production of biochar. Communities will be trained to make their own small plants to make biochar using biomass from cleared sickle bush which is a problematic invasive species in the area. This will provide them with energy for cooking and building soil carbon in agricultural lands, which is a way of sequestrating carbon thus contributing to mitigation of CO_2 emissions.

Learning centre

The *natuurboerdery* centre has evolved to be a learning centre for sustainable agriculture initiatives. The *natuurboerdery* farming approach has attracted interest from many educational institutions and farmers locally and internationally. Between April and July 2010 farmers from Egypt and Zimbabwe visited the *natuurboerdery* centre to learn about the techniques of *natuurboerdery*. The Egyptian farmers were interested in the strategies used by ZZ2 to reduce the use of synthetic pesticides and fertilisers while the Zimbabweans were interested mainly in the production of compost, compost tea and FPEs. Local farmers with their agricultural extension officers also visit the *natuurboerdery* centre to learn the techniques of *natuurboerdery* after appreciating its performance and sustainability. Students from local universities majoring in agricultural and environmental studies come to the centre to get a practical feel of techniques and management of a sustainable agricultural system. ZZ2 staff is more than willing to share their knowledge and experience of *natuurboerdery* to anyone to allow the diffusion of *natuurboerdery*.

Agriculture scholarship programme

To ensure continuity of sustainable agriculture practices (van Zyl, 2010), ZZ2 is offering scholarships for local youth to train in agriculture at local institutions and receive training in *natuurboerdery* at ZZ2 as interns during and after college. The students are identified from previously disadvantaged communities and are expected to return to their communities after training.

Improving quality of life

According to Prinsloo (2010) and van Zyl (2010) ZZ2 has moved to be a more social or people-driven entity than profit-oriented organisation and this has contributed to social changes and beneficial programmes to the community and workers. van Zyl emphasis that they have also noticed that ZZ2 can not achieve overall sustainability if they do not fulfil their social corporate responsibility.

The elimination of highly toxic chemicals is a positive move towards a healthier environment for workers, community and the consumers. The target production system has resulted in increased productivity and increased wages for workers because workers are paid according to how they work. According to one general worker (Anonymous, 2010) this targeted production system motivates the workers to work to the best of their abilities so as to earn more. Workers are also happy with the bonus they get if the farm they work for attains set targets. They also appreciate the social services which they receive at a subsided cost and this include the provision of medical care by a state-registered nurse at every farm and weekly visits by a medical doctor, transport is offered for free around all farms and to their surrounding rural homes at month end.

The general worker (Anonymous, 2010) cited that some houses for general workers need attention and is also against the system of hostels where they share one big room, as this affects privacy of individuals.

4.6.5 Economic and production changes

This section will first look at the changes in production costs by comparing the input costs[53] for plant protection and plant nutrition in *natuurboerdery* and conventional farming. This is then followed by an analysis of the yield trends and lastly by the changes in equipment and energy utilisation.

Production costs

Noffke (2010); van Zyl (2010) and Venter (2010) recognise that there has been a marked improvement in production costs due to the integrated plant protection and plant nutrient management programmes as shown in Appendix L and M respectively. Tables 9 and 10 shows that *natuurboerdery* uses less inorganic pesticides and fertilisers, more organic pesticides and fertilisers than conventional farming. The tables also show that there has been 50 percent and 40 percent cost savings on plant protection (pesticides) and plant nutrition (fertilisers) respectively

[53] All the input costs (fertilisers and pesticides) in tables have been adjusted to 2010 market values.

in *natuurboerdery* as compared to conventional farming. The decrease in the costs may be a result of the use of more organic inputs which are produced on-farm using locally available and renewable resources instead of externally purchased inputs. This is supported by Gliessman (2007) who states that the greatest financial challenges faced by farmers is mostly a result of the use of externally purchased inorganic fertilisers and pesticides whose prices are ever rising.

Table 9: Comparison of quantities and costs of pesticide use in *natuurboerdery* versus conventional farming (tomato production)

Farming system/Pesticide Use	**Number of pesticides/ha**		**Quantity (l/ha)**		**Quantity (kg/ha)**		**Cost (R/ha)**		**Total Cost (R/ha)**
	Inorganic	Organic	Inorganic	Organic	Inorganic	Organic	Inorganic	Organic	
Natuurboerdery	3	12	172	256	78	189	1460.20	4679.60	6139.80
Conventional	17		1490		136		12212.20		12212.20

Source: ZZ2 Land records BHB farm Kariba land, 1995-2010 and D.A. Agriculture commodity budgets, 2010.

Table 10: Comparison of quantities and costs of fertiliser use in *natuurboerdery* versus conventional farming (tomato production)

Farming system/Fertiliser Use	**Number of fertilisers/ha**		**Quantity (l/ha)**		**Quantity (kg/ha)**		**Cost (R/ha)**		**Total Cost (R/ha)**
	Inorganic	Organic	Inorganic	Organic	Inorganic	Organic	Inorganic	Organic	
Natuurboerdery	3	9		1557	90	17100	666	9476	10142
Conventional	8		196.55		2230.07		16968.99		16968.99

Source: ZZ2 Land records Vreedsam farm Chembere land, 1995-2010 and D.A. Agriculture commodity budgets, 2010.

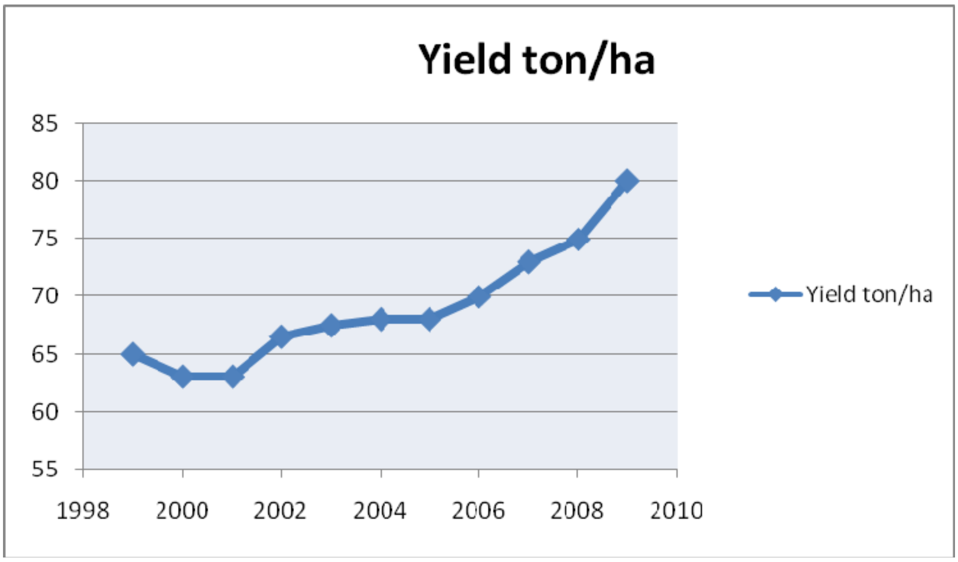
Crop productivity

Noffke (2010), Venter (2010) and van Zyl (2010) recognise that there has been a steady increase in crop productivity or yield (tonnes per hectare) across all crops from 1999 to date. Available ZZ2 production records[54] show that average tomato yield was declining during the last decade of the 20th century up to 2001. Noffke (2010) and van Zyl (2010) agree that this could have been a

[54] Records for onions, avocados, pears and apples were not accessible

result of decline in soil health and unmanageable pest and disease pressures. They mention that yield increases have been noticed on almost all farms as from 2001 when strategies for improving and building soil health were being implemented. Figure 34 shows that average yield dropped to its lowest 63 tons/ha in 2001 before starting to increase steadily up to 80 tons/ha in 2009 which reflects an increase of almost 21 percent.

Figure 34: Trends in tomato production tonnes per hectare



Source: ZZ2 Production Statistics, 2009.

Prinsloo (2010) suggests that there was an improvement in quality, flavour, and taste of ZZ2 tomatoes due to production practices of *natuurboerdery*. He also mentions that some customers are now more willing to pay premium prices for the products and that they are aware of the *natuurboerdery* farming approach. This is consistent with sentiments by Douglas (2010) a student in a Systems and Technologies for Sustainable Agriculture module, that he will choose ZZ2 tomatoes after my presentation of the *natuurboerdery* farming approach at the Sustainability Institute in March 2010.

Utilisation of equipment and energy

Venter (2010) points out that ZZ2 tillage equipment is now being used in a more efficient way as the soil is less compacted due to improved soil health and estimates that this contributes to approximately 30 to 50 percent savings on maintenance costs, tractor hours and fuel consumption. Van Zyl (2010) indicates that individual farm electricity bills have decreased by approximately 30 percent and attributes this to the reduction in pumping water for irrigation, which he considers to be the most electricity consuming activity in agricultural production. The reduction in volumes of water pumped can be attributed to the techniques for water use efficiency in irrigation.

4.6 Section summary

The conversion to *natuurboedery* brought in significant changes which are grouped into four categories (strategic and technical, environmental, social and economic changes). Firstly ZZ2 started to produce and use organic inputs for plant nutrient management and plant protection. Other technical changes include leaf sap and soil water analysis, strategies for water use efficiency and the food health model. The *natuurboerdery* checklist developed includes the WFF and the GGAP and serves as an internal audit for the implementation of *natuurboerdery* farming practices by ZZ2 farmers.

The use of organic amendments resulted increased soil carbon and organic matter content. There is also reduction in the proliferation of weed species and return of natural grass due to a balance in fungi to bacteria ratio from the use of compost teas and EM. Clearing of alien species improves grazing for wildlife and biodiversity and provides raw material for producing EM lantana used for control of soil nematodes which substituted the use of inorganic nematicides. The return of natural springs and increased volumes of available water has been attributed to the clearing of blue gum and black wattle on water catchment areas and other various water saving and measures being implemented.

ZZ2 has now introduced programmes which benefit the community which include community outreach programmes on sustainable farming methods and provision of scholarships and internships to local students. The *natuurboerdery* centre is becoming a learning centre for sustainable farming methods attracting local and international visitors. The reduction of toxic inorganic pesticides and fertilisers improved environmental, food and human health.

The reduction in the use of inorganic pesticides and fertilisers has resulted in reduced costs of production. This was enabled by the implementation of integrated plant protection and nutrient management programmes. Efficient methods of production have resulted in reduced and efficient utilisation of energy. There has been a steady increase in tomato crop yields which is mainly attributed to improvement in soil health.

CHAPTER 5: SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

The final chapter presents an overview of the key findings of each research objective followed by other conclusions not directly related to the research objectives. Next, a Strength, Weaknesses, Opportunities and Threats (SWOT) analysis is presented, based on a critical analysis of *natuurboerdery* and how it both contributes to and mitigates the polycrisis, which feeds into a set of recommendations. Lastly, areas for further research which were identified are proposed.

5.2 Summary of findings

The summary of findings is presented as per each research objective.

5.2.1 Research objective one

To investigate the reasons for and processes of converting from conventional farming to natuurboerdery *farming.*

ZZ2 is a large farming conglomerate in South Africa which initially practiced intensive chemical or conventional agriculture. ZZ2 developed and converted to *natuurboerdery* or natural farming approach at the end of the 20th century due to a number of challenges they faced with conventional farming methods. The aim for conversion to *natuurboerdery* can be summarised as: to implement a sustainable farming system which supports all the pillars of sustainability (economic, social and environment).

Towards the end of the 20th century ZZ2 encountered major problems with soil borne diseases, especially *Verticilium wilt* and *Fusarium oxsyporium*, and problems with failure of nematicides to control soil borne nematodes in tomato production. These problems have a direct negative impact on crop productivity and are mainly attributed to unbalanced soil components or poor soil health. Also pests like lyriomyzas, whiteflies and aphids and leaf diseases like bacterial blight were becoming resistant to pesticides used for control. This is mainly due to the over application of the same pesticides resulting in pest populations which are tolerant to the active ingredients of the pesticides.

Another problem linked to conventional agriculture was the over reliance on inorganic fertilisers, ZZ2 reached a situation where yields were falling despite providing all the chemical nutrients needed for plant growth. This can be explained by poor soil conditions like low levels of organic matter and low carbon content which influence pH and CEC which in turn determines nutrient availability to the plant.

These two problems also presented financial challenges to ZZ2 as the cost for inorganic pesticides and fertilisers continued to increase as they are linked to the price of oil and influenced by international foreign currency (whereas ZZ2 trades the bulk of their produce in local currency). This implied that production costs were not matching the outputs.

At around the same period ZZ2 became aware of green consumerism where consumers were developing a preference for nutritious food which is produced in ethical and environmentally friendly ways.

The conversion to *natuurboerdery* was not a whole sale conversion but rather an incremental process. The first step was the introduction of fluvic and humic acids in the plant nutrition programme with the aim of increasing soil carbon. ZZ2 also introduced EM and later compost tea to build and balance soil microbes. Compost and manure were introduced at the same time to increase organic matter content and substitute inorganic fertilisers for plant nutrition. This can be considered a transition from feeding the plant to feeding the soil. To manage pests and diseases FPEs produced from herbal plants with insecticidal properties fermented with EM were incorporated into the plant protection programme which also included the use of biological control agents. The aim was to substitute inorganic pesticides. However it must be noted that ZZ2 continues to use inorganic fertilisers and pesticides but at a much reduced rate and frequency.

5.2.2 Research objective two

To describe the principles and practices of natuurboerdery *farming.*

The principles and practices of the *natuurboerdery* farming approach can be best described in terms of the five health aspects namely agroecosystem health, soil health, plant health, food health and human health. These health aspects are interrelated and equally contribute to achieve the goals of *natuurboerdery* of increasing farm productivity, maintaining ecological balance and achieving agricultural sustainability on all pillars.

Agroecosystem health management in *natuurboerdery* recognises the importance of ecosystems and biodiversity in maintaining ecological balance. The techniques used to increase productivity protect ecosystems and threatened vegetation by limiting land clearing for agricultural purposes. Water use efficiency strategies conserve and improve available water which is important for all forms of life and for year-round agricultural production. Protection of aquatic ecosystems is also important for improving available water and conserves biodiversity through habitat provision.

Soil health monitoring in soil health management is important in understanding the soil components and the impact of different management practices on soil health over time. The soil health monitoring strategy involves pair side comparison of artificial ecosystems or productive lands with natural ecosystems, pair side comparison of sorghum cover crop land and natural grass (fallow) land and effects of tillage system and cover crop type on soil health. This assists in decision making for maintaining, improving and taking appropriate action for soil health. The methods used in soil health building and improvement include use of compost, manure, vermicompost, EM, compost tea, biochar, cover cropping and fallowing.

The plant health management programme of *natuurboerdery* encompasses integrated pest management and integrated plant nutrient systems, reducing the use of inorganic chemical pesticides and inorganic fertilisers respectively. The techniques for pest and disease monitoring and management and plant nutrient monitoring allow for wise and sustainable utilisation of resources. This is important for increasing microbial diversity and promotes nutrient balance, cycling and availability for plant growth. It contributes to reduced input costs, increased productivity, environmental integrity and is a precursor for food health and human health.

The practices of soil health and plant health promote food health which meets customer demands and needs. The balancing of nutrients in the soil and plant produces quality and nutrient dense fruits with extended shelf life. Quality control checks on products used for soil health and plant health prevents contamination of produce and also spot checks ensure that farmers stick to standards for food health.

By reducing the use of toxic inorganic pesticides *natuurboerdery* promotes a healthy working environment and improves the health of those handling the pesticides. This also produces food with zero chemical residues which is good for the health of the consumers. Contamination of water resources (surface and underground water) is minimised by reduced leaching of nitrates and toxins from pesticides, this promotes the health of the community, wildlife and livestock which drink the water.

5.2.3 Research objective three

To describe and explain the changes and benefits realised by converting to natuurboerdery *farming approach.*

Since the conversion to *natuurboerdery* ZZ2 has implemented a number of technical and strategic changes and this has resulted in significant beneficial changes on three pillars of sustainability (environmental, social and economic).

The production practices have moved from being based on intensive inorganic agrochemicals to one which is based on an integrated use of inorganic, organic or natural and biological inputs. It also involves the use of scientific measurements and laboratory analysis of inputs and outputs and is supported by research and development.

The implementation of techniques for improving and building soil health has resulted in significant increases in soil carbon content by 80 to 85 percent at selected ZZ2 farm lands. The reduction in weed species and return of natural grass on fallow fields is linked to the correct fungi to bacteria ratio which is considered to be a result of balancing soil microbial population through the use of EM and compost teas (Noffke, 2010).

The clearing of invasive alien species improves the diversity of indigenous vegetation. Also the clearing of alien species on water catchment areas has resulted in the return of natural springs with year-round flow thus increasing water availability. Water availability has improved due to the techniques of water use efficiency. Water quality has also improved due to the reduced use of inorganic fertilisers and pesticides as there is reduced pollution from leaching of nitrates and toxins from fertilisers and pesticides respectively.

By engaging communities to implement sustainable farming practices through the *natuurboerdery* community outreach programmes and offering scholarships to local students and creating *natuurboerdery* learning centre ZZ2 ensures the diffusion and continuity of sustainable farming practices.

Natuurboerdery has improved quality of life for both its workers and the consumers of its products through use of environmentally-friendly farming methods. By reducing use of highly toxic pesticides, the health of the workers handling the pesticides and carrying out the sprays is improved and creates a healthy environment for the surrounding communities. Improved water quality for the community, wildlife and livestock is also a result of the reduced pollution from leaching pesticides and fertilisers. The production practices of *natuurboerdery* also produce nutritious food with extended shelf life and zero residues which meet the demands of customers and also improve human health.

High production costs at ZZ2 during the periods of conventional agriculture were mainly linked to high use and cost of inputs mainly inorganic pesticides and fertilisers (van Zyl, 2010). The conversion to *natuurboerdery* uses an integrated approach to plant nutrition and protection and soil health. This has resulted in reduced cost for plant protection and nutrition by 50 and 40 percent respectively. Most of the organic or natural products used in *natuurboerdery* are produced on-farm with locally available and recyclable raw materials.

ZZ2 had experienced decreasing production levels up to 2001 mainly due to the unsustainability of conventional agriculture practices (van Zyl, 2010 and Noffke, 2010). The introduction of sustainable practices of *natuurboerdery* which improve and build soil health and plant health and sustainable utilisation of resources has resulted in upward trends in productivity or yield tons/ha by almost 21 percent (ZZ2, 2009).

Reduced pumping of water for irrigation due to the adopted water use efficiency strategies have resulted in reduced electricity farm bills by approximately 30 percent (van Zyl, 2010). Venter (2010) claims that the efficient utilisation of machinery and equipment results in maintenance and fuel savings of 30 to 50 percent.

5.3 Conclusions

This section reflects some conclusions that I came to at the end of this research which I felt were important to reflect on at this stage, despite the fact that they were not strictly related to the original research objectives.

5.3.1 *Natuurboerdery* is neither organic nor conventional farming

The *natuurboerdery* farming approach is neither organic nor conventional farming, it selects and interlinks the best practices of conventional and organic farming to achieve improved farm productivity and overall sustainability.

Table 11 compares *natuurboerdery* with conventional and organic farming on seven key practices. The main difference among the farming systems is that *natuurboerdery* uses inorganic, organic or natural and biological inputs for plant nutrition, soil health management and pest and disease management. Conventional farming systems are mainly based on the use of inorganic chemical inputs while organic farming totally disqualifies inorganic inputs. In *natuurboerdery* inorganic fertilisers are used at reduced levels and inorganic pesticides are used when other control measures fail and start with the least toxic until control is achieved. All three farming systems can use both conventional tillage and minimum tillage systems. Organic farming and *natuurboerdery* farming integrate cropping systems with livestock systems while in conventional farming these are normally taken as different entities. Conventional farming systems are seen to be more market and profit oriented while *natuurboerdery* and organic farming are concerned with human and food health and environmental integrity.

Table 11: Comparison of *natuurboerdery*, conventional and organic farming

Practice	*Natuurboerdery*	Conventional	Organic
Plant nutrient management	Based on soil health, soil water and sap analysis	Normally based on soil chemical analysis with emphasis on NPK	Does not rely much on laboratory analysis
	Uses both inorganic and organic fertilisers, EM and EM derivatives and natural products	Largely based on inorganic synthetic fertilisers	Strictly based on organic fertilisers and natural products
Soil health management	Soil health monitoring and improvement using organic amendments, fallowing and cover cropping	Soil fertility improvement through use of nitrogenous fertilisers and limited rotations	Soil health improvement through use of organic amendments, cover cropping, crop rotations, intercropping and mulching
Pest and disease management	Based on threshold levels after scouting	Preventative spraying and scouting followed by complete pest eradication	Threshold used but nature is believed to balance itself
	Uses FPEs, natural products, biological control agents and inorganic pesticides	Based on inorganic pesticides with preference for the most efficient, even if this is the most toxic	Based on natural and biological control, balancing of pests by pest predators and also organic pesticides
Tillage system	Conventional and minimum tillage	Conventional and minimum tillage	Conventional and minimum tillage
Cropping system	Monocrops with fallow and cover crops	Extensive monocrops with limited rotations	Diversified cropping systems with rotations, intercrops, cover crops and fallows
	Integrates livestock systems	Does not always integrates livestock	Integrates livestock
Products	Food and human health a priority	Markets and profits a priority	Food and human health a priority
Environment	Maintains biodiversity and ecosystems for ecological balance	Environmental issues not a priority	Maintains biodiversity and ecosystems for ecological balance

Source: Based on Gliessman, 2007 and Lampkin, 1999.

5.3.2 Organic or natural products are compatible with inorganic agrochemicals

Natuurboerdery uses both organic and natural agricultural inputs with inorganic agrochemicals to increase soil and crop productivity while maintaining environmental integrity. This enables the selection of the best technology or practice to address a given condition. For example, inorganic pesticides are only used when organic or natural pesticides fail to reduce the economic injury level of pests. Inorganic fertilisers provide readily available plant nutrients but cannot build soil carbon and organic matter content which are a prerequisite for balanced soil health, while organic soil amendments are used to build soil carbon and organic matter content which enhances plant nutrient availability. In other words the availability of the nutrients supplied by inorganic fertilisers is promoted by soil conditions which are created by use of organic amendments.

5.3.3 *Natuurboerdery* works with nature

The practice of *natuurboerdery* incorporates and maintains nature as a living and functional component of the farming system in its five health aspects. In agro ecosystem health, biodiversity is preserved and promoted in various ways: cropping systems (fallow and cover cropping), integration of crop and livestock systems and wildlife conservancies. Ecosystems (agroecosystems and aquatic ecosystems) are protected through conducting EIAs on all proposed land development activities together with management and monitoring plans and programmes.

Water resources are conserved through water use efficiency strategies which include zoning of available water, limiting water extraction levels and clearing alien species around water catchment areas. Cropping programmes are determined by the quantity of available water. Field operations which enhance water use efficiency include the use of irrigation equipment to determine crop water needs and water conservation is achieved through mulching and improving soil health.

Natural and organic products (compost, manure, vermicompost, biochar, EM and compost tea) used in soil health management enhance soil microbial diversity. This is critical in maintaining and balancing the population of beneficial and harmful organisms and contributes to sustainable soil and crop productivity. The products increase soil carbon and organic matter content which provide food and energy to the soil microbes. Also the products are produced from natural and renewable raw materials which ensures nutrient cycling thus mimicking natural ecosystems. The succession wheel used in *natuurboerdery* puts emphasis on optimum fungi to bacterial ratio for each crop species.

The integrated pest and disease management approach uses pesticides with the least impacts to the environment. Crop protection manages rather than controls or eliminates pests and is based on threshold levels. This prevents unnecessary eradication of microorganisms including beneficial pests and biological control uses pest predators which increases biodiversity.

5.3.4 *Natuurboerdery* is a promising sustainable farming system which mitigates the global polycrisis

Natuurboerdery is a promising sustainable farming system which integrates social, economic, and environmental factors of production to ensure sustained farm productivity, ecological balance and human well-being which leads to overall sustainability. The *natuurboerdery* farming approach fits into sustainable agriculture systems as it mitigates the causes and impacts of the global polycrisis discussed in Chapter Two as shown in Table 12 below. This is achieved by the management strategies for the five health aspects employed in the practices of *natuurboerdery* discussed in Chapter Four.

ZZ2 *natuurboerdery* farming system also fulfils social corporate responsibility through its outreach programmes, scholarship programme, exchange of knowledge and using its *natuurboerdery* centre as a learning centre for sustainable agriculture practices. This allows the diffusion of innovation, continuity and access to information which are preconditions to sustainability.

5.4Recommendations for the *natuurboerdery* farming system

Please note that this section of the thesis is not available to the public. If you would like to contact the author or other persons connected with this study, please visit the website of the Sustainability Institute: www.sustainabilityinstitute.net.

5.5 Opportunities for further research

Further research on *natuurboerdery* is critical to further draw some conclusions and correct some errors in the implementation of *natuurboerdery* farming practices. Based on the limitations and delineation of this study presented in Chapter Three, opportunities for further research have been identified and are presented below.

- As the first scholarship study, this research provided in depth background information on the practices of the *natuurboerdery* farming approach and did not seek to differentiate *natuurboerdery* from organic or conventional farming systems. This presents a platform to critically differentiate *natuurboerdery* from other farming systems in more detail and to conduct a more critical analysis of the whole *natuurboerdery* farming approach and its sustainability as a farming system.
- This thesis merely provided an overview of principles and practices of *natuurboerdery* farming as a sustainable farming system, so there is an opportunity to further investigate the sustainability of *natuurboerdery*. This should also develop and establish reference values and indicators of agricultural sustainability to *natuurboerdery*.
- There is a need for a breeding programme to come up with varieties which are adaptable to the *natuurboerdery* farming approach.
- There is a need for analysis of FPEs LD_{50} and to determine their persistence in fields and other agroecosystems.
- This research revealed some elements of promotion of biodiversity in the *natuurboerdery* farming approach. There is a need to investigate and evaluate the long term influence of *natuurboerdery* on flora, fauna and microbial diversity.
- Research also needs to be carried out to quantify the impact of *natuurboerdery* on the environment and ecosystems.

- There is a need to carry out detailed analysis on the influence of *natuurboerdery* on food health (shelf life and nutrient content) and human health.
- The *natuurboerdery* farming approach was investigated as practiced by ZZ2 on its main crops at a highly organised commercial level mainly in Mooketsi valley. This calls for the need to investigate the adaptability and applicability of the practices of *natuurboerdery* on different crops, different locations and regions and also on different scales of operation.

5.6 Chapter Summary

This chapter summarised the research findings based on each research objective which was used as the basis for drawing up conclusions. A SWOT analysis of the *natuurboerdery* farming approach was performed which also offered recommendations to improve on weaknesses and threats and exploit opportunities. Lastly areas for further research were outlined to improve the *natuurboerdery* farming approach.

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List of Appendices

Appendix A

Letter of introduction and purpose

Thank you very much for giving me this time out of your busy schedule. As an intern student under the Research and Development, I am carrying out research on the *natuurboerdery* farming approach for my MPhil Sustainable Development Planning and Management (Sustainable Agriculture) at Stellenbosch University. I have a set of questions to enhance my understanding of *natuurboerdery* as developed and adopted by ZZ2. Your contribution is highly valuable and greatly appreciated. Should you wish some of your points to be kept anonymous, confidentiality will be maintained.

Appendix B

Questionnaire: Chief Executive Officer

Name of interviewee:	**Tommie van Zyl**
Date of interview:	**30 June 2010**

1.	Can you briefly describe the history of ZZ2 as a company?
2.	Briefly explain the vision and mission of ZZ2.
3.	When and why did ZZ2 convert from conventional agriculture to *natuurboerdery* farming?
4.	Can you briefly explain the transition or stages of conversion from conventional farming to *natuurboerdery* farming?
5.	Which practices of conventional agriculture have you abandoned since converting to *natuurboerdery*?
6.	Which new practices have you adopted on conversion to *natuurboerdery*?
7.	What economic benefits have you realized after converting to *natuurboerdery*? What environmental or ecological benefits have you observed after converting to *natuurboerdery*? What social changes or benefits have been brought by converting to *natuurboerdery*?
8.	What challenges have you encountered during the transition to *natuurboerdery*?
9.	Can you distinguish *natuurboerdery* from other farming systems?
10.	Why did you not convert to organic farming wholly?
11.	Was this based on a cost benefit analysis or any feasibility study?
12.	What are the future plans of *natuurboerdery*?
13.	Do you plan to trademark *natuurboerdery*?
14.	What are the shortcomings of *natuurboerdery*?
15.	What do you see as future challenges of *natuurboerdery*?
16.	How does *natuurboerdery* compare with Woolworth's farming for the future?
17.	As the CEO how do you see the future or potential of *natuurboerdery* in global agriculture?
18.	Are you aware of the concept of sustainable development and other key issues like oil peak crisis, population growth, climate change, and ecosystem and land degradation? If yes, can you rank them in order of importance.

Appendix C

Questionnaire: General Manager *Natuurboerdery* Products

Name of interviewee:	**Johhan Noffke**
Date of interview:	**21 June 2010**

1.	For how long have you been at ZZ2?
2.	What does your job entail and how does it relates to *natuurboerdery*?
3.	Were you involved in the planning of conversion to *natuurboerdery*? If yes describe the process of conversion to *natuurboerdery*. If no do you regard this as a problem?
4.	Which practices of conventional agriculture have you abandoned since converting to *natuurboerdery*?
5.	Which new practices have you adopted on conversion to *natuurboerdery*?
6.	How do you get information on the practices implemented in *natuurboerdery*?
7.	What economic benefits have you realized after converting to *natuurboerdery*? What environmental or ecological benefits have you observed after converting to *natuurboerdery*? What social changes or benefits have been brought by converting to *natuurboerdery*?
8.	What challenges have you encountered during the transition to *natuurboerdery*?
9.	Can you distinguish *natuurboerdery* from other farming systems?
10.	Why did you not convert to organic farming wholly?
11.	Was this based on a cost benefit analysis or any feasibility study?
12.	What are the future plans of *natuurboerdery*?
13.	Do you plan to trademark *natuurboerdery*?
14.	What are the shortcomings of *natuurboerdery*?
15.	What do you see as future challenges of *natuurboerdery*?

Appendix D

Questionnaire: ***Natuurboerdery* Projects Manager**

Name of interviewee:	**Piet Prinsloo**
Date of interview:	**18 June 2010**

1.	For how long have you been at ZZ2?
2.	What does your job entail and how does it relates to *natuurboerdery*?
3.	Were you involved in the planning of conversion to *natuurboerdery*? If yes describe the process of conversion to *natuurboerdery*. If no do you regard this as a problem?
4.	Briefly describe or define *natuurboerdery* as a farming system?
5.	What are the objectives or principles of the *natuurboerdery* farming system?
6.	Can you classify *natuurboerdery* as conventional or organic farming? If not explain.
7.	What do you regard as the main reasons for converting to *natuurboerdery*?
8.	Briefly describe and explain the process of conversion to *natuurboerdery*?
9.	How do you get information on the practices implemented in *natuurboerdery*?
10.	What are the changes or benefits which have been brought in by conversion to *natuurboerdery*?
11.	Describe the opportunities or future plans for *natuurboerdery*.
12.	Briefly explain the challenges which you encounter in implementing *natuurboerdery* farming approaches.
13.	Explain how you address the challenges in *natuurboerdery*.
14.	Can you elaborate on the succession wheel and SFI link to *natuurboerdery*?
15.	How does *natuurboerdery* ensure ecological balance?
16.	How does *natuurboerdery* conserve natural resources and increase biodiversity?
17.	How does *natuurboerdery* lead to promotion of the health concept

Appendix E

Questionnaire: Agronomist

Name of interviewee:	**Bertus Venter**
Date of interview:	**22 June 2010**

1.	For how long have you been at ZZ2?
2.	What does your job entail and how does it relates to *natuurboerdery*?
3.	Were you involved in the planning of conversion to *natuurboerdery*? If yes describe the process of conversion to *natuurboerdery*. If no do you regard this as a problem?
4.	What are the key features or practices of *natuurboerdery* which distinguish it from other farming systems?
5.	Do you have special training on the practice to *natuurboerdery*, like courses, seminars and meetings?
6.	Can you explain how crop cultivars or varieties are selected for production in *natuurboerdery*?
7.	Describe land preparation procedures for *natuurboerdery*?
8.	How is plant nutrition achieved in *natuurboerdery*?
9.	How is plant protection against pest, diseases and weeds achieved in *natuurboerdery*?
10.	What the benefits or changes have been brought about by the adoption of *natuurboerdery*?
11.	What are the agronomic pros and cons of *natuurboerdery*?

Appendix F

Questionnaire: **Compost and FPEs Manager**

Name of interviewee:	**Geoff Miller**
Date of interview:	**19 June 2010**

1.	For how long have you been at ZZ2?
2.	What does your job entail and how does it relates to *natuurboerdery*?
3.	Before converting to *natuurboerdery* what was your operation area?
4.	Were you involved in the planning of conversion to *natuurboerdery*? If yes describe the process of conversion to *natuurboerdery*. If no do you regard this as a problem?
5.	Which *natuurboerdery* products do you produce?
6.	What are the sources for your raw materials?
7.	Can you briefly explain the production process of each product you mentioned?
8.	Can you elaborate on: i) Disease suppressive compost. ii) Anaerobic compost tea.
9.	Are there any wastes and how do you handle them.
10.	To whom do you sell your products?
11.	Are there any ZZ2 farmers who do not use *natuurboerdery* products?
12.	What are the benefits of using *natuurboerdery* products?

Appendix G

Questionnaire: **Ordinary Worker**

Name of interviewee:	**Anonymous**
Date of interview:	**02 July 2010**

1.	For how long have you been working for this company?
2.	What kind of job are you engaged in?
3.	Are you aware of the ZZ2 *natuurboerdery* farming system?
4.	What can you say about the ZZ2 *natuurboerdery* farming system?
5.	What are the changes which you have observed since ZZ2 converted to *natuurboerdery*?
6.	Does *natuurboerdery* take into account your social concerns?
7.	Which issues do you think should be addressed for your well being as a worker?

Appendix H: *Natuurboerdery* checklist and compliance criteria

***NATUURBOERDERY* CHECKLIST AND COMPLIANCE CRITERIA**			
ASSESSMENT TEAM			
NAME OF FARM MANAGER			
NAME OF FARM			
NAME OF LAND			
NAME OF CROP			
DATE OF ASSESSMENT			
DATE OF LAST ASSESSMENT			
LASTCOMPLIANCE SCORE			
COMPLIANCE SCORE			
FARM MANAGEMENT AND PLANNING	**COMPLIANCE CRITERIA**		**COMPLIANCE STANDARD**
	Documentation and Planning		
	1.1.1	Do you have a valid Global Good Agricultural Practice (GAP) certificate?	Global GAP audit must be conducted annually to obtain a certificate for all produced and marketable products.
	1.1.2	What is you latest score for Farming for the Future?	There must be a gradual improvement on the Farming for the Future score.
	1.1.3	Do you have a farm management plan and map illustrating operational and productive farm units?	A farm plan and map must be available which illustrates physical layout and current operations and their management and monitoring.

	1.1.4	Do you have a *Natuurboerdery* plan outlining your short term and long term sustainable targets and objectives?	There must be a *Natuurboerdery* Plan which sets out sustainable short term and long term goals to improve soil health, plant health, food and human health and agroecosystem health and overall sustainability.
	1.1.5	Have you had a *Natuurboerdery* audit in the previous year?	An annual audit for the *Natuurboerdery* plan must be carried out. Theaudit must identify the success, failures, potential and areas which needs improvement as well as the strategies to achieve desired outcomes.
	1.1.6	Do you have a strategic management plan in place?	You must have a strategic management plan to deal with unexpected or unlikely events. This must be linked to *natuurboerdery* farming.
	1.1.7	Is there evidence that the planting programme is linked to climate, rotation cycles and other factors of production?	There must be a link between planting programme and prevailing climatic conditions and the length of rotations. (A planting programme must be available)
	1.1.8	Do you have a crop and livestock integration plan.	A crop livestock integration plan must be in place and take into consideration grazing, rotation and bailing for compost etc.
	1.1.9	Is the farm manager a certified *Natuurboerdery* farmer?	The farm manager must attend the *Natuurboerdery* training course and must be certified and issued with a certificate.
	Labour Management		

	1.2.1	Is the farm workforce aware of the *Natuurboerdery* farming approach?	You must organize annual training sessions to explain to staff what the *Natuurboerdery* farming approach aims to achieve. (Up to foreman level and production team).
	1.2.2	Do you have manuals (SOP) for *natuurboerdery* farming approach?	There is need to compile manuals (SOP) and put them in black and white and avail them for use by farmers.
	1.2.3	What % of the blood tests were above the norm?	There must be a graph to show occurring trends.
	1.2.4	Do you constantly check and monitor your labour days.	There must be a graph to show trends on man hours per tonne of produce.
	Equipment and Machinery Management		
	1.3.1	What is your previous score on technical report for equipment.	There must be an assessment on the status of the equipment by the Technical department and a completed assessment form indicating the score.
	1.3.2	Is there a dedicated storage facility for equipment?	Equipment must be stored in dedicated areas.
	Land Management		
	1.4.1	Is the post harvest protocol fully implemented?	The post harvest protocol must be followed and implemented fully. The general manager certifies the land also signed for by the farm manager and project manager.

SOIL HEALTH	**Soil Management**		
	2.1.1	Has a soil study been conducted to describe your soil type on the farm? (y/n/na)	The whole farm must have a complete soil description and classification through a soil survey.
	2.1.2	Do you have a soil chemical analysis report for the current fields?	A soil chemical analysis report must be on file showing laboratory analysis results and fertiliser recommendations.
	2.1.3	How advanced is the farm on soil health monitoring?	Each land must have one block for long term soil health monitoring all indicated on a map accompanied with a progress report.
	Soil Health Indicators		
	2.2.1	What is the physical quality rating of your soil? (Aggregate Stability %, Available Water capacity m/m, Surface Hardness psi, Subsurface Hardness psi)?	Each land must have soil samples taken and sent for analysis every six months based on the ZZ2 Cornell Soil Health Test. The idea is to find areas which need corrective measures to improve soil health.
	2.2.2	What is the biological rating of your soil? (organic matter %, Active carbon ppm, Potentially mineralizable Nitrogen, Root health)	Each land must have soil samples taken and sent for analysis every six months based on the ZZ2 Cornell Soil Health Test. The idea is to find areas which need corrective measures to improve soil health.

	2.2.3	What is the chemical rating of your soil? (pH, Extractable Potassium ppm)	Each land must have soil samples taken and sent for analysis every six months based on the ZZ2 Cornell Soil Health Test. The idea is to find areas which need corrective measures to improve soil health.
	2.2.5	What is the rating of your soil ecological indicators (SFI)? (Microbial activity, Fungi and Bacteria Ratio and Protozoa Numbers).	Each land must have soil samples taken and sent for analysis every six months based on the ZZ2 Cornell Soil Health Test. The idea is to find areas which need corrective measures to improve soil health.
	2.2.6	What is the overall quality score of your soil test?	The overall score is the sum of the individual scores of soil health indicators as a %.
	***Natuurboerdery* applications**		
	2.3.2	What is your % reduction on inorganic fertilizer use?	There must be a reduction in the application of inorganic fertilizer on consecutive plantings.
	2.3.3	Do you have proof that fertilizers you use do not contain persistent and toxic heavy metals?	Only registered and approved fertilizers should be used. Products from new suppliers must be checked on.
	Soil Conservation and Tillage		
	2.4.1	Do you incorporate cover cropping to address specific needs?	Specific cover crops must be incorporated based on specific needs, functions and climatic conditions.

	2.4.2	Do you incorporate fallow management?	Fallow periods must be incorporated to improve soil health and to allow livestock integration.
	2.4.3	Do you apply the minimum tillage concept on land preparation and what % of cropped area was achieved through minimum tillage?	There must be a gradual increase in hacterage under minimum tillage to achieve set goals. This must be showed graphically on a chart.
PLANT HEALTH	**Pest and Disease Control**		
	3.1.1	Do you have a pest and disease control programme?	Disease and pest control programme must be consistent with the *Natuurboerdery* standards. Compliance is determined according to the IPM value system.
	3.1.2	Do you have a list of available FPEs, Natural Products and chemicals?	Each farmer must have a list of available products which are recommended for *Natuurboerdery* farming approach.
	3.1.3	Do you have a biological pest control strategy (beneficial insects, bats)?	There must be a record and evidence for the release of beneficial insects, pherome traps or other biological methods.
	3.1.4	Does the spraying record indicate adherence to the preferential use of soft approaches and insecticide resistant strategy.	An up to date spraying record must be in place showing type of spray, rate per hectare, thresholds levels and sequence of products used.
	3.1.5	Do you make use of plant indicators?	All planted blocks must have indicator plants on each line on both ends.

	3.1.6	What is the % cost for control to total production cost?	The cost must show a declining trend to total production cost per hactare.
	3.1.7	What is the ratio of chemical control vs. natural/organic/biological?	Check on the ratios of reds, yellow and green (sprays being done in each zone). A ratio of less than one to the green zones is preferred.
	3.1.8	What is the % reduction for inorganic pesticides/Ha used?	There must be evidence for year on year reduction in the use of pesticides.
	Plant Nutrition		
	3.2.1	Do you have a record for sap analysis? (NO3, K+, EC, pH, Brix)	SAP analysis must be done every week and an up to date record must be kept.
	3.2.2	Do you have a record for lysimeter analysis? (NO3, NO2, NH4, P, K, Ca, pH Quantofix, pH Cardy, EC)	Leachate water analysis must be done every week and an up to date record must be kept.
FOOD & HUMAN HEALTH	**Chemical Residues**		
	4.1.1	Do you have a record of the assessment for chemical residues on products?	The must be a record of assessments for chemical residues. How many residue compounds have been detected?
	4.1.2	Does the chemical residues on products show year on year reduction? What is the average % for the chemical residues?	*Natuurboerdery* target 0% chemical residues on products.

IRRIGATION AND WATER MANAGEMENT	**Water Use Efficiency**		
	5.1.1	Do you have a method or programme for calculating water demand?	A proper mathematical calculation procedure or computer programme which takes into account local conditions, crop stage, water infiltration, weather changes or climatic forecasts must be available.
	5.1.6	What is the amount (m^3) of water use per tonne of produce?	The amount of water used to produce a tonne of produce must be measured.
	5.1.8	Do you have water harvesting methods in place?	There must be evidence of effort/attempt to implement water harvesting techniques.
	Aquifer Management		
	5.2.1	Do you have an aquifer management system/plan?	An aquifer map should be available indicating the green, yellow and red zones for water availability.
	5.2.2	Does your planting programme match water availability?	The planting programme/hectarage must match the available water.
	5.2.3	Do you have a record of annual measurements of available water for boreholes and aquifers?	Annual measurements of available water can be done by subtracting extracted water from initial available water and taking into account other factors.
	5.2.4	Do you have a record for water extraction per month?	There must be a record for water extraction from each source.
	Water Quality Management		

	5.3.1	Do you analyze the chemical quality of your irrigation water?	Irrigation water must be analyzed for COD, conductivity, pH, suspended solids, SAR, Na, Ca, Mg, and K.
	5.3.2	Do you analyze the microbial/pathogen levels in your irrigation water?	Irrigation water must be analyzed for faecal coli forms and *E coli*.
	5.3.3	What strategy have you used to improve water quality? Is it working? Is it in use?	An ideal strategy must be used to improve water quality based on different situations. The must be evidence like ozone replacement and use of hydrogen peroxide.
ENVIRONMENTAL AND AGROECOSYSTEM MANAGEMENT	**Environmental Legislation and Protection**		
	6.1.1	Do you have an Environmental Management Plan (EMP) for operations on the entire farm?	An EMP must be in place to mitigate all possible environmental impacts due to farm operations.
	6.1.2	Do you have a license from DWA for wastewater emission?	It is mandatory to have a license for wastewater emissions from DWA.
	Biodiversity and Ecosystem Management		
	6.2.1	Do you have a management plan to increase ecological diversity of your farm?	A plan to conserve and increase biodiversity on the farm must be available.
	6.2.2	Do you have an identification/note/map/plan for threatened ecosystems on your farm?	The farmer must be aware of all threatened ecosystems and must have a plan of conserving them.

	6.2.3	Do you have an assessment report and management plan of vegetation type classifying it as critically endangered, endangered, vulnerable or least vulnerable?	To prevent species extinction threatened vegetation must be protected.
	6.2.4	Do you have an assessment report and management plan for your aquatic ecosystems (wetlands, farm dams and rivers)?	Aquatic ecosystems must be conserved to serve aquatic life which they provide habitat.
	6.2.5	Do you have an identification map and management plan for alien species control?	Invasive alien species must be identified on map. There must be a plan for control of all identified alien species.
	6.2.6	Do you have a management plan for clearing invasive alien species?	There must be a plan for clearing invasive alien species
	6.2.7	Do you have a management plan for endangered species (flora and fauna)?	To contribute to minimization of species extinction, there
	6.2.8	Do you have a record of beneficial species (flora and fauna) on your farm?	Evidence and records of beneficial species like dung beetles, tick (stock) birds, guinea fowls.
	6.2.9	Do you have a management plan for fire control?	A veld fire management plan must be available in addition to fire guards on farm boundaries.
	6.2.10	Do you have a corridor and habitat fragmentation management plan?	A study must be carried out to identify potential and remaining

	6.2.11	Do you sustainably manage and utilize non arable land/degraded lands?	There must be a plan to positively develop and rehabilitate degraded lands.
	6.2.12	Are all crops established more than 30metres from sensitive ecosystems?	A distance of 30m away from all sensitive ecosystems must be maintained.
	Waste Water Management		
	6.3.1	Do you have a waste water management plan?	A waste water management plan must be on file and there must be evidence of implementation. Waste water emission must be registered with DWA if necessary.
	6.3.2	Do you monitor the volumes of the water used and discharged as wastewater for the pack house?	There must be devices for measuring water used and discharged as waste water. Records should also be available.
	6.3.3	Do you monitor the quality of wastewater?	Wastewater must be sampled at a apposition just before irrigation/disposal and analyzed for pH, EC, K, SAR, COD, and *E. Coli*. The critical time for measurements and report formats must be outlined in the management plan.
	6.3.4	Do you use environmentally friendly cleaning agents in the pack house to improve the quality of waste water discharge and to minimize environmental impacts?	A list of cleaning agents and disinfectants used in the pack house must be on file. It is encouraged to use environmentally friendly and biodegradable products.

	6.3.5	Are all sewage treated by a formal waterworks?	Although the disposal of sewage by a soak away drain is sometimes allowed by DWA, producers are encouraged to treat and dispose wastewater in an environmentally friendly way.
	6.3.6	Do you have sustainable and environmentally friendly treatment for waste water?	Farmers are encouraged to develop sustainable and environmentally friendly treatment systems for wastewater which use low energy while offering opportunities for water reuse and recycling.
	6.3.7	Do you have a separation system for solid particles from waste water?	There must be a system in place for separation of solid from wastewater.
	6.3.8	Do you recycle and reuse sludge from waste water?	Sludge from wastewater can be reused positively.
	Solid Waste Management		
	6.4.1	Do you have a solid waste management plan?	There must be a waste management plan communicated to all staff.
	6.4.2	Do you monitor the volumes of waste generated from all farm activities?	There must be a continuous record for all waste generated on the farm.
	6.4.3	Do you have a recycling and reusing programme?	It is encouraged to recycle waste generated on the farm.

	6.4.4	Do you have a record for volumes of materials discharged for recycling?	There must be an up to date record of volumes of waste collected for recycling.
ENERGY USE	**Measurements**		
	7.1.1	Do you measure your energy use?	Energy consumption must be measured and converted to kilowatts
	7.1.2	Do you have a strategy in place to improve energy use efficiency?	There must be a laid down strategy to increase energy use efficiency.
	7.1.3	Do you have a tool or method to measure you carbon footprint?	The farm must have a programme to calculate its carbon footprint.
	Efficiency		
	7.2.1	What is your electrical consumption in terms of kwh/tonne of produce?	Electrical consumption must be recorded.
	7.2.2	What is your total fuel consumption in terms of litres/tonne of produce?	The total fuel used for farm operations must be recorded.
	7.2.3	How many tractor hours (soil preparation, carting labour etc) do you use per tonne of produce?	Tractor hours for all operations must be recorded.

Appendix I: Tomato economic pests, traps and lures

Scientific name	**English common name**	**Responding to**
Helicoverpa armigera	African bollworm	T.V. Pherolure (Plant volatile)
Chrysodeixis acuta	Tomato semi looper	T.V. Pherolure (Plant volatile)
Myzus persicae	Green peach aphid	Yellow card
Thrips tabaci	Thrips	Yellow card
Bemisia tabaci	Tobacco white fly	Yellow card
Tuta absoluta	Tomato leaf miner	Yellow Delta Trap and T.A. Pherolure
Bactrocera invadens	Invader fly	McPhail Trap and M.E. Pherolure
Phthorimaeoperculella	Potato tuber moth	P.T.M. Pherolure (Sex pheromone)

Source: Booysen *et al.*, 2010

Appendix J: Description of trapping devices

Trapping device	**Description**
Yellow Bucket Funnel Trap and Green Bucket Funnel Trap	Consist of three main parts which slide into each other. The trap has a wire which is attached to the top dome lid which is hung on a pole. The pheromone cap or volatile bulb is placed inside the clear plastic cage on top of the dome lid. A DDVP block is placed in the bucket of the trap to kill all insects entering the trap.
Yellow Card	The yellow card trapping system consists of glue on yellow plastic card and a wire. The yellow card has a standard grid to facilitate counting of insects. The card and wire is attached to a pole. It is used to monitor thrips, aphids, leaf miners and white flies. Flytac is used on the cards to stuck insects coming into contact until it is cleaned.

Source: Booysen *et al.*, 2010

Appendix K: FPEs recipes and pest targets

Name of FPE	**Recipe**	**Pest Target**
EM Lantana	10 litres EM verleng, 4kg brown sugar, 8 litres molasses, 20kgs garlic, 60kgs chipped lantana whole plant, 600 litres water and fermented anaerobically for 14 days.	Soil borne nematodes
EM Defender	10 litres EM verleng, 4kg brown sugar, 8 litres molasses, 80kgs chipped aloe vera leaves, 600 litres water and fermented anaerobically for 14 days.	Plant strengthening
Lemon FPE	10 litres EM verleng, 4kgs brown sugar, 8 litres molasses, 20kgs garlic, 120kgs lemon fruit and leaves, 600litres water and fermented anaerobically for 14days.	Bollworms and lepideptera
EM Neem	10 litres EM verleng, 8 litres molasses, 60kgs leaves of neem plant, 600 litres water and fermented anaerobically for 14days.	Whiteflies, aphids, thrips and leaf miners.
Wild garlic FPE	10 litres EM verleng, 8 litres molasses, 20kgs garlic, 80kgs of wild garlic, 600 litres water and fermented anaerobically for 14days.	Whiteflies, aphids, thrips and leaf miners.

Appendix L: Comparison of plant protection programme and budget for *natuurboerdery* versus conventional farming

FARMING SYSTEM	PEST & DISEASE	CONTROL	Total Quantity	Unit Cost. R	Total Cost. R
CONVENTIONAL	Aphid	Chlorpyrifos 250CS (OP) l/ha	3	206	618
	Whitefly	Thiamethoxam 240SC (N) l/ha	7	85	595
		Buprofezin (A) l/ha	8	96	768
		Methomyl (CB) l/ha	8	98	784
		Fenoxycarb (JHM) l/ha	8	96	768
	Leafminer	Abamectin 018 EC (MC) kg/ha	4.4	78	343.2
		Spinosad 480 SC (M) l/ha	14	28	392
	Thrips	Acephate (OP) l/ha	6	98	588
		Fluvalinate (P) l/ha	6	122	732
	R spider mite	Oxamyl © l/ha	6	123	738
	Fungal diseases	Fenoxam l/ha	8	97	776
		Tebuconazole l/ha	12	59	708
		Chlorothalonil l/ha	12	78	936
	Bacterial diseases	Copper oxychloride kg/ha	16	58	928
		Mancozeb l/ha	6	87	522
		Proxan l/ha	6	98	588
	Soil borne nematodes	Nemacur l/ha	12	119	1428
NATUURBOERDERY	Leafminer and whitefly	EM Neem l/ha	55	10	550
		EM Wild garlic l/ha	50	10	500
		Wenfinex oil l/ha	10	16	160
		Thiamethoxam 240SC (N) l/ha	7	85	595
		Abamectin 018 EC (MC) kg/ha	4.4	78	343.2
	Insect general	Razor kg/ha	2.25	63	141.75
		Blade kg/ha	0.9	63	56.7
		Arrow kg/ha	3.15	63	198.45
		Lemon FPE l/ha	3.15	10	31.5
	Fungi and bacteria	Bismark l/ha	1.8	56	100.8
		Mancozeb l/ha	6	87	522
		T Grow l/ha	1.8	128	230.4
	Microbial life	Stock EM l/ha	52.5	14	735
		Compost tea l/ha	550	2.5	1375
	Soil borne nematodes	EM lantana l/ha	60	10	600
(green)	Inorganic pesticide				
(yellow)	Organic pesticide				

Source: ZZ2 Land records (1995-2010) and D.A. Agriculture commodity budgets (2010).

Appendix M: Comparison of plant nutrition programme and budget for *natuurboerdery* versus conventional farming

FARMING SYSTEM	FERTILISER	Total Quantity	Unit Cost. R	Total Cost. R
CONVENTIONAL	NPK 7:14:7 (kg/ha)	800	6.2	4960
	Ca(NO3)2 (kg/ha)	400	7.5	3000
	Mg(NO3)2 (kg/ha)	117	7.8	912.6
	KNO3 (kg/ha)	745.08	7	5215.56
	AMMSO4 (l)	99.05	8.9	881.545
	AN (kg/ha)	36	6.5	234
	H3PO4 (kg/ha)	131.99	6.8	897.532
	K2SO4 (l)	97.5	8.9	867.75
NATUURBOERDERY	Compost (tons/ha)	10	125	1250
	Manure (tons/ha)	4	85	340
	Vermicompost (tons/ha)	3	145	435
	Compost tea (l/ha)	1200	2.5	3000
	Afrikelp (l/ha)	23	17	391
	Amino stimulant (l/ha)	280	7.5	2100
	Humic and Fluvic acids (kg/ha)	100	13	1300
	Stock EM (l/ha)	30	14	420
	EM Verleng & Silica (l/ha)	24	10	240
	KNO3 (kg/ha)	36	7	252
	Mg(NO3)2 (kg/ha)	30	7.8	234
	Ca(NO3)2 (kg/ha)	24	7.5	180
KEY				
(yellow)	Inorganic fertilisers			
(green)	Organic ammendments			

ZZ2 Land records (1995-2010) and D.A. Agriculture commodity budgets (2010).

Appendix N: R & D focus areas and aims

Focus area	Aim
Crop protection	The aim is to identify pests and diseases affecting crops, assess and develop pest and disease management strategies which reduce the use of inorganic pesticides. The management strategies must enhance yield and quality at sustainable costs while minimizing environmental impacts and protecting human health.
Crop production	The aim is to improve growth and development, yield and quality of crops by conducting and disseminating applied research for best crop production practices which adhere to Global Good Agricultural Practices Global (GAP) and ensure sustainable agricultural productivity.
Soil health	The long term aim is to implement management practices which result in soil health improvement and stabilization by increasing organic matter and carbon content of the soil. This is seen as a prerequisite to optimum and sustainable yields. Emphasis is placed on the use of organic amendments like compost, manure, vermicompost, biochar, and cropping techniques like minimum tillage, cover cropping and fallowing and also involves soil health monitoring across ZZ2 farms.
Food health	The overall aim is to produce high nutritional value products with long shelf life and zero chemical residue through use of environmentally friendly and ethnically accepted practices.
Natural resource management	The long term aim is to develop strategies which maintain and increase biodiversity at ZZ2 farms and undertaking environmental impact assessments on new and existing projects to ensure that there is minimum impact on the environment and suggest mitigation measures.
Crop livestock integration	The aim is conduct research on ways for integrating livestock with cropping systems which enhances health, diversification and sustainable management of natural resources.
Product development	The focus is on developing and qualifying organic products that can be used for the enhancement of plant health (plant nutrition and protection), soil health and food health using locally available natural resources and recycling agricultural wastes.
Standards development	The main task is to develop and implement tools for assessing and evaluating the performance and sustainability of *natuurboerdery* and to provide guidelines on the standards.
Data management	The aim is to store and process agricultural data into usable information for decision making processes and for diffusion of the *natuurboerdery* farming approach.

Source: Nzanza, 2010.

Appendix O: Other tests and analysis conducted by Z22 Laboratories

Tests and analysis	Significance
Soil foodweb institute tests (SFI)	ZZ2 laboratories carryout full SFI tests which describe the microbial food webs in soil, compost, and compost tea to determine total bacteria and total fungi, active bacteria and active fungi. Determining total fungi and bacteria is important to know the total biomass of both which determine retained nitrogen which can be released later for plant growth and also fungi is important for immobilizing calcium in solution form. A balance of both organisms is also important to support other organisms which graze on bacteria and fungi. Active fungi and bacteria stimulate other beneficial organisms and enhance the degradation of pesticides and herbicides.
Nematode community profile	Determining the nematode community profiles is important to know the population of beneficial and root feeding nematodes present. For example it is important to know if the population of root feeding nematodes is at economic threshold levels for decision making purposes. Bacterial feeding nematodes help balance total bacteria populations while fungal feeders balance total fungi, this both help release nitrogen locked up in bacteria and fungi for plant growth. Predatory nematodes represent higher order predators responsible for all populations of nematodes.
Mycorrhiza root colonisation	Mycorrhizae are a unique group of fungi that form intimate symbiotic associations with plant roots. Mycorrhiza root colonization are carried out to measure the percentage of root colonization with mycorrhizae. They help protect the plant from soil borne pathogens and diseases, enhance drought tolerance and improve nutrient uptake and availability to plants especially phosphorous and nitrogen and micro elements.

Source: Malherbe, 2010.