# An Impact Assessment of Agro-Ecology on Climate Change Mitigation and Economic Sustainability: A Case of Mopani District

**By**

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A research dissertation submitted to the Department of Geography and Geo-Information Science, in fulfilment of the requirements for the degree of Masters of Environmental Science, University of Venda

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## Declaration

I, **TSHILIDZI CLOUDIA MANYANYA,** hereby declare that the dissertation for the Master of Environmental Sciences in Geography degree at the University of Venda, hereby submitted by me, has not been submitted previously for a degree at this or any other university, that it is my own work in design and execution, and that all reference material contained therein has been duly acknowledged.

Signature...T C Manyanya..... Date...23/08/2016.....



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## Abstract

The United Nations Framework Convention on Climate Change (UNFCCC), Food and Agriculture Organization (FAO) and other global structures advocate for agro-ecology in response to climate change. However most of the expected outcomes concerning agro-ecological were not empirically tested for universal application. Economic sustainability is directly related to yield capacity, which is theorized to increase by 3-10% in a space of ten years as a result of agro-ecological implementation. Agro-ecology is theorised to increase over ago-ecological farms and decrease over conventional farms. Increased crop health means increased carbon sequestration and thus less $CO_2$ in the atmosphere. This is in line with the view that global warming is anthropogenically enhanced through Greenhouse Gasses (GHG) emissions. Agro-ecology mainly affects crop health, soil carbon content and yield on the cultivated land. This study aimed to empirically assess the practicality and validity of these assumptions. The study utilized mainly Geographical information systems (GIS) and Remote Sensing (RS) techniques to assess the effectiveness of agro-ecology as a strategy for climate change mitigation and economic sustainability. The assessment involved a longitudinal study (2013 – 2015) assessing the changes that occur after a farm retrofits from conventional agriculture to agro-ecology. The assumptions guided the objectives of the study. For each objective, an agro-ecological farm was compared with a conventional farm in the same climatic conditional occupying the same general location. Crop health was assessed using satellite images analysed through Normalized Difference Vegetation Index (NDVI) using ArcGIS. Crop health is an indicator of soil carbon content, therefore soil carbon patterns were inferred from crop health patterns based on this relationship. A regression was performed to assess the relationship between surface temperatures and crop health. Yield capacity was calculated based on the production records acquired from the farmers. The results of the study showed increasing surface temperature trends over 80% of the conventional farms and a decrease over 80% of the organic farms. Crop health, Soil carbon and yield capacity revealed an increase over agro-ecological farms and a decrease over conventional farms.

**Key words:** *Agro-Ecosystem, Agro-ecology, Dialectical, Sustainability, Clean Development Mechanism (CDM), Conventional farm, Agro-ecological farm.*

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## Acknowledgement.

My deepest and most sincere gratitude goes to God for the grace and good health that he provided to enable me to finish this study.

My most sincere gratitude to my supervisor Dr Nethengwe for the assistance he provided. He not only provided technical assistance but also encouragement when I had no will to go on. I would like to highly acknowledge the critical eye, expertise and support which I got from my co-supervisor and mentor Mr. E Kori. He has proven most competent repeatedly through the years. I cannot forget to appreciate the assistance of Mr. Bvuma for his excellence in language and proof reading skills.

This study would not have been possible without the emotional and financial support of my family, especially my mother Mary Manyanya. Their support enabled me to conduct this study in the most efficient of ways. I would also like to appreciate the support of my classmates, who became as much a pillar to me as I was to them. I want to give my sincere appreciation to my friends Gundo and Sluu. This journey was worth it because of you.

The NRF made the research process most efficient by providing more than adequate financial support. I feel honored to have had the support of an institution as reputable as the NRF.

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## List of Abbreviations

| Abbreviation | Full name. |
|---|---|
| COBAM: | Climate Change and Forests in The Congo Basin |
| COGTA | Corporate Governance and Traditional Affairs |
| FAO: | Food and Agriculture Organisation of the United Nations |
| GFC: | Global Forests Coalition |
| GHG: | Greenhouse Gas |
| IPC: | Intergovernmental Panel on Climate Change |
| LST | Land Surface Temperatures |
| NCCRWP: | National Climate Change Response White Paper |
| NDVI: | Normalised Difference Vegetation Index |
| NOAA: | National Oceanic and Atmospheric Administration |
| NOPI: | National Organic Produce Initiative |
| NPOP | National Policy on Organic Production |
| NPPI: | Novel Plant Pathogen Interactions |
| OSSIC: | Organic Sector Strategy Implementation Committee |
| SAOSO | South African Organic Sector Organisation |
| UNFCCC: | United Nations Framework Convention on Climate Change |
| WGCC | Working Group on Climate Change |

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# Chapter 1: Introduction.

## 1.1. Background to the study.

### 1.1.1. Agro-ecology and climate change.

Climate change is defined by the Intergovernmental Panel on Climate Change (IPCC) as a long-term change in the average/mean statistical quantification of the state of the climate extending over decades to millennia (IPCC, 2007; Breidenich *et al.,* 1998). The occurrence of periodic variations in the global as well as the local climatic state have been observed and traced back to pre-historic times. Climate change is not always detrimental and it is essential for the co-ordination of seasons and major global weather systems. Records from the past 60 years show an increase in global temperatures despite mitigation strategies which have been put into place (Solomon *et al.*, 2009). The United Nations Framework on Climate Change Convention (UNFCCC) was established in 1992 and only in 1994 did it come into effect. It is a branch of the United Nations (UN) that deals with matters pertaining to climate change mitigation and adaptation (Breidenich *et al.,* 1998). The main culprit of this global warming is greenhouse gas (GHG) emissions from industrialised agriculture and other sectors of development.

According to West & McBride (2005), agriculture is among the highest contributors of upper atmosphere greenhouse gases, contributing about 14% of all annual GHG emissions. Agriculture not only impacts climate change but it is also significantly influenced by climate change. As such it has both climate change mitigation and climate change adaptation potential. Synergy and overlap exists between adaptation and mitigation measures. This means that an agricultural practice that is aimed at mitigation can concurrently be an effective adaptation strategy. The 14% GHG emissions caused by conventional agriculture led to the conceptualisation of sustainable agriculture. Gliessman (2007) calls this farming approach Agro-ecology because it is ecologically, socially and economically sustainable. Climate-resilient agriculture has the potential to address the worsening conditions within the rural communities in Second and Third World countries. These are conditions such as food security, water, health, and land reform (Bezner-Kerr *et al.,* 2012)

The agricultural sector is the largest consumer of water through irrigation and is vulnerable to changes in water availability. Farming is affected by increased water pollution from toxic algal or bacterial blooms and soil erosion from more intense rainfall events and increased



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evapotranspiration, which are all intensified by climate change. This then leaves the under-resourced, small-scale and subsistence farmers extremely vulnerable to the impacts of climate change which they cannot technologically mitigate (Altieri, 1995).

The core principle of agro-ecology is recycling nutrients and energy on the farm, rather than introducing external inputs (Gliessman, 2007). Agro-ecological systems are often difficult to classify and study as they must include considerations based on ecological, economic, and social factors which are complicated by human management. The aim of these sectors working together is to create a well-developed, mature natural ecosystem known as an agro-ecosystem. This system is resilient, stable, self-sustaining, self-recovering from disturbances as well as adapting to change. Agro-ecological systems maintain productivity using energy inputs of solar radiation alone (Gliessman, 1998; Madison, 2004).

### 1.1.2. Agro-ecology and economic sustainability

Economic sustainability is defined as "The use of various strategies for employing existing resources optimally so that a responsible and beneficial balance can be achieved over the longer term. Economic sustainability involves using the assorted assets of the company efficiently to allow it to continue functioning profitability over time" (The business-dictionary, 2014). Economic sustainability in relation to agriculture is dependent on a sustainable amount of produce. This means that agricultural systems should keep the harvest at an equilibrium or surplus state. Conventional agriculture can only produce for so long before it starts to fail dismally due to the pitfalls it creates within itself which then leave the land unable to produce (Gliessman, 2007). These are problems caused by the use of chemical fertilizers, pesticides and monoculture among others. These leave the land unable to sustain a consistent amount of crop thus leading in reduction of both crop quality and yield.

Agro-ecology enhances economic development through an increase in yield and human labour force (Diao *et al.*, 2007; OXFAM, 2014). De Shatter (2012) contends that agro-ecology could double the yield capacity within a space of ten years. This doubling in yield capacity means an increase in market supply and thus more profit. The elimination of mechanical equipment and industrialized intervention leads to an increased need for human force. This leads to much community involvement and thus not only helps with the domestic economy but also improves community livelihoods.



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### 1.1.3. Agro-ecology in South Africa

The adoption of agro-ecology in South Africa started from small scale farmers before the national departments drafted related policies and adopted agro-ecological projects of their own. As such agro-ecological developments are further along among small scale farmers than they are in the large scale agriculture sector (DAFF, 2011). However, there are large-scale farmers such as Kuhestan farmers that have, to some extent, adopted agro-ecology and are showing positive developments. South Africa is a non-Annex I party to the Kyoto Protocol yet it is one of the largest emitters of greenhouse gases among developing countries (Babiker *et al.,* 2000). For this reason, the government committed to reducing GHGs by 34% by 2020 and 42% by 2025. The second communication by South Africa to the UNFCCC by the year 2000 categorized 8% of South Africa's total GHGs emissions to have been caused by the agriculture sector (RSA, 2011)

The South African Department of Agriculture (NDA) has established a Working Group on Climate Change (WGCC). This structure was established to deal with climate change related agricultural projects and challenges. In light of agriculture being one of the sectors most affected by climate change, the WGCC identified mitigation and adaptation strategies. These includes strategies such as supporting risk management initiatives and research on large-scale epidemics. This working group later on added identifying hazards and agro-ecological practices to their strategies (Kgakatsi *et al*., 2007). The South African government together with the business sector and civil society drafted a framework for climate change. This framework addresses measures to be implemented and regulations thereof in the agricultural sector both looking at climate change and the resulting economic implications.

Various policies have been drafted to deal with agro-ecological issues nationally. These include the National Policy on Organic Production (NPOP) and National Climate Change Response White Paper (NCCRWP) through corporate governance and traditional affairs (COGTA) (RSA, 2011). This led to the establishment of other national organisations such as South Africa Organic Sector Organisation (SAOSO) and National Organic Produce Initiative (NOPI). This has seen the establishment of large scale organic farms such as Kuhestan, Wensleydale, Blueberry Heights and Nkomamonta Farmers among others. However, agro-ecology is still shelved under organic farming policies, which reduces the accuracy with which implementation occurs.



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## 1.2. Problem Statement

Agricultural soil is the most important element of agriculture in relation to climate change. Conventional and industrialized agriculture are large contributors towards anthropogenic global warming. They emit about 14% of the total annual atmospheric GHG levels due to chemicals in the soil (Gliessman, 2007). Conventional agriculture is responsible for 20 – 25% of the total atmospheric $CO_2$. Agro-ecology thus influences three major elements of agriculture while also reducing the greenhouse gas emission levels. These elements are soil carbon composition, crop health and yield (Manlay *et al.,* 2007; OXFAM, 2011).

The conceptualisation of climate change paradigm is relatively new and most related initiatives, including agro-ecology, are still in their developmental stages. The projected outcomes concerning agro-ecology were made from on-going experiments and as such they are not completely statistically reliable. This leaves a gap in the body of knowledge about the effectiveness of this new agricultural approach in the real world in areas that have only recently adopted its implementation. The traditional assessment for climate change studies requires measuring climatic variables variations over a specified period of time. This only reveals the composition of the atmosphere but cannot attribute the individual gases to their respective causes. This then makes GIS and Remote sensing the best approach as they focus on measuring changes on the land rather that in the atmosphere in order to achieve the aim of the study.

The South African Department of Agriculture Forests and Fisheries (DAFF) drafted a policy for agro-ecology and sustainable agricultural practices. This policy is aimed at serving as a guideline for implementation. This policy is still in the draft stages and has not been finalized yet, thus shelving agro-ecology under the organic policy. This compromises adherence to the strict implementation of agro-ecological methods by farmers. There is therefore a need for more studies on this new farming approach in order to strengthen the policy content. South Africa has a dual agricultural economy which consists of well-developed large scale and developing small scale farming (DAFF, 2011). De Schutter (2011), has proposed that agro-ecology can double yield in a space of 3-10 years. The economic implications are thus worth investigation.



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## 1.3. Research aim and specific objectives

### 1.3.1. Research aim

The aim of this research was to assess Agro-ecology as a strategy for climate change mitigation and economic sustainability in the Mopani District of Limpopo Province.

### 1.3.2. Specific objectives

The specific objectives of this study were to.

- Examine the patterns in surface temperature readings over an agro-ecological farm as compared to a conventional farm;
- Characterise the changes in crop health and soil carbon content resulting from agro-ecological implementation;
- Assess the relationship between surface temperature patterns and crop health over the sampled farms; and
- Evaluate the impacts of agro-ecological farming methods on yield capacity.

## 1.4. Research questions

The study answers the following questions:

- What noticeable patterns can be deduced from surface temperature readings over both agro-ecological and conventional farms respectively?
- What changes occur in crop health and soil carbon as a result of agro-ecology implementation?
- How is crop health and soil carbon related to the patterns in surface temperature?
- What are the impacts of agro-ecological farming methods on yield capacity and economic sustainability?

## 1.5. Justification and significance of the study

The infancy of agro-ecology as a practice makes for very little information to be available in this field. However, the problem initially is with the ecological degradation caused by the over-exploitation of conventional agriculture. Gliessman (2007) states that the commercialisation of agriculture was established to fulfil the two goals that conventional agriculture was established around. These goals are maximum production and maximum profit return. The methods used to



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commercialize conventional agriculture have brought ecological dynamic imbalances which are eliminating the favourable conditions for agriculture. This has led to industrialisation of agriculture, where genetic manipulation is the primary methodology in achieving high production. This then makes conventional agriculture unsustainable.

Climate change poses a threat to various aspects of human existence such as food security, and optimal atmospheric composition. Conventional agriculture in its unsustainability cannot, therefore, continuously meet the food requirements of the large growing global population. The sustainability of production with agro-ecological practices ensures a stabilized economy that is not self-destructive. This study is significant in the sense that it evaluates a practical contribution of agro-ecology based on the theoretical assumptions of its contribution to climate change through natural resources preservation and its role in economic sustainability. It adds more practical results to a rather theoretically backboned discipline. It also provides a platform for the adoption of agro-ecology based on evaluation of actual real life applications.

## 1.6. Delimitation of study and description of study area

### 1.6.1. Delimitation of study

Climate change is a large scale phenomenon that is usually assessed at the Macro and Meso-scale. However, studies conducted by Nautiyal (2011) show that climate change can just as well be analysed at the micro-scale. As such this study only looks at one district municipality which comprises of five (5) local municipalities. Farms are fixed spatial elements and as such the microclimatic influence that a single farm can exert is localized to the area extending to about 2.5 times the diameter of the farm (Kori & Manyanya, 2014). This means that even at a district level, the contribution of farm activities towards climate change mitigation can still be accurately assessed and analysed.

The study only focuses on the validity of the theoretical assumptions that make agro-ecology to be adopted globally and nationally as a strategy for climate change mitigation and economic sustainability. Only farms which already have established agro-ecological farming practices to some extent were used for effectiveness assessment. The main part of the actual field and desktop work was centred on RS and GIS in relation to properties of agricultural soils.



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### 1.6.2. Description of the study area

#### a) Farming background

The chosen area for assessment in this study is Mopani District Municipality in the Limpopo province of South Africa. Mopani district is made up of five local Municipalities, i.e. Greater Giyani, Greater-Tzaneen, Greater-Letaba, Ba-Phalaborwa and Maruleng. Mopani District is a pioneer of agro-ecological farming in the Limpopo province and as such, most of the farms that are past their initial agro-ecological implementation phases are located within this district. Mopani is known for its fresh produce and citrus farming. Some farmers are still practicing conventional agriculture while others have slowly been introducing agro-ecological practices to a point where some of the farms, such as Kuhestan, are almost completely agro-ecological in all aspects of farming.

#### b) Climate, soil and vegetation

The Area is in the north-eastern side of South Africa characterized by a subtropical climate with cold winters in June through august and hot summers in November through March. Seasonal subtropical rainfall occurs during the summer as a result of the movements of the high pressure belt that circles the entire globe (NDA, 2003). Summer temperatures generally go as high as 38°C. However, the position of some of these farms on a mountainous area makes them cooler than the surrounding areas and as such they do not experience high temperature extremes that the rest of the surrounding areas experience. In the winter, the area becomes very cold due to its montane location (NDA, 2003)

#### c) Farm Profiles

- **Kuhestan Farm**

Kuhestan is an organic farm that specialises in the farming of agro-ecologically produced fruits and vegetables with the main crops being organic raspberries and avocadoes. Kuhestan Farm is located at Magoeboskloof at Haenesburg within The Greater Tzaneen local municipality (NP1333). The farm is geographically located at (WGS84) dms S23° 51' 36.8" and (WGS84) dms E029° 59' 08.3" on the crest of Magoebaskloof Pass adjacent to Woodbush Afro-montane forests that are home to exotic birds and Samango monkeys. Kuhestan produces Hans and Fuerte avocados under the management of Shahrzad and Brett Hone. The farm has been organically operating since its purchase in 2001.



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The farm produce is sold nationally to both small and large scale markets. Kuhestan has two stores nationally, one on the farm and the other in Sandton, Gauteng. Some of the harvested avocadoes and blueberries are processed into other organic products such as syrups, wine, and vinegar among others which are sold at retail stores and at the farm.

- **ZZ2 Farms**

ZZ2 is a farming conglomerate with farms all over the Limpopo Province. For the purpose of this study, focus will only be on the farm that is in Politsi area in Mopani District. ZZ2 produces products such as potatoes, onions, tomatoes, and pears with tomatoes being their main product. ZZ2 is a world leader in tomato production and exportation.

- **Bavaria Fruit Estate**

Bavaria Fruit Estate is a fruit producing farm located in Hoedspruit. The farms produces citrus fruit with mangoes as their primary produce. The farm is a host of the annual mango-mania festival where consumers come with baskets and pick their own mangoes directly from the orchards. For the purposes of this study, the orchard was considered as a whole without being crop specific.

- **Mangena Tomatoes**

This is a conventional farm located in Mashishimale which produces tomatoes. The farm was established in 2005. Since its establishment, it has grown into a large farm with more than 12 employees. The crop diversity has also increased to include a variety of other vegetables in addition to the tomatoes. A drip irrigation system was established when the farm lands were expanded. Mangena supplies fresh produce to the local markets and communities.

- **Alon Mosaic Farm**

Like Kuhestan, this is a multi-functional farm. Alon is an agro-ecological farm located in Duiwelskloof, Letaba, established in 2004. The primary retail spot for the farm's fresh produce is a restaurant in situ. The food served on the restaurant menu is organically grown on the farm. The farm also grows their own coffee and makes their own wine, which are part of the restaurant menu.



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- **Makosha Organic Farmers**

Makosha Organic Farmers is a farm in Giyani registered as a non-profit organisation. The farm organically grows a variety of vegetables which are sold to the nearby communities and markets. The farm is located in the Makosha Village near the Nsami Dam

- **Mabunda farmers' co-operative**

Mabunda Farmers' Co-operative is a conventional farm which is managed as a co-operative from Ka-Xitlakati Village in Giyani. The farm primarily grows vegetables sold to the communities and local markets.

- **Bombyx-Mori silk farm**

Bombyx-Mori is one of only two silk farms in the whole of South Africa. Bombyx-Mori produces organic silk. The farm produces high quality silk which is moulded into Duvets and Hypoallergenic cosmetic products which are sold nationally. The farm can have as many as 250 000 silkworms in the summer months of October through February. The silkworm population decreases to 50 000 in winter, mid-May through mid-August.

- **Ba-Phalaborwa**

Ba-Phalaborwa Marula is primarily an organic food supplier located in Namakgale, Phalaborwa. In addition to the secondary supply of organic produce grown elsewhere, they have an organic Marula farm from which they make products sold nationally.

- **Bosveld Citrus**

This is a group of conventional citrus farms located in Letsitele, Tzaneen. Bosveld is a large company with more than 600 workers during the picking season. The citrus produce is sold to the local, national and international markets.



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All the farms are represented on the study area map below (Figure 1.1)

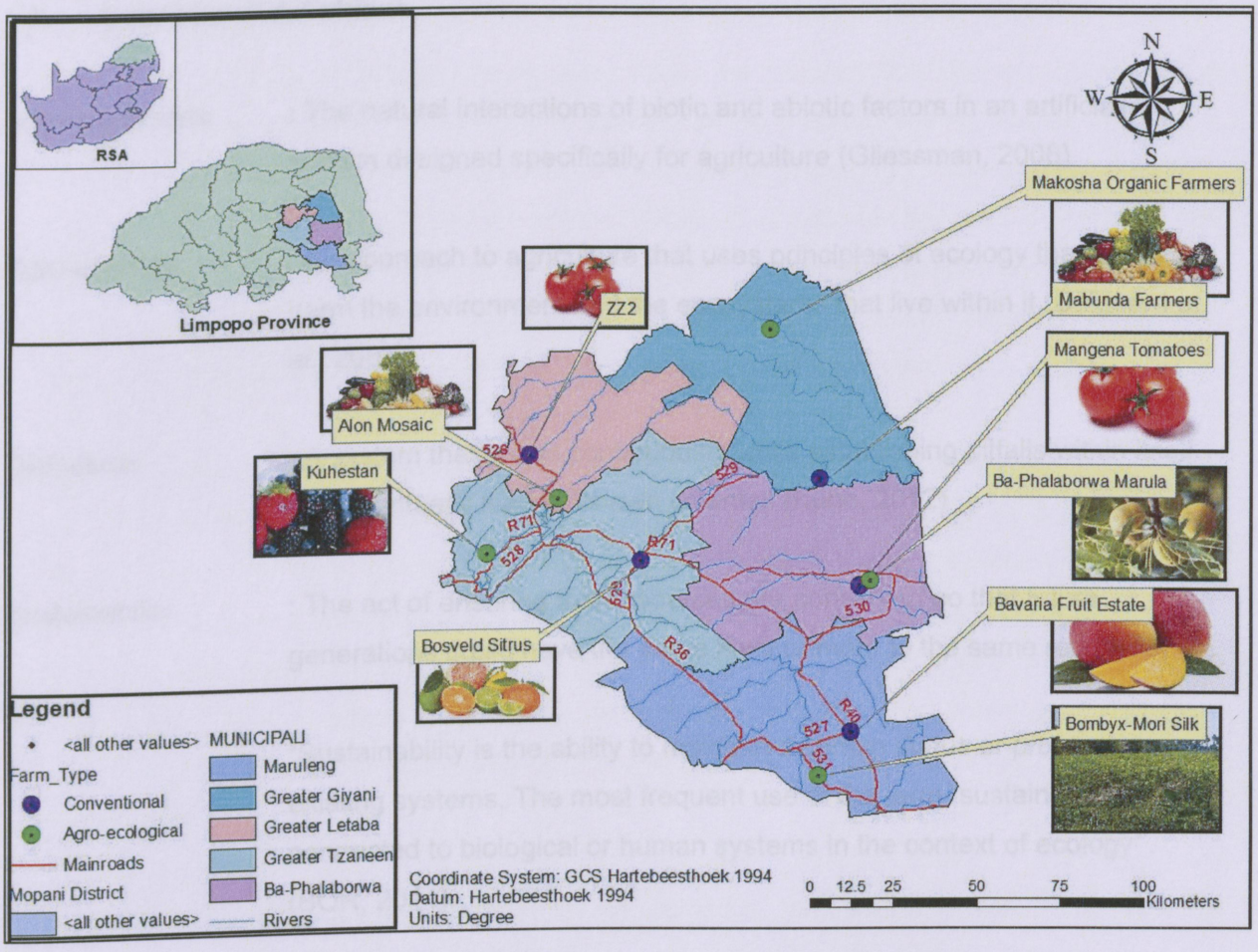



**Figure 1.1: Location of sampled farms in Mopani District**



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## 1.7. Operational definitions

Agro-ecosystem : The natural interactions of biotic and abiotic factors in an artificially system designed specifically for agriculture (Gliessman, 2008)

Agro-ecology : An approach to agriculture that uses principles of ecology that do not harm the environment and the ecosystems that live within it (Dalgaard *et al.*, 2003)

Dialectical : A system that grows continuously while establishing pitfalls within itself that eventually lead to its own downfall (Kuhn, 2012)

Sustainability : The act of ensuring that resources are conserved so that future generations could have the same level or more to the same resources.

"Sustainability is the ability to maintain a certain status or process in existing systems. The most frequent use of the term "sustainability" is connected to biological or human systems in the context of ecology" (BOR, 2014).

CDM : Clean Development Mechanism (CDM) is a structure within the Kyoto Protocol operations which deals with registration of carbon emission reduction projects or any other green projects that are developed by Annex I or II countries as per Kyoto protocol documentation. (Breidenich *et al.*, 2007)

Conventional Farm : A Farm that utilises industrial and chemical methods in most or all of the farming procedures. This includes chemical fertilizers as well as pesticides (Altieri *et al.*, 1987)

Agro-ecological Farm: A Farm that utilises agro-ecological principles in the design and management of the entire farming process (Gliessman, 2007)

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## 1.8. Dissertation outline

Chapter one (1) introduces the geographical as well as the socio-political aspects that led to the identification of the problem. The chapter expounds on the problem setting, further breaking it down into objectives, which link to address the main aim of the study. The background section entails a general as well as a national view of the relationships between agro-ecology and climate change, as well as the link between agro-ecology and economic sustainability. The problem setting sections consist of the problem statement, aim and objectives, research questions, delimitation of study and study area, as well as a justification of the study.

Chapter Two (2) entails the review of the available literature on agro-ecology in relation to climate change and economic sustainability. The chapter introduces agro-ecology as a concept and critically explores the paradigm shift that led to its adoption and global advocacy. The chapter then expounds on the theories which arose from this paradigm shift towards agro-ecology. Furthermore, the concepts are broken down and critically explored alone from a global as well as national scale. This is where contrasting views within the scientific community emerged. Ultimately, the chapter explores the use of GIS and Remote Sensing techniques in agricultural environments.

Chapter three (3) introduces the research design, guided by the literature review. This research design includes type of design, sampling design and ethical considerations. The concepts are broken down into themes based on the objective. Each section with its own methods of data collection and analysis guided by the nature of the study and the research design. This is to produce results presented in the next chapter

Chapter four (4) presents and analyses the data collected in the previous chapter. This presentation is done guided by the themes adopted in the previous chapter. This is to achieve the goal of addressing every objective individually to achieve the main aim of the study.

Chapter Five (5) provides a discussion of the results. This is in relation to the results of each individual objective as compared to the expected outcomes found in the literature. The chapter expounds on the patterns and explanations of anomalies which are in contradiction to the literature. This is to provide explanations before concluding in the next chapter



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Chapter Six (6) concludes on the outcomes of the study, individually in relation to the objective. The chapter also makes an overall conclusion of the outcomes in relation to the main aim of the study. Based on the outcomes of the study, recommendations are made in this chapter for further studies



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# Chapter 2: Literature review

## 2.1. Introduction

This section deals with the review of previously published material relating to the subject matter. It is guided by the conceptual framework in section 2.9 which shows the connection between concepts broken down into constructs and further broken down into variables. This section forms the backbone of the study as it introduces the researcher to methods and methodologies previously adopted by other researchers. Pitfalls that exist within the study of agro-ecology through GIS and RS are highlighted in this section, so that the researcher might now how previous researchers dealt with them. This section also shows the gap in knowledge that this study aims to fill. The take-off for this section is the shift in agriculture paradigms as discussed below.

## 2.2. The concept of Agro-ecology

Agro-ecology as a discipline is defined in many ways, depending on the sub-field of interest and origin. The practice of agro-ecology can be approached from two main angles. Agro-political ecology is an approach that combines population dynamics with ecological principles in agriculture (Weiner *et al*., 1990). Inclusive agro-ecology is the term given to a holistic approach which is seen as composed of two sub approaches. Inclusive agro-ecology has the main focus on ecology either through the natural ecology sub-approach or through agro-ecology (Wojtkowski, 2006). The practice of inclusive agro-ecology can be applied to an agricultural, forestry as well as an agro-forestry environment (Altieri, 1995). This is done through Agronomy, Organic farming, Natural farming, Permaculture as well as Silviculture among others. Overall, inclusive agro-ecology focuses on agro-ecology as a philosophy instead of a farming method.

According to DAFF (2009), "agro-ecology is a discipline that considers and uses ecological theory to design, manage and evaluate agricultural systems in production while also conserving natural resources". Similarly, Gliessman (2007) defines agro-ecology in a simpler form as "the science of applying ecological concepts and principles to the design and management of sustainable food systems". Altieri (1995) defines agro-ecology as "a discipline that defines, classifies and studies agricultural systems from an ecological and socio-economic perspective". A more detail definition is given by Dalgaard et al (2003) as "an integrative discipline that includes elements from agronomy, ecology, sociology and economics", "the study of the interactions between plants, animals, humans and the environment within agricultural systems". Wojtkowski (2006) offers a



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more generalised definition as "the interactions among natural processes in artificial systems designed to meet human goals"

All the preceding definitions have various central aspects in common; they all keep the primary goal of agriculture central to their approaches and practices though they attain it differently. This primary goal is maximisation of production for food and economic gain (Gliessman, 2007). These definitions also centre the practices of this type of agriculture on the synergy between sociology and ecology. The practice of agriculture should be performed in a way that conserves the available natural resources. Agro-ecology involves not only agriculture but also management of an integration of systems which are very diverse yet all essential for the survival of all life on earth. What distinguishes agro-ecology from other agricultural practices is the ecologically friendly methods used in design, implementation, management, monitoring and harvest stages. Most of these are addressed in sections which follow.

## 2.3. The paradigm shift from conventional agriculture to agro-ecology

In every field of scientific research, continued work known as normal science introduces new approaches to old principles that replace and fill the gaps that have been created by old practices (Kuhn, 1962). Normal science in the field of agriculture has discovered pit-falls within the old practices of conventional and industrial agriculture and thus highlighted the need for a more sustainable approach. The focus of this new approach should address three main sectors of human and planetary survival which are food security, climate change and economic sustainability (Daponte, 2006).

These three sectors form part of a larger interconnected system that is formed by agricultural practices as shown in Figure 2.1 below. Agriculture as a practice has evolved from traditional peasant agriculture through industrialisation to the current practice of agro-ecology which is yet to find worldwide establishment. The continuous agriculture revolution has been about serving these three sectors, as shown in Figure 2.1 below despite the increasing advocacy for agro-ecology, there still exists professional researchers who are pushing for conventional agriculture to remain in practice.

Conventional agriculture was invented for the sole purpose of satisfying humanity's increasing demand for food caused by population growth. However, during the inception of agriculture, the



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need was so pressing that the long-term consequences were overlooked and ignored (Randhawa, 1980). These consequences include the effects of conventional agriculture on climate change, ecosystems and human livelihoods as critically explored in the following sections.

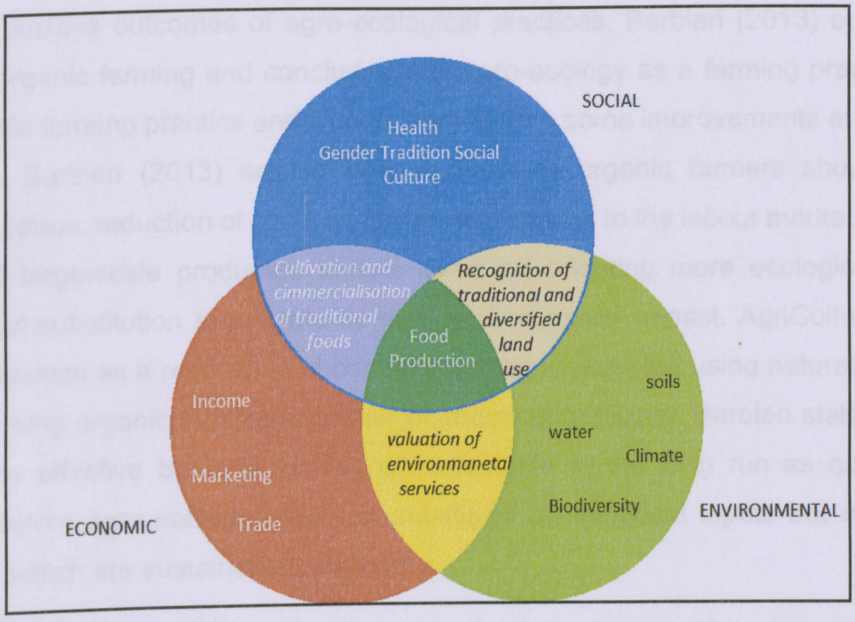



**Figure 2.1: Multi-functionality of Agriculture (Adopted from Oxfam, 2014)**

According to Koohafkan (2011), the industrialisation of agriculture increased food production and lowered poverty. But this is not what other researchers have discovered. As much as industrialisation meets the goal of increased yield capacity as stated by Kimbrell (2002), it does not alleviate poverty and increase sustainable food security (OXFAM, 2014). Industrial agriculture increases inequality among farmers in the sense that some can access Green Revolution technologies (GRTs) while others remain unable to. Industrial agriculture also caused increased dependence on expensive external inputs which then leaves farmers in economic debt or incites a rural exodus (Mazoyer, 2008; Utviklingsfondet, 2011; McKay, 2012). Industrial agriculture thus cannot meet the food security sector as well as economic sustainability.

Lack of sustainability in conventional and industrial agriculture brought about the paradigm of agro-ecology in the 1930s to the USA and Germany (Wezel and Soldat, 2009). However, agro-ecology remains a relatively new approach and the practical applications are still in the early stages and have not yet been fully adopted worldwide. However, the few countries that have adopted it have shown some positive outcomes and it seems to meet all three sectors (Altieri, 2012). Agro-ecology has been adopted by 57 developing countries and a crop yield increase of 80% has been observed and a 116% increase has been observed on all African projects. A study



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was conducted in some African countries which demonstrated that a doubling of crop yield had occurred within a period of 3-10 years (De Schutter, 2011).

Despite all these positive outcomes of agro-ecological practices, Barbieri (2013) conducted a survey on Italian organic farming and concluded that agro-ecology as a farming practice is not the most sustainable farming practice and it could benefit from some improvements at both small and large scales. Barbieri (2013) argued that small scale organic farmers should aim at maximisation of produce, reduction of costs and increased access to the labour market. He added that, Medium and large-scale producers should focus on adopting more ecologically based alternatives to input substitution to mitigate its high environmental impact. AgriCultures (2014) defines input substitution as a replication of conventional agriculture but using natural/ecological systems such as using organic fertilizers instead of chemical fertilizers. Barbieri states that this approach might be effective but it is just as unsustainable in the long run as conventional agriculture is, therefore agro-ecology must not substitute conventional inputs but must rather develop new ones which are sustainable indefinitely.

There are global structures that side with Barbieri's (2013) philosophy and remain sceptical about the role of agriculture in addressing climate change issues (GFC, 2012). In all these arguments, the main point is not whether or not climate change is taking place; rather, the interest is in the source of this change. GFC (2012) base their scepticism on two points. The first point is that agro-ecology would result in environmental degradation caused by land clearing for agriculture. Their second point is that the general cause for climate change is not anthropogenic but rather cyclic, as corroborated by studies conducted by De Jager (2008).

De Jager (2008) attributes climate change to solar activity, as indicated below on Figure 2.2. According to this theory, the global temperature of the earth coincides with the intensity of solar activity. He attributes the rise in atmospheric carbon dioxide to solar heating on the world's oceans. Oceans have a sense memory of about 1000 years (Manabe *et al.,* 1991). When oceans are heated, they release $CO_2$ into the atmosphere. This $CO_2$ lags temperature by 1000 years due to the oceans sense memory. It is this $CO_2$ that is being measured in the atmosphere at present and as such the global warming currently experienced is not caused by anthropogenic activities, such as agriculture but rather by natural processes.



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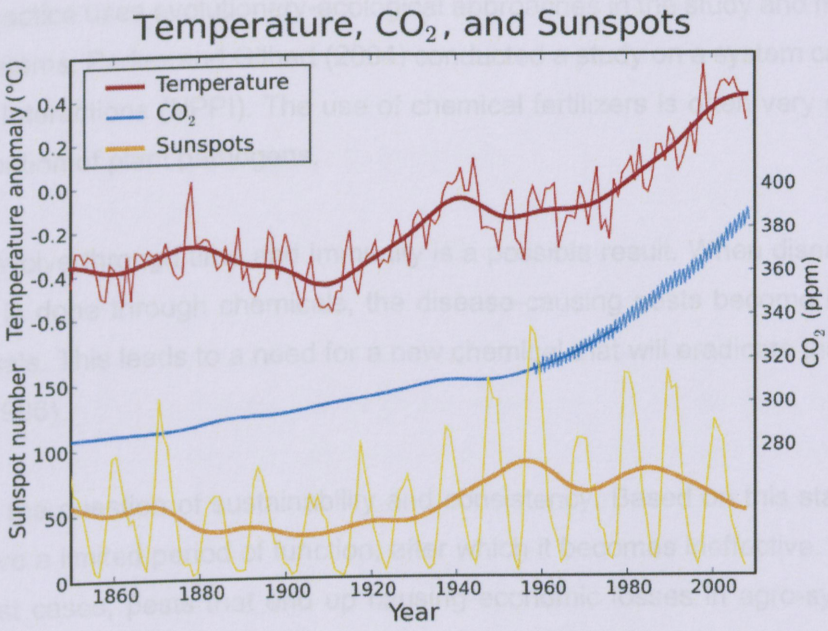



**Figure 2.2: Solar activity, Global CO2 and Temperature (Wordpress, 2010)**

NOAA (2004) attributes global warming to Milankotvich Cycles. Milankovitch Cycles are changes in the rotation of the earth with respect to tilt and precision. The Earth's axis of rotation completes one full cycle of precession every 26,000 years. At the same time the elliptical orbit rotates more slowly. The combined effect of the two precessions leads to a 21,000-year period between the astronomical seasons and the orbit. In addition, the angle between Earth's rotational axis and the normal to the plane of its orbit oscillates between 22.1 and 24.5 degrees on a 41,000-year cycle. It is currently 23.44 degrees and decreasing. These cycles bring about the cooling and warming of the earth's atmosphere as a result of changes in positions of perihelion and aphelion. These are the arguments that sceptics use to advocate the continuity of conventional and industrial agriculture, based on the fact that agro-ecology would not have an influence on climate change and hypothesised.

## 2.4. Critical agro-ecological theories

### 2.4.1. Evolutionary-ecological theories of plant-pathogen interactions (PPI)

Pests and weeds are among the biggest causes of annual yield decreases across the globe. Gliessman (2007) also attributes the lack of sustainability of conventional and industrial agriculture to interactions between the soil, chemical fertilizers and pesticides used in agro-systems. Pesticides form part of the 13% of GHG that agriculture contributes to global warming



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annually. This practice uses evolutionary-ecological approaches in the study and management of pests in agro-systems. Parker and Gilbert (2004) conducted a study on a system called the Novel Plant Pathogen Interactions (NPPI). The use of chemical fertilizers is often very effective in the temporary elimination of plant pathogens.

Plant diseases evolve through time and immunity is a possible result. When disease monitoring and eradication is done through chemicals, the disease-causing pests become immune to the remedial chemicals. This leads to a need for a new chemical that will eradicate the now immune pests (Pedigo, 1996)

This now raises the question of sustainability and consistency. Based on this statement, every pesticide will have a limited period of function, after which it becomes ineffective. Charlet (1995) says that in most cases, pests that end up causing economic losses in agro-systems are not naturally-occurring; rather, they are mutations of the original pest. The mutation is caused by the chemicals in the fertilisers and pesticides caused by chemicals used to eradicate a different pest. These chemicals end up killing the natural predators of other pests and thus create favourable conditions for new pests to gain dominance.

Agro-ecological approaches have led to a re-introduction of a traditionally used method among peasant farmers in underdeveloped and developing countries. These approaches are aimed at filling this gap. This method is called Natural Predator Re-introduction (NPR). Natural predators are naturally-occurring biological control agents which include predators and parasites (Charlet, 1995; Pedigo, 1996). These organisms work in agricultural and urban environments to provide excellent regulation of many pests without human and chemical assistance (Charlet, 1995). This is the reason why most plant-feeding insects do not become economic pests. This theory was applied in the methodology and served as a guide to classification of farming methods in practice around Mopani district.

### 2.4.2. Agro-ecological zoning (AEZ)

Agro-ecological zoning is a process of identification of land and climatic conditions in relation to specific types of crops (Seo, 2014). The ultimate output of an agro-ecological zoning process is a GIS-based system which places certain types of crops in certain types of soils and climate for maximum yield and crop health. A study conducted by Seo (2014) about agro-ecological zoning in micro-farming in relation to climate change revealed that agro-ecological zoning has limitations.



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The study showed that agro-ecological zoning poorly represents livestock farming and diversification. Also is has limitations when it comes to distinguishing grain size for taller trees. However, despite the disadvantages, Agro-ecological zoning is an important principle in the conversion from conventional to agro-ecological farming.

## 2.5. Conventional, Industrial Agriculture and Climate change

There are two main views in the scientific world concerning climate change. One is that it is driven by anthropogenic activities and mostly through the emissions of GHGs into the atmosphere. Another group of scientists, mostly astrophysicists and paleo-climatologists, believe that the earth goes through cyclic changes driven by Milankovitch Cycles (Bennett, 1990). This is when there is a shift in the tilt and precision of the earth relative to the sun and its orbit that result in changes in aphelion and perihelion. This then drives the earth through cycles of ice-ages and extremely hot periods known as global cooling/warming respectively (Ravelo *et al.*, 2004). This same group of scientists also believe that the concentration of atmospheric GHGs is driven by the activity within our sun which then warms up the ocean and thus induces an emission of oceanic $CO_2$ which is what is causing global warming and not human activities (Hoyt, 1997)

However, this study focused on climate change from the first perspective which considers global warming to be influenced by anthropogenic activities of which agriculture is a major part. Agriculture accounts for one-third of all the GHGs in the atmosphere, through crop and soil emissions (WRS, 2008). An analysis study done by Rosengrant et al (2008) came to the conclusion that agriculture accounts for 13% of the total GHGs which were in the atmosphere by 2000 (Figure 2.3). The following pie chart was then drawn to indicate the distribution and contribution of land use activities in GHG emissions.

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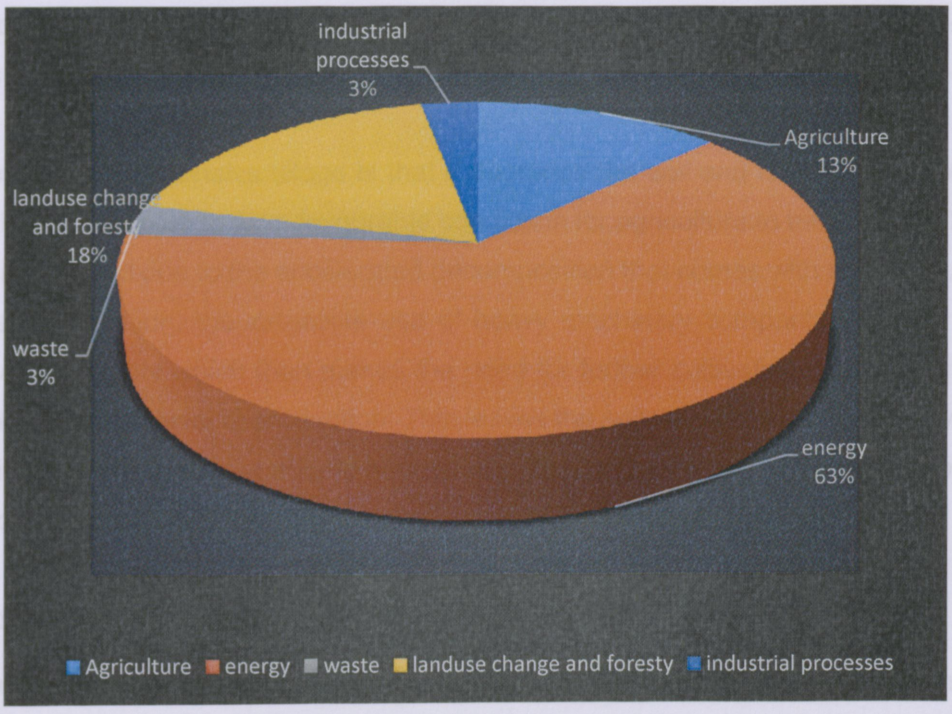



**Figure 2.3: Emission percentages per sector of civilisation (Rosengrant et al., 2008)**

Unlike other contributors, agriculture is mostly responsible for the contribution of non-$CO_2$ GHGs like $MH_4$ and $N_2O$ (Rosengrant *et al.*, 2008). Agriculture also generates large fluxes of $CO_2$ through photosynthesis and respiration into the atmosphere (Gliessman, 2007; IFOAM, 2009). The problem with conventional agriculture lies in its inception that is not inclusive of the long-term effects that it would have on the ecosystem. Conventional agriculture is based on various methods which are aimed at maximising production for maximum profit. These methods, however, combine to form a system that is dialectic and thus not sustainable. This includes practices such as intensive tillage, monoculture, chemical pest and weed control. These individual methods combine to form a Conventional Agriculture Framework System (CAFS) where in one method requires the use of another to achieve the goal of maximum production.

### a) Intensive tillage

This is when the soil is cultivated extensively at regular intervals throughout the year. Tillage is done with the aim of loosening the soil for better drainage, faster growth, aeration, ease of sowing seeds and weed control. Tillage methods range from manual to mechanical, depending on the size of the land to be cultivated. Manual tillage uses smaller tools like hoes to cultivate the soil while mechanical tillage involves the use of heavy machinery like tractors. The regular intervals



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at which the soil is cultivated leave the land exposed for longer periods without any cover (Gliessman, 2007)

The problem with intensive tillage is that it degrades the soil and leaves it void of the essential minerals that combine to form favourable conditions for agriculture to take place. The soil organic matter is reduced due to the accelerated decomposition that comes with soil overturning and lack of cover. In addition, the extensive use of heavy machinery compacts the soil. This leads to reduced soil fertility which then makes the need for further cultivation more pressing in order to maintain the same level of production. This leaves the soil vulnerable to erosion by either wind or air. Ultimately the land is unable to sustain any form of agriculture at its initial capacity and thus leads to lowered production.

**b) Monoculture**

Monoculture is when a farm specialises in a certain crop as opposed to the original practices in agriculture which included growing a vast number of crops while also raising livestock. The commercialisation of agriculture at a larger scale pushed farmers towards specialisation as a result of what is more in demand on the market. According to Gliessman (2007) monoculture is most appropriate for present day conventional agriculture as it allows for more efficient use of heavy machinery for cultivation, sowing, weed control and harvest. At the same time creating large economies through purchases of seeds, fertilizers and pesticides.

However, this leads to similar problems that arise from intensive tillage, leaving the land vulnerable to erosion and void of soil minerals. At the same time, it creates a pseudo-successful economy which then fails to sustain itself when the land degradation problems become extensive and the land can no longer produce enough yield. Vast fields of the same crop are more vulnerable to certain pest infestation, which can lead to decimation of an entire field. To ensure that infestation doesn't occur then severe protection is required through the use of chemical pesticides. Monoculture plays into the CAFS by requiring the addition of pesticides into the mix.

**c) Chemical pesticides and weed control**

The origin of chemical pesticides was fuelled by economic gain (Gliessman, 2009). After World War II, chemical pesticides were introduced to farmers as the new scientific invention to rid them of the pests which damaged their crops and thus reduced their profit (Altieri, 1995). The problem



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with chemical pesticides is that they do not only eradicate pests but also the natural predators of pests. This then makes them only effective for a short period of time. As soon as the pests resurface then the natural predators which were initially there to fight off the pest population are no longer there and this requires an increased frequency with which the pesticide is applied. A dependence called the 'Pesticide treadmill' system (Nicholls & Altieri *et al*., 2002)

## 2.6. Agro-ecology and climate change

### 2.6.1. Global and national Agro-political views

According to a study by Nicholls & Altieri (2002), the principles and practices of agro-ecology have both climate change mitigation and adaptation potential. They suggest that for the adoption of diverse farming systems, enhancement of soil organic matter and managing soil cover should be practiced. All these strategies enhance the mineral content of the soil without strain that leads to degradation as caused by conventional agriculture (Nicholls & Altieri, 2002). While this contributes towards enhanced crop health and yield, it also reduces the levels of GHGs that are directly and indirectly emitted into the atmosphere.

#### 2.6.1.1. South African agro-ecological policies and implementation practices

With all its promises for a less volatile atmosphere and endurable temperatures, agro-ecology is however not without opposition from both civil and official parties. The South African government has drafted a policy to implement agro-ecology nationally. According to the National Policy on Organic Production draft 8 of 2008, the implementation of agro-ecology in South Africa would be faced with a few challenges based on the current status of the agricultural sector. This policy is still limited because agro-ecology is shelved under the organic farming policy. This is not practical because agro-ecology is the mother concept (Gliessman, 2007; Altieri, 1995). The lack of a standard specialised legal framework creates room for compromise in the implementation of methods.

The biggest challenge is fragmentation of the organic sector. The fragmentation of the organic sector was marginalised by agri-business and only a small group of farmers was informed and equipped with the methods and practices of organic farming. Politics influenced the marginalisation further when the Organic South Africa organisation did not accept membership from black farmers until 2006. However recently the intervention of the South African Organic



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Sector Organisation (SAOSO) has advanced the implementation of organic farming (DAFF, 2011). SAOSO advocates inclusivity and sharing of methods and technologies. This then put an end to the euro-centric methods which protested against sharing of ways and methods. Yet this development is still in the initial stages, as such very few farmers have access to neither knowledge nor skill for agro-ecological implementation.

Another challenge which faces agro-ecological practices in South Africa is the lack of a standardized certification board. There are private certification boards but not a national one regulated by the government (NOPP, 2008). The South African Bureau of Standards (SABS) has drafted a framework on organic certification but it is not in implementation yet. This creates different levels of implementation by organic farmers and other agro-ecological farmers in general.

The main discussion and battle of priorities still exists among climate change oriented organisations and projects. The main challenge is deciding on the one that holds the highest priority between climate change mitigation and climate change adaptation. Bargout (2014) argued that mitigation should take the back seat since the people who suffer the impacts of climate change are rural citizens who cannot afford any of the proposed means of mitigation. Bargout (2014) also argues that the effects of mitigation can only be significantly experienced globally. The efforts of mitigation cannot be localized and serve only a small area since they are dispersed globally. But adaptation can however be localized and as such; agro-ecology should be used primarily for adaptation.

#### 2.6.1.2. Kyoto Protocol

The Kyoto Protocol is an international agreement initiated by the UNFCCC aimed at mitigation and adaptation to climate change. This agreement commits its parties to emission reduction based on their pre-1990 level of development (Breidenich *et al.*, 1998). The Kyoto Protocol was drafted in Japan in 1997 and was first put into commission in 2005 for a phase 1 stage. The Kyoto Protocol thus necessitates a re-evaluation of all sectors of development which contribute towards high emission levels. In the agricultural sector, the chemical methods used to hasten production come with detrimental consequences for the environment and emission of GHGs into the atmosphere (Gliessman, 2007; UN, 1998).



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### 2.6.1.3. Work programme on Agriculture.

After the UNFCCC's 17th conference of the parties (COP17) in 2011, a need for a work programme on agriculture was observed. Major global organisations such as FAO, GAIA and others submitted their views to the UNFCCC concerning such a programme (McKay, 2012)

In March 2012, the GAIA Foundation released a statement to the UNFCCC pertaining the work programme discussed at the COP17. They were sceptical about the effectiveness of the work on programme. They were basing their argument on a number of factors, the main one being that agriculture is so important that it cannot just be dealt with in any way at any place. They do not believe that the UNFCCC is the right platform to address such issues. They are aware that climate change will affect agriculture, yet, according to GFC (2012), the UNFCCC can offer the best framework to handle the complexities and challenges of the realities of agriculture. The GAIA Foundation believes that the UNFCCC can only handle minor projects aimed at addressing climate change and not entire sectors like agriculture. The drive and ambition of the UNFCCC has been lowering and it has gone from being a scientific structure to being one that is commercially driven. Trusting such a big sector to such a framework would thus undermine the development of such a sector including the food security of all the other less developed nations (GFC, 2012). There are other organisations such as Committee on world food security (CFS) among others, which would be more appropriate and better equipped to handle such complex sectors as agriculture.

The GAIA Foundation has major concerns about carbon markets. COP17 discussions concerning a work programme on agriculture put agriculture entirely on the mitigation side. Yet the concern is that focusing strictly on mitigation would undermine the work on adaptation and bring agriculture and soils into carbon markets. This is problematic because carbon markets have persistently failed in addressing climate change in general. The UNFCCC might have a smaller role in agriculture and climate change. However, before these roles are played, a few policies must be drafted which clearly ensures the role played focuses on climate change and less on commercial gain (Nicholls & Altieri, 2012). These strategies must reject linkages to carbon markets and technologies that create dependence and vulnerability for small-scale food providers (GFC, 2012)



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As much as the GAIA Foundation has valid points, it hinders development in the green economy. The GAIA foundation is against the practice of conservation tillage, biofuels, bio-char and geo-engineering. The GAIA Foundation claims that these endeavours pose risks to farmer rights and food security and must be avoided. However, due to the crisis facing the fuel industry globally, advances in green fuel are essential for climate change mitigation and adaptation (GFC, 2012). Phasing out industrial agriculture might be a good idea yet their assumption that the UNFCCC can handle agriculture without leaning towards industrialisation has no academic and sound facts to support their thesis.

The FAO published a statement on the agriculture work-programme. They had many interesting points based on previous published work on the UNFCCC's role in climate change mitigation. They believe that the agricultural sector should be challenged to ensure food security for the projected population of three billion by 2050. Climate change however will complicate the climatic conditions for this already great task.

FAO takes Article 3.1 of the UNFCCC seriously. The article states that "developed country Parties should take the lead in combating climate change and the adverse effects thereof". However, these parties should pursue their targets in ways that do not jeopardize but enhance nationally-owned development processes that prioritize food security.

Agriculture could be at the centre of the solution to the inter-dependent challenges of climate change mitigation and adaptation provided that there is adequate funding, policies and capacity-building support. Early discussions on climate change dealt with scientific, technological and methodological aspects of agricultural mitigation. These ranged from the Subsidiary body on scientific and technological advice (SBSTA) to the AWG-LCA which is more policy focused
The FAO believes that SBSTA and AWG-LCA are the two structures that could lead agricultural mitigation to the potential it can have in addressing climate change related issues. Systematic discussions should thus be motivated and established within such structures.

## 2.7. Agro-ecology and economic sustainability

### 2.7.1. Kyoto protocol CDM feasibility mechanism and Carbon Credits

According to the Kyoto Protocol, the countries involved are divided into Annex I and Annex II, based on their level of development (Babiker *et al.*, 2000). The aim of the Kyoto protocol is to



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promote sustainability by retrofitting dialectic systems into sustainable systems. Sustainability is defined as "Being able to be maintained at a certain rate or level"; "Conserving an ecological balance by avoiding depletion of natural resources". (Oxford-Dictionaries, 2014). This then means that the purpose of sustainability is ensuring that future generations have access to the same natural resources that the current generation does. The dialectic nature of conventional agriculture then could not meet this standard of sustainability and hence the introduction of agro-ecology.

As stated under Article 12 of the Kyoto Protocol, there are feasibility mechanisms through which Annex I countries can reduce their emissions and meet their targets without hindering their own development (Babiker *et al.*, 2000). This is done in conjunction with Annex II countries in a partnership through a UNFCCC structure called Clean Development Mechanism (CDM) (Larson et al., 2011). Annex II countries are allowed to develop green (ecologically friendly) projects that do not pose any harmful threats to the environment. These projects can be in any field, however for the purpose of this study the focus is only going to be on agro-ecological projects. Then these projects have to be registered with the UNFCCC CDM structure. The CDM then awards carbon credits to the registered projects. Annex I countries can benefit from these projects either by buying the carbon credits or buy investing in the projects in exchange for carbon credits. (Larson et al., 2011). This process is a dual strategy that curbs climate change while also promoting sustainable agriculture based economy for Annex II countries.

### 2.7.2. COP17 work-programme on agriculture

At the COP17 convention in Durban, South Africa in 2011, the UNFCCC drafted and discussed a work programme on agriculture. This programme completely relies on hypothetical assumptions which must take place in order for atmospheric stability to be maintained for the survival of every living organism on the planet. This programme hypothesises that if the direct cause of climate change can be isolated and addressed, then the mean temperature increase can be kept below 2 degrees, catastrophic sudden change avoided, adaptation costs kept to a minimum then all the relevant contributing sectors will be required to be involved in reducing and removing anthropogenic GHGs from the atmosphere (FAO, 2011).

Agriculture as a field will also be required to ensure the sustainable supply of food to the increasing world population which is estimated to reach an additional three billion by 2050. This is all to be done under changing climatic conditions in an adaptation manner. Agriculture offers



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options that can provide multiple benefits for mitigation, adaptation, development and food security or that allow, in some instances, the management of trade-offs across these requirements. Incentives, policy approaches and institutional mechanisms, including adequate financing, technology and capacity-building support to enable the adoption of these options, could make agriculture a significant part of the solution to the interdependent challenges of climate change and food security in the context of continuing economic development (Gliessman, 2009).

There are many controversies within the scientific community and political activists about the environmental impacts of trading in carbon (De Schutter, 2011). The GFC proposes that trading in carbon is opening up a market that seems viable yet it hasn't been thought through in terms of its long-time impacts on the environment. They propose that instead of farming retrofitting, there is a possibility for extension of farming lands into areas occupied by natural vegetation in order to benefit from this market. According to GFC (2012) forests face major anthropogenic deforestation threats brought about by this trade.

### 2.7.3. Labour and biomass energy from agro-ecology

The paradigm of climate change globally has opened up a market for sustainable energy sources that are alternative to fossil fuel energy. Biomass energy has been identified as one of those energy sources (Volenec et al., 2010). Low carbon biomass provides a significant fraction of the new renewable energy that is needed to reduce emissions of GHGs into the atmosphere. Biomass production can have detrimental impacts on the environment if not done in an eco-friendly way. The agro-ecological approach to biomass production ensures that it does not damage ecosystems, produce harmful pollutants, consume too much water and produce net greenhouse gases.

Agro-ecology as an agricultural practice creates a doubling of yield capacity. This doubling of yield means that biomass production is doubled. This means that one farm would be able to produce enough biomass to support the energy needs of double the area that a farm on conventional agriculture methods would supply. An increased energy supply means a lowering or rates and increased economic stability. The reduction in mechanical equipment thus requires more human resources and as such this improves the domestic economy while enhancing the livelihoods of the communities surrounding the farms.



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## 2.8. Agriculture, remote sensing and GIS

The increase in world population continues to put pressure on farmers to increase yield. This thus calls for better and more effective strategies for agriculture monitoring and management (Steven & Clarke, 2013). Crop monitoring is essential at all stages of growth to ensure proper irrigation methods, pest control, fertilisation and crop health (Collado *et al.,* 2002). During the earliest stages of commercial agriculture, crop monitoring depended entirely on farmers and other human employees without the aid of technology. The quantitative revolution however did not just introduce mathematical solutions to the hard natural sciences but also to the earth sciences. Human observation fails in situations where the farm covers a larger area and much land must be manually observed. Human observation also cannot catch the early stages of pest infection or over-hydration of plants. This then calls for a more effective monitoring strategy that requires less manual work and is more precise in covering large areas and detecting even the smallest of health problems. Remote sensing techniques provide this strategy in the sense that the crop images are taken from space which means they can cover an entire farm just from one image. Remote Sensing techniques can detect different interactions within the plant physiology using different sections of the electromagnetic spectrum. This makes the interpreters to know exactly the condition of the crop and the cause for such a situation (Robinson & Metternicht, 2006; Mulla, 2013).

There are satellites orbiting the earth which were designed to cover such specifics as crop health and have the images analysed and interpreted at specific locations so that farmers can be clear of the conditions their crops were in (Robinson & Metternicht, 2006). These satellites use different remote sensing techniques depending on the structure and components aboard the satellite. Remote sensing applications in agriculture rely on the interaction of electromagnetic radiation with soil or plant material. This involves the measurement of radiation reflected back into the atmosphere by plants or soil on the surface. The platforms for making these measurements include orbital satellites, aircraft, tractors and hand-held sensors. In addition to reflectance, transmittance and absorption, plant leaves can emit energy by fluorescence or thermal emission (Apostol *et al.,* 2003; Cohen *et al.,* 2005). Thermal remote sensing for water stress in crops is based on emission of radiation in response to temperature of the leaf and canopy, which varies with air temperature and the rate of evapotranspiration



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The different types of pigments in the plant absorb radiation at different intensities at different wavelengths. Chlorophyll absorbs strongly in the visible spectrum, from 400-700 nm, depending on the type of chlorophyll (Pinter *et al.*, 2003). Chlorophyll-A absorbs at wavelengths of 430nm (blue) and at 660nm (red) while Chlorophyll-B absorbs at 450(blue) and 650(red). Anthocyanins and carotenoids are pigments which also have their own absorption regions on the electromagnetic spectrum. Remote sensing techniques can also produce reflection values which are then used to assess certain attributes of plant canopy development such as leaf area index, biomass, chlorophyll and nitrogen content. This is often most visible in the near infrared region of the spectrum as a result of leaf density and the structure of the plant canopy. Figure 2.4 below shows reflectance curves of similar plants in different conditions as would be shown through remote sensing techniques.

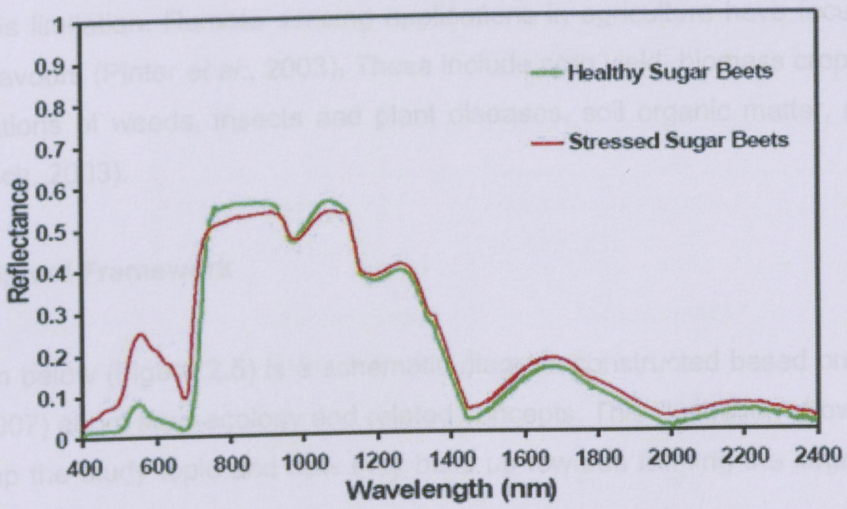



**Figure 2.4: Spectral reflectance curves of crops of different health conditions (Haboudane *et al.*, 2004)**

The soil is an important part of agriculture and the analysis there of reveals the presence and proportions of crucial minerals such as carbonates, iron oxides and organic matter. Each soil constituent has a specific spectral region where reflectance is strongest (Ben-Dor, 1995), and a specific spectral signature. Bare soil and crop canopies are often both present in a remotely sensed image, and the mixture of two spectral signatures often confounds the interpretation of reflectance data (Figure 2.4). Spectral unmixing algorithms, derivative spectra or spectral indices that adjust for soil effects are often used to isolate information about plant characteristics when the reflectance is affected by both sources (Haboudane *et al.*, 2004).



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Remote sensing applications in agriculture are typically classified according to the type of platform for the sensor, including satellite, aerial, and ground based platforms. These platforms and their associated imaging systems can be differentiated based on the altitude of the platform, the spatial resolution of the image, and the minimum return frequency for sequential imaging. Spatial resolution affects the area of the smallest pixel that can be identified. As spatial resolution improves, the area of the smallest pixel decreases, and the homogeneity of soil or crop characteristics within that pixel increases. Low spatial resolution implies large pixels with increased heterogeneity in soil or plant characteristics. Return frequency is important for assessment of temporal patterns in soil or plant characteristics.

The availability of remote sensing images from satellite and aerial platforms is often severely limited by cloud cover (Moran *et al.,* 1997). Ground based remote sensing however, is less affected by this limitation. Remote sensing applications in agriculture have focused on a wide range of endeavours (Pinter *et al*., 2003). These include crop yield, biomass crop nutrient, water stress, infestations of weeds, insects and plant diseases, soil organic matter, pH and salinity (Corwin & Lesch, 2003).

## 2.9. Conceptual Framework

The illustration below (Figure 2.5) is a schematic diagram constructed based on information by Gliessman (2007) about agro-ecology and related concepts. This illustration shows the concepts which make up the study topic and how they build up towards forming the larger theme of the research study.

The conceptual framework below illustrates the broadness of agro-ecology as a discipline. Agro-ecology considers all stages involved from the methods of seed acquisition to the food back on the table for consumption. The framework below focuses on agro-ecology only in climate change mitigation. Which plays into the Kyoto protocol through the three feasibility mechanisms. At the same time this affects and boosts the economy of the country internationally as well as domestically.



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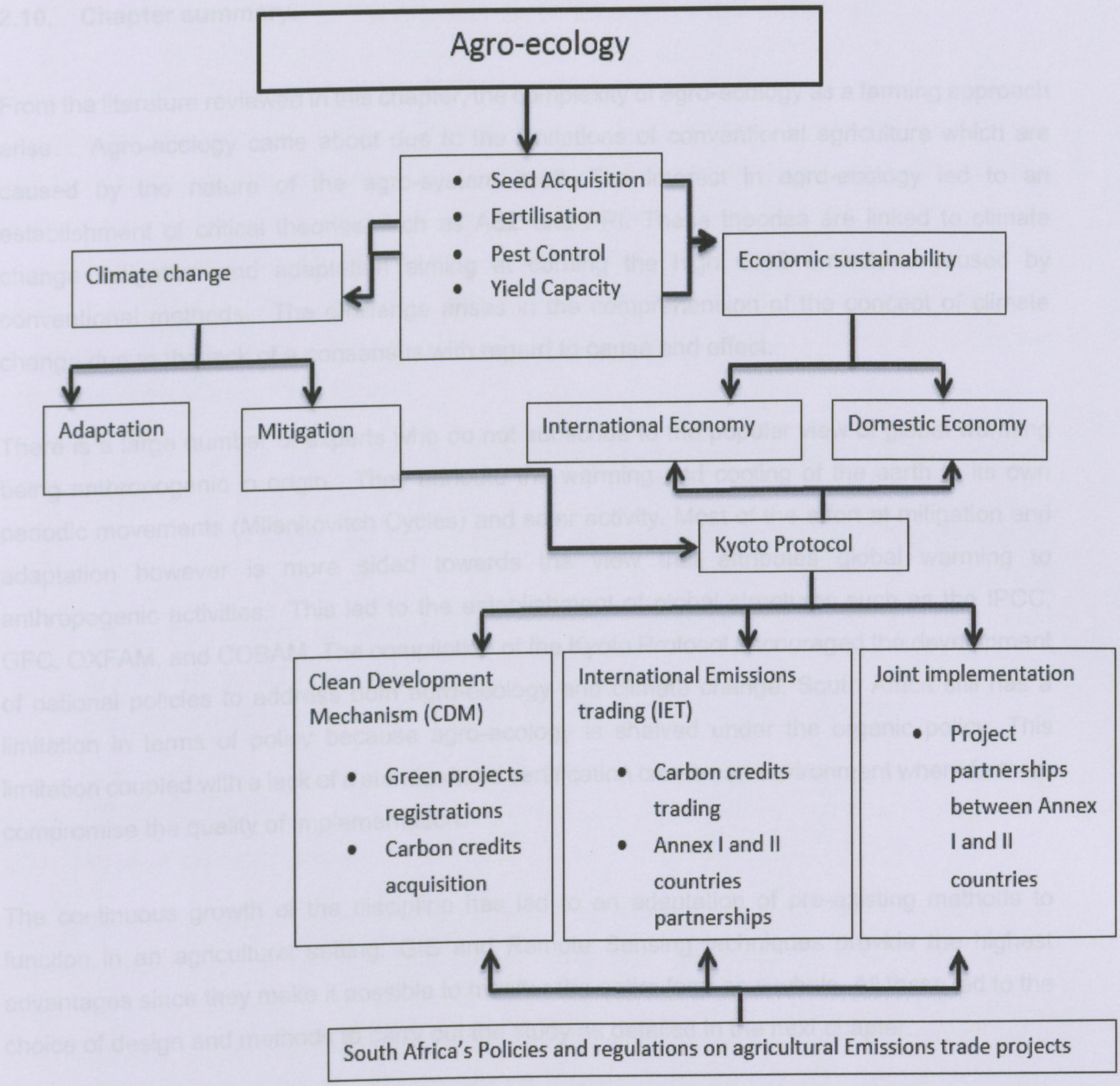



**Figure 2.5.: Conceptual framework (created based on Gliessman (2007))**



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## 2.10. Chapter summary.

From the literature reviewed in this chapter, the complexity of agro-ecology as a farming approach arise. Agro-ecology came about due to the limitations of conventional agriculture which are caused by the nature of the agro-system itself. The interest in agro-ecology led to an establishment of critical theories such as AEZ and PPI. These theories are linked to climate change mitigation and adaptation aiming at curbing the high GHG emissions caused by conventional methods. The challenge arises in the comprehension of the concept of climate change due to the lack of a consensus with regard to cause and effect.

There is a large number of experts who do not subscribe to the popular view of global warming being anthropogenic in origin. They attribute the warming and cooling of the earth to its own periodic movements (Milankovitch Cycles) and solar activity. Most of the effort at mitigation and adaptation however is more sided towards the view that attributes global warming to anthropogenic activities. This led to the establishment of global structures such as the IPCC, GFC, OXFAM, and COBAM. The compilation of the Kyoto Protocol encouraged the development of national policies to address both agro-ecology and climate change. South Africa still has a limitation in terms of policy because agro-ecology is shelved under the organic policy. This limitation coupled with a lack of a standardized certification creates an environment where farmers compromise the quality of implementation.

The continuous growth of the discipline has led to an adaptation of pre-existing methods to function in an agricultural setting. GIS and Remote Sensing techniques provide the highest advantages since they make it possible to monitor the entire farm as a whole. All these led to the choice of design and methods to carry out the study as detailed in the next chapter.



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# Chapter 3: Research Methodology

## 3.1. Introduction

This chapter introduces the technical aspects of the research. It entails the methods followed as well as the overall methodologies guiding the collection of data and analysis thereof. Also covered is how the methodology was influenced and guided by theories reviewed in the previous chapter. These scientific and environmental theories of agro-ecology guided every technical aspect of the study. This chapter entails, research design, sampling design, ethical considerations, data collection and data analysis. These sections cover the methods used to address the respective objectives of this study which were to:

- Examine the patterns in surface temperature readings over an agro-ecological farm as compared to a conventional farm;
- Characterise the changes in crop health and soil carbon content resulting from agro-ecological implementation;
- Assess the relationship between land surface temperature (LST) patterns and crop health over the sampled farms; and
- Evaluate the impacts of agro-ecological farming methods on yield capacity.

## 3.2. Research design

### 3.2.1. Type of research design.

This study used a mixed design of experimental and ex-post facto. This was a two-part study where an impact and a comparative assessment were done. The basis of the ex-post facto design is that the variables under study should be of the same nature but have a varying component which occurred in the past (Simon & Goes, 2013). In this study the farms are both agricultural in nature and located in the same general area; the difference is in the farming practices. The agro-ecological farmer may have started out using conventional practices and later converted to sustainable farming or it may have been initiated as such. This then makes the ex-post facto design suitable for such a study.

However ex-post facto alone has limitations in addressing the rest of the objectives that do not require comparison. In this study, experimental design supplements the limitations of ex-post facto design. Experimental design requires that the researcher have some degree of control over some of the factors which may influence the outcomes of the study indirectly. The results should



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not be predictable to a certain degree but are still subjective to the lack of total control of the experiment. Experimental design requires for there to be categories of results under which the subjects of research can fall into. The sampling of both agro-ecological and conventional farms provides for conventional farmers to be used as a control element against which agro-ecological farms can be measured. This thus means the study is largely quantitative in methodology.

### 3.2.2. Sampling design

The scientific conceptualisation of agro-ecology is relatively new and very few projects exist that exclusively utilize agro-ecological methods in farm management regimes. As such there are few farms to choose from. There was a total population of 35 organic farms distributed unevenly across the entire Mopani District. Most of these farms are located in Greater Tzaneen. This uneven distribution further reduces the sample size in order to have an equal number of farms per local municipality. For this reason, Critical case purposive sampling was used. This type of purposive sampling allows for generalisation of outcomes and global application of findings despite the small sample size (Guetterman, 2015). This is a great challenge when it comes to non-probability sampling for quantitative research. This challenge was mitigated for by having a control farm for each of the sampled farm. This thus makes it a critical case sampling study and thus allows for generalisation. The researcher makes informed choices about which farms to sample from the limited number available (Tongco, 2007). In this study, the choice of sampling units was based on the following criteria. Utilisation of agro-ecologically acceptable methods in farm operations;

- The farm must be geographically accessible; and
- Trade in farm produce at any scale.

The sampling of farms is divided into two groups according to farming practices as follows

- Agro-ecological: This is a category comprised of farms which use agro-ecological methods in their farm design and management due to the limited number of purely agro-ecological farms nationally, the scope was expanded to include organic farmers. The challenge in this regard is that not all organic farms are agro-ecological farms.

- Purely conventional: This is a category of farms which use conventional farming methods in their farm design and management.



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The final sample size was a total of ten (10) farms, five (5) of which are agro-ecological and five (5) are conventional. These farms make a total of 827 ha of Agro-ecological farm lands and 849 ha of conventional agricultural lands.

### 3.2.3. Ethical considerations

The sampled farms for this study are all under private ownership, either by the individual farmers themselves or by a registered private corporation. As such, permission was sought from the farm owners for farms that are privately owned and also from the management authorities. This is for going into the field and consent to use other information about the farm that could have been acquired online and from satellite images.

## 3.3. Data collection

### 3.3.1. Desktop study

Much of this study was based on the theoretical body of knowledge about the role of agro-ecology on climate change mitigation. As such the take-off place for the methods of data collection and analysis was the evaluation of the major global and national policies and guidelines for agro-ecology implementation. These include proposals put forward to the UNFCCC, COP and other global organisations such as FAO, OXFAM and COF among others about the role that agro-ecology could play in climate change mitigation and economic sustainability. These organisations are the largest global entities that deal with environmental and climate challenges. Agro-ecology is part of these organisations' operations and their approaches to climate change vary in execution, yet the central thesis remains sustainability of climate and food (Henard, 2013; Gebretsadik, 2012). This includes a review of proposals such as FAO's Agro-ecological zoning method, South Africa's National Policy on organic production, publications by national South African organisations such as OSSIC-SAOSO, IFOAM, OXFAM and NOPI (DAFF, 2011). These national organisations take the proposals suggested by the global forum in relation to agro-ecology and implement them in conjunction with the national policies which serve as guidelines for all forms of implementation.

This serves as a guideline for the study and method selection. These proposals are projections made on a theoretical basis. As such this phase of the study evaluated the theoretical assumptions that these proposals suggest towards climate change mitigation and economic sustainability.



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The proposals consider the following agricultural elements:

- Seed acquisition;
- Fertilisation;
- Cop management (pest and weed control); and
- Yield capacity

The proposals single out the soil as the primary element since it ultimately affects crop health and yield. In addition, agriculture is one of the highest GHG emitters at 13% (Rosengrant *et al.,* 2008).

The following documents were reviewed as the policy basis for this section

- South Africa national policy of organic farming (Draft) (DAFF, NOPI, OSSIC-SAOSO, DOA);
- South Africa national climate change response white paper (DAFF, NOPI, OSSIC-SAOSO);
- Kyoto protocol (UNFCCC);
- FAO climate-smart agriculture sourcebook;
- Scaling up Agro-ecology (OXFAM); and
- Agro-ecology and the right to food (UN)

### 3.3.2. Climate change data

This is the collection of all data relating to the impact of agro-ecology in climate change mitigation.

#### a) Meteorological variables

Climate change is observed through a pattern variation in the mean annual levels of certain climate variables. These variables include sea and land surface temperatures and rainfall among others. The collection of such variables in the field would not yield the required results since data from the period prior to this study was also required. As such secondary data was used for this part of the data collection. South Africa has a database managed by the South African Weather Services which records land surface temperature (LST) and rainfall statistics and fluctuations thereof. For the purposes of this study, land surface temperature (LST) was the chosen variable. The choice of LST as the variable of climate change indication was based on the climate change view selected for this study. For this study, the researcher chose the view that attributes climate



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change to anthropogenic activities. The carbon temperature graph is the basis of this theory (Letcher, 2014). For this reason, temperature was selected.

Temperature records were acquired for the period 2013 – 2015. Three years is the minimum number of years it takes for an agro-ecological system to start producing the theorised results (De Schutter, 2011). This was because most of the agro-ecological farms in Mopani District have only adopted the green farming approach recently. Selecting a larger period would have drastically reduced the sample size thus compromising the validity of results.

**b) Crop variables**

- **Crop Health.**

Based on the global and national policies and proposals concerning agro-ecology and climate change, two major crop elements were identified as major indicative variables of the contribution agriculture has towards atmospheric GHG levels. These variables are crop-health and soil carbon content. Crop health is also an indicative property of soil composition and health. The data collected for this section was therefore used for assessment of crop health and soil carbon patterns. Remote sensing is the main technique used for collection of data for this section. Secondary data composed of remotely sensed images covering the entire farm area for each farm was collected. Remote sensing techniques are able to cover an entire farm whereas any other method of manual observation would be more time consuming and less accurate.

The images were acquired from South Africa National Space Agency (SANSA) and United States Geological Society (USGC). This is a Landsat ground station database of imagery from earth observation Landsat satellites (CSIR/SAC, 2014). The CSIR/SAC is managed from two subdivisions which handle different aspects of satellite imagery acquisition. The Earth Observation Data Centre (EODC) handles imagery data receiving, hosting and distribution while the Tracking, Telemetry and Command (TT&C) hosts, builds, maintains and manages ground segment equipment for commercial and scientific entities (CSIR/SAC, 2014). For purposes of this research study, the EODC was more relevant.

The data in the EODC from CSIR only contains information from Landsat. The EODC however contains data from other sources and other satellites. Using images provided by only one satellite introduces some bias. As such the SANSA database was used to access satellite imagery. SANSA has a satellite imagery archive dating back to 1972 from the first Landsat satellite. This



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archive has imagery from satellites such as Landsat 2-5, 7; SPOT 1-5; SumbandilaSat; CBERS-2B; SAC-C; ERS-1 and 2 radar imagery. The archive contains imagery covering most of the SADC countries in the footprint region of the Hartebeesthoek ground receiving station. This archive forms the part of the Earth Observation Data Centre (EODC) of the Department of Science and Technology (DST) (SANSA, 2013). Having multiple sources provides the opportunity to utilise images of the highest quality.

- **Soil Carbon**

Agriculture influences global warming in different ways, the most significant of which is emission of GHGs from the soil (Gliessman, 2007). This thus makes the soil composition of an agro-ecological farm an important part of this study. A cultivated farm makes it difficult to directly assess soil from the images. As such, vegetation composition was used as a soil indicator. The images collected for crop health analysis were used to infer soil carbon patterns. The disadvantage is that it does not account for any fluctuations in the soil carbon content occurring within the farm. This gap was compensated for by making an inference about soil based on the relationship between crop health and soil carbon (Powlson *et al..,* 2016).

### 3.3.3. Economic sustainability data

This part details the collection of data relating to the impact of agro-ecology on economic sustainability.

- **Yield statistics**

Agricultural economy depends heavily on yield capacity (Gliessman, 2007). Agro-ecology has been theorised to increase yield capacity as compared to conventional agriculture (De Schutter, 2011). Yield statistics were acquired from the records kept by the farmers themselves. This is an account of how much yield was produced over one growth period.



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## 3.4. Data Analysis

### 3.4.1. Climate change data analysis

#### a) Analysis of Surface temperature patterns

The South African Weather Services (SAWS) database contains records of daily temperature readings. These temperature readings have random fluctuations, depending on influences from the prevailing climatic conditions. Trend-line internal linear regression was performed on Microsoft Excel was used to analyse these temperature records. They were averaged monthly and plotted on a graph for each farm location. Trend-line analysis was used to estimate patterns in the data. The trend-line analysis outputs a linear equation from which further analysis was made. The gradient of this equation is the one that reveals the trend of the variables under analysis for that specific year. This gradient was then compared with the gradients of the linear equations of the subsequent years to assess for patterns. A percentage variance was used to assess how much the annual average temperatures had changed and the direction of the change. The results are presented in tables and graphical figures.

### 3.4.2. Analysis of crop variables using Remote Sensing and GIS techniques.

#### a) Crop health assessment.

Remote Sensing and GIS are the main methods of analysis in relation to this section. They were used to assess how agro-ecology has been growing and how that growth has impacted climate change from a mitigation point of reference. Remote sensing allows for temporal and spatial assessment of any changes that result from the adoption of agro-ecological practices. This study therefore focused on both the temporal and spatial assessment in the analysis of patterns in crop health and soil carbon.

Pinter *et al.* (2003) stated that since the adoption of satellite imaging in land observations there have been crucial developments made which are adaptable to agriculture and crop monitoring. These techniques are based on the findings made from high resolution spectral signatures for natural and cultivated land. They form the basis for the distinction between healthy and diseased crops caused by nutrient deficiency, pests and abiotic stresses. These include techniques such as Spectral Reflectance Properties of Leaves, Crop Canopies and Vegetation Indices, Spectral Reflectance Properties of Soils, Emitted Thermal Radiation, Evapotranspiration (ET) and Crop Coefficient, colour-infrared (CIR) photography and supporting hyper-spectral reflectance. Multi-spectral image processing produces NIR, red, green, NR, NG, NDVI and NDNG indices or



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images, which can be used to evaluate biomass, crop health, biotypes, and pest infestations in agricultural fields (Huang *et al..,* 2008).

- **Spatio - Temporal Assessment**

The temporal assessment is done on a farm that previously used conventional and industrialised agriculture methods before retrofitting to agro-ecology. This then means that remotely-sensed images of the farm before method retrofitting was collected and compared to those taken after the adoption of agro-ecology to assess any changes that may have been brought about by retrofitting of methods. The spatial assessment comes when two images taken at different locations at the same time are compared to each other in order to identify differences. The fundamental difference between the two locations in this study was agriculture methods practiced. One farm used agro-ecological methods and the other used conventional methods.

- **NDVI (Normalized Difference Vegetation Index)**

NDVI is a numerical assessment method that is created from satellite imagery collected in the red and infra-red regions. NDVI categorises vegetation and displays it in a form of graduated colours and ranges. The healthy crops appear red on the image while the stressed crops appear paler. Through NDVI the whole farm can be displayed on one output which then makes it possible to spot areas where the crops are stressed and areas of complete health. NDVI can show various aspects of ground crop parameters such as percent of ground cover, photosynthetic activity of the plant, surface water, leaf area index and the amount of biomass.

Theoretically, NDVI values are represented as a ratio ranging in value from -1 to 1. Extreme negative values represent water while values around zero represent bare soil. Values around 0.4/0.5 represent agricultural lands, values between 0.5 and 0.7 can represent very healthy agricultural lands or light natural forests. The extreme highest values represent dense natural forests (Unsalan & Boyer, 2005). NDVI was used to assess patterns in the health of the crop spatially or temporally.

NDVI was performed for each of the ten sampled farms for 2013, 2014 and 2015. This was performed in ArcGIS 10.2. ArcGIS was also used to do the pre-processing of the images before calculating NDVI. Pre-processing is important because it corrects for atmospheric disturbances such as clouds and rainfall at the time the image was taken (Blackledge, 2005).



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These include pre-processing techniques such as Radiometric correction, which corrects for the target reflectance from the measured reflectance (Unsalan & Boyer, 2005). Atmospheric correction is another pre-processing method performed, which corrects for atmospheric disturbances such as mist, fog and clouds. Spatial correction was performed to correct for spatial location of features.

- **Re-classified NDVI and Area percentages**

Re-classified (Unsupervised) NDVI images allow for the NDVI range outputs to be renamed according to what they represent on the actual land. Negative NDVI ranges would represent rivers, dams and swamps, while extreme positives represent forest vegetation. This also allows for colour reversals of the NDVI output (Unsalan & Boyer, 2005). ArcGIS which was used to create the NDVI outputs was also used to do the Re-classification. ArcGIS also provides tools to calculate area percentages of the identified classes which allows for spatial growth analysis of the farms. During the re-classification process, the same number of classed chosen for the NDVI image must be chosen for the re-classification procedure. The values from the NDVI represent various features on land, which are then matched in the re-classification procedure.

- **NDVI Range Floating Bars and Delta function**

The NDVI outputs ranges of difference classes with agricultural lands as one of the ranges. Every range has a minimum value and a maximum value (Yengo *et al..,* 2015). Crop health is given by the changes in the minimum and the maximum values. The minimum value indicates the lowest wavelength which is classified as agricultural lands. This means that this is the wavelength for the least healthy of the crops on the agricultural lands. The maximum value is the highest wavelength which is classified as vegetation and indicates the healthiest crops. The shift in these values from 2013 through 2014 up to 2015 is what indicates crop health (Powlson *et al..,* 2016).

Histogram Floating bars were used to graphically present the shifts in the ranges produced by the NDVI. Floating bars are effective in assessing ranges because the entire range is plotted instead of the average which would only be a singular number. An average does not indicate the minimum and maximum values and as such, equal averages can have different minimum and maximum values (Richardson, 2012). For this reason, floating bars were chosen. The floating bars were created using the Microsoft Excel delta function. NDVI range as the dependent variable and Year



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as the independent variable. Floating bars introduce a Delta function into the plot. A delta function is a function which depends on the minimum and maximum values and is calculated using the formula below.

$$Delta = Maximum\ value - Minimum\ value\ \{all\ in\ the\ NDVI - red\}$$

**Equation 3.1: Delta function**

Excel plots the Delta function on top of the minimum value. The top value of the Delta function is the maximum value. This makes it possible to assess the shifts in the ranges with each year for each farm.

**b) Soil carbon analysis**

The traditional method of analysis is laboratory testing of the soil samples. However, in this study, the entire period of 2013 – 2015 makes it impossible to physically collect samples and analyse them in the laboratory. This is because the data collection process began after 2013. Normalized Soil Index (NDSI) would also not be applicable since very small parts of the farms are covered. NDSI of the images would produce biased results because it would take into account the bare lands that are within the buffer zone and outside of the farm. Powlson et al (2016) provides an inference method based on the relationship between soil carbon and surface temperature through carbon sequestration. The results provided by the NDVI used in crop analysis were thus used to infer about patterns over farms in both agro-ecological and conventional farms. Relationship inference in NDVI and soil mean that a farm with an improved crop health from NDVI analysis indicates a reduction in soil carbon and vice versa.

### 3.4.3. The relationship between average temperatures and crop health patterns

This section links objective one and two, which are addressed by the LST analysis and crop health analysis respectively. Multiple regression was used to assess the relationship that exists between crop health and LST. The independent variable was the period of assessment (2013 – 2015). The multiple regression algorithm regressed the crop health with LST's for a statistical relationship they display over the years.

Regression performs two main significance tests and outputs them concurrently. These comprise of the ANOVA and Pearson's Correlation. A null hypothesis is required in order to carry the tests out. For the purposes of this research the Null Hypothesis was as stated below.



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*H0 = There is a relationship between crop health patterns and LST average patterns.*

The most significant outputs of the regression are R-square, Significance F, Co-relation coefficient and the P-square. Regression was performed at 0.05 % confidence level. R-square indicates the percentage of variation in variable 1 which can be explained by variations in variable 2. A p-square value of more than 0.05 means there is a higher than 5% chance that the correlation is random and thus the Null Hypothesis is rejected. A p-value of less than 0.05% means that there is greater than 95% chance that the correlation is not random. Thus we accept the Null Hypothesis. Significance F indicates the statistical significance of the ANOVA. A significance of less than 0.1 means there is a 90% chance that the test is statistically significant. The correlation coefficient is the gradient which indicates the direction of the relationship and the rate of change for future predictions.

### 3.4.4. Economic sustainability data analysis

#### a) Crop yield

Yield is a complicated variable to measure as it is dependent on farming methods and the size of land farmed. In this case, the yield records acquired from the farms were analysed using equation 3.2, below. This formula excludes the contributions of other farming elements, which may contribute to the change in yield. For this part, the following assumptions were made.

- The area of the farms has remained constant throughout the chosen temporal restrictions for the purposes of the study.
- The farms receive equal irrigation.
- Any change in the climatic conditions is thus caused by the changes in the farms and not vice versa.

$$Seasonal\ Yield = \left[\frac{Amount\ of\ Crop\ Harvested\ per\ Season(kg)}{Total\ Area\ of\ Farm\ that\ Season(m^2)}\right]\ \text{In Kg/m}^2$$

**Equation 3.2: Seasonal yield**



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## 3.5. Chapter summary

The choice of a mixing of Ex post facto and Experimental designs led to an adoption of Critical-case sampling. Critical-case sampling allows for the results to be generalised from a small sample. The choice of data, collection and analysis was grouped into themes guided by the objectives of the study. The analysis of crop health was primarily done through remote sensing techniques from satellite imagery. Soil was analysed through inference based on crop properties. Yield was calculated from seasonal produce records, acquired from the farmers. Regression was used as a major tool for relationship analysis between the different objectives. The results obtained are presented in the next chapter.



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# Chapter 4: Results Presentation and Analysis

## 4.1. Introduction

This chapter presents the data collected and processed for the purposes of the study. The data is not self-explanatory, as such the data presented must be interpreted according to the objectives of the study. This chapter provides an interpretation of the data as well as explanations for data discrepancies in order to account for the validity of the results. The specific objectives of the study were to:

- Examine the patterns in surface temperature readings over an agro-ecological farm as compared to a conventional farm;
- Characterise the changes in crop health and soil carbon content resulting from agro-ecological implementation;
- Assess the relationship between surface temperature patterns and crop health over the sampled farms; and
- Evaluate the impacts of agro-ecological farming methods on yield capacity.

All these objectives were addressed in various sections of this chapter, including, surface temperature patterns over farms, changes in crop health and soil carbon content. This is followed by the relationship between crop health, soil and temperature. This relationship assessment links temperature patterns with patterns in crop health and soil carbon. The last section of this chapter analyses farm yield patterns.

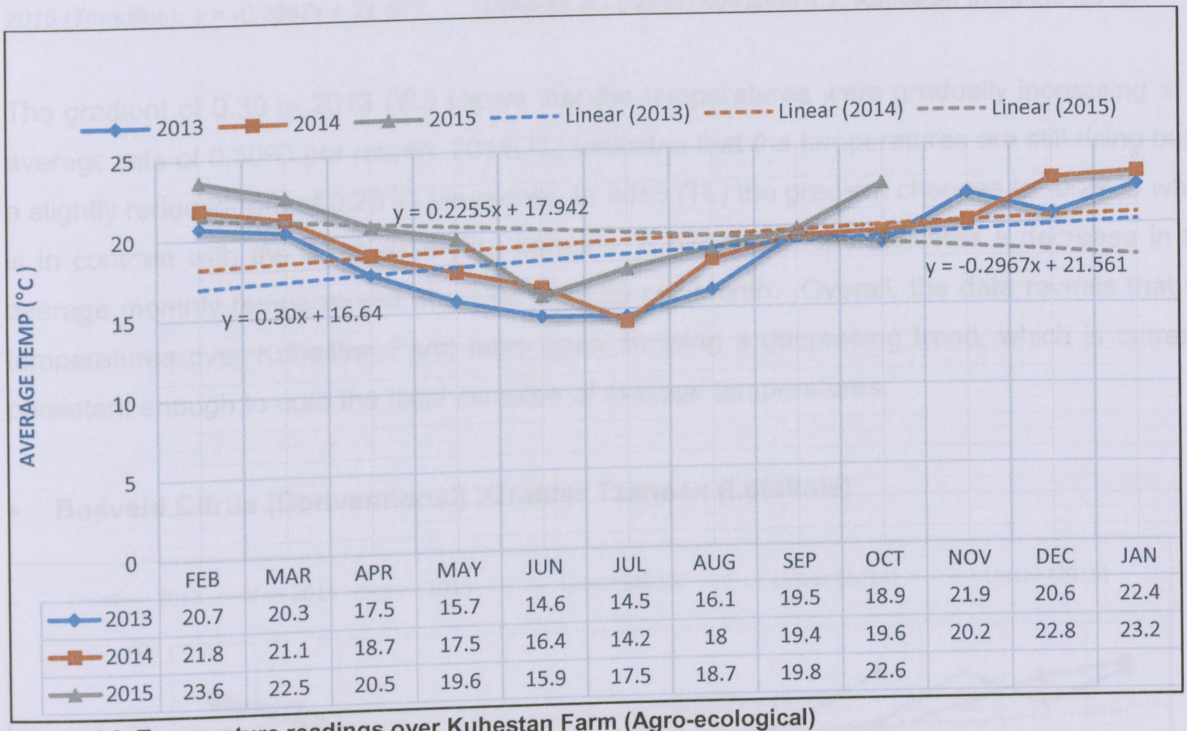
## 4.2. Surface temperature patterns over farms.

This part of the study addresses objective number one, which seeks to examine the patterns in temperature readings over the specific sampled locations in each municipality. The daily temperature readings were averaged monthly for each farm and plotted as a linear graph for trends analysis. This section of the chapter consists of various Microsoft Excel outputs, which include linear graphs, summation tables and percentage variance outputs. These plots are done for each agro-ecological farm and compared to those done on a conventional farm in the same general location. The Greater Tzaneen municipality temperature plots are shown in Figures 4.1 and 4.2 below.



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- **Kuhestan Farm (Agro-ecological): Greater Tzaneen**




| | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | JAN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | 20.7 | 20.3 | 17.5 | 15.7 | 14.6 | 14.5 | 16.1 | 19.5 | 18.9 | 21.9 | 20.6 | 22.4 |
| 2014 | 21.8 | 21.1 | 18.7 | 17.5 | 16.4 | 14.2 | 18 | 19.4 | 19.6 | 20.2 | 22.8 | 23.2 |
| 2015 | 23.6 | 22.5 | 20.5 | 19.6 | 15.9 | 17.5 | 18.7 | 19.8 | 22.6 | | | |

**Figure 4.1: Temperature readings over Kuhestan Farm (Agro-ecological)**

Figure 4.1 presents the average temperatures plotted for each year. Linear regression trend-lines were also fitted through the average temperature plots. Trend-lines perform an analysis of statistical patterns in the distribution of data. The data was collected up to October 2015 due to time constrains. This poses a validity threat which is compensated for by taking averages as opposed to taking every single measured unit. Readings for 2013 are taken as the reference year, meaning that the analysis of patterns thus starts from 2013 to 2015. According to Figure 4.1, the 2015 graph appears to lie higher than the 2014 which lies higher than the 2013. This thus means that the average annual temperatures follow similar trend. In this study the primary period of measurement was taken as a month.

Annual averages are not statistically reliable enough to give a conclusive indication of the prevailing patterns. A trend-line fitted through the data performs an internal linear regression and displays the output as a straight line with an equation of its own. The average temperatures for 2013 in general are the lowest, followed by 2014 and then 2015. However the trend-lines gradients reveal the opposite of what the main graphs are showing. The trend-line equations below compensate for the limitations of the main graphs.



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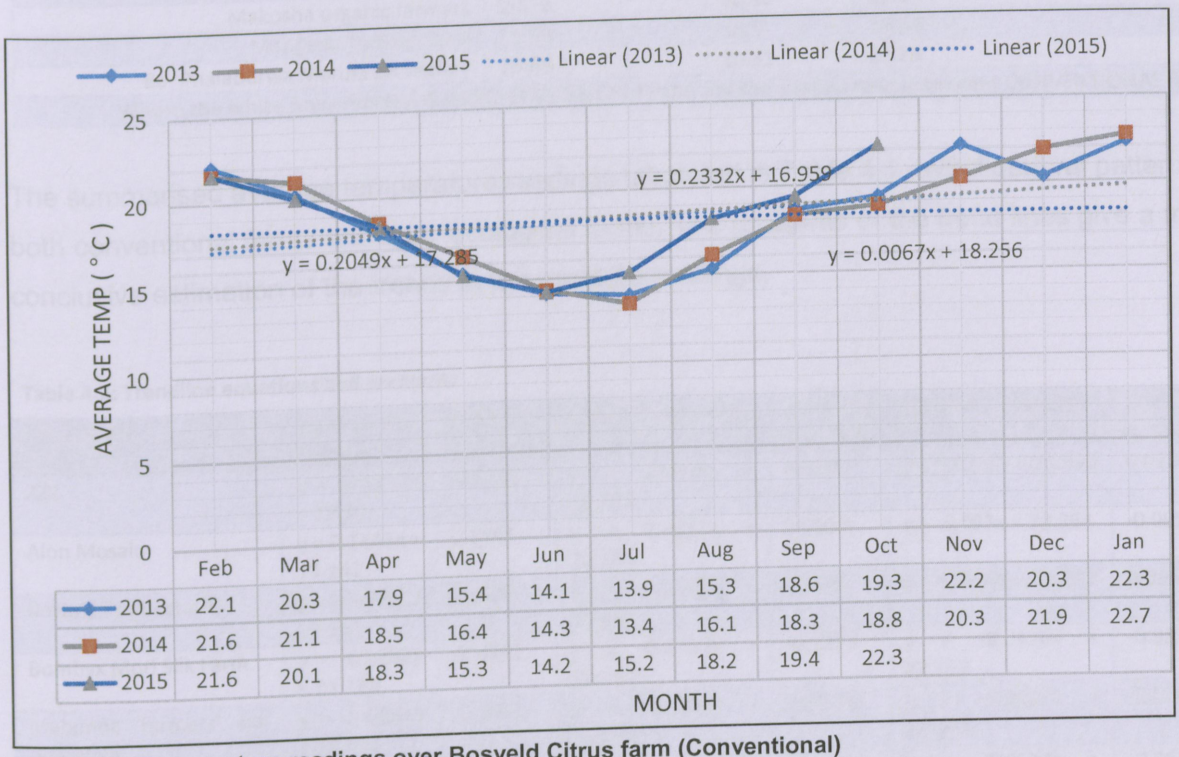
*2013 (Trendline): y = 0.30x + 16.64* *(Gradient is 0.30)* **equation 4.1: Kuhestan trendline (2013)**

*2014 (Trendline): y = 0.2255x + 17.942* *(Gradient is 0.2255)* **equation 4.2: Kuhestan trendline (2014)**

*2015 (Trendline): y = -0.2967x + 21.561* *(Gradient is - 0.2967)* **equation 4.3: Kuhestan trendline (2015)**

The gradient of 0.30 in 2013 (TL) shows that the temperatures were gradually increasing at an average rate of 0.30°C per month. 2014(TL) indicates that the temperatures are still rising but at a slightly reduced rate of 0.23 °C per month. In 2015 (TL) the gradient changes to -0.29 °C which is in contrast with the 2013/2014 (TL) patterns. A negative slope indicates a decrease in the average monthly temperatures at a rate of -0.29 per month. Overall, the data reveals that the temperatures over Kuhestan Farm have been showing a decreasing trend, which is currently persistent enough to curb the local increase of average temperatures.

- **Bosveld Citrus (Conventional) :Greater Tzaneen (Letsitele)**




| | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | 22.1 | 20.3 | 17.9 | 15.4 | 14.1 | 13.9 | 15.3 | 18.6 | 19.3 | 22.2 | 20.3 | 22.3 |
| 2014 | 21.6 | 21.1 | 18.5 | 16.4 | 14.3 | 13.4 | 16.1 | 18.3 | 18.8 | 20.3 | 21.9 | 22.7 |
| 2015 | 21.6 | 20.1 | 18.3 | 15.3 | 14.2 | 15.2 | 18.2 | 19.4 | 22.3 | | | |

**Figure 4.2: Temperature readings over Bosveld Citrus farm (Conventional)**

A similar trend line regression of the data performed over Bosveld Citrus Farm produced the equations listed below.

*2013 (Trendline) = y = 0.0067x + 18.256* *(Gradient is 0.0067)* **equation 4.4: Bosveld trendline (2013)**

*2014 (Trendline) = y = 0.2049x + 17.285* *(Gradient is 0.2049)* **equation 4.5: Bosveld trendline (2014)**

*2015 (Trendline) = y = 0.2332x + 16.959* *(Gradient is 0.2332)* **equation 4.6: Bosveld trendline (2015)**



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The preceding equations reveal an increase in gradient from 2013 through 2014 to 2015. The average temperatures are increasing at a rate of 0.0067 in 2013. The rate of change in 2014 increases drastically to 0.2049 and increases even further in 2015 to 0.2332. This analysis of trend lines gradients reveals that the average temperatures over Bosveld Citrus show a positive linear increasing pattern. This is contrary to the patterns shown by the Agro-ecological farm in the same general area; namely, Kuhestan. Trendline gradient analysis was performed on the rest of the eight (8) remaining farms. The results are listed in the two tables below.

**Table 4.1: Average temperatures (°C)**

| Farm Name | 2013 | 2014 | 2015 |
|---|---|---|---|
| ZZ2 | 19.77 | 20.2 | 20.75 |
| Alon Mosaic | 20.08 | 20.14 | 19.89 |
| Bavaria Fruit Estates | 19.95 | 20.33 | 19.82 |
| Bombyx Mori Silk Farm | 20.93 | 21.03 | 20.87 |
| Mabunda farmers' co-operative | 20 | 20.07 | 20.31 |
| Makosha organic farmers | 20.23 | 20.36 | 19.6 |
| Mangena Tomato farm | 19.93 | 20.1 | 19.54 |
| Ba- Phalaborwa Marula secondary | 19.69 | 20.33 | 20.78 |

**Where the white rows represent AGRO-ECOLOGICAL farms and the shaded rows represent CONVENTIONAL farms.**

The summarised average temperature readings tabulated in Table 4.1 reveal general patterns in both conventional farms and agro-ecological farms. The gradients of the trend lines give a more conclusive estimation of the trends in temperature readings.

**Table 4.2: Trendline equations and gradients**

| Farm Name | 2013 (TL) Equation | 2013 (TL) Gradient | 2014 (TL) Equation | 2014 (TL) Gradient | 2014 (TL) Equation | 2015 (TL) Gradient |
|---|---|---|---|---|---|---|
| ZZ2 | y = -0.0252x + 19.93 | -0.0252 | y = 0.0699x + 19.745 | 0.0699 | y = 0.0285x + 20.593 | 0.0285 |
| Alon Mosaic | y = 0.1448x + 19.142 | 0.1448 | y = 0.0052x + 20.108 | 0.0052 | y = -0.095x + 20.364 | -0.095 |
| Bavaria Fruit Estates | y = 0.0608x + 19.555 | 0.0608 | y = 0.0748x + 19.847 | 0.0748 | y = 0.0958x + 20.347 | 0.0958 |
| Bombyx Mori Silk Farm | y = -0.0392x + 21.188 | -0.0392 | y = -0.1713x + 22.147 | -0.1713 | y = -0.3376x + 22.727 | -0.3376 |
| Mabunda farmers' co-operative | y = -0.0881x + 19.661 | -0.0881 | y = -0.0486x + 20.042 | -0.0486 | y = -0.3017x + 21.142 | -0.0302 |
| Makosha organic farmers | y = 0.0021x + 20.014 | 0.0021 | y = -0.072x + 19.598 | -0.072 | y = -0.0633x + 20.713 | -0.0633 |
| Mangena Tomato farm | y = -0.0465x + 20.227 | -0.0465 | y = 0.0797x + 19.582 | 0.0797 | y = -0.03817x + 21.453 | -0.03817 |
| Ba- Phalaborwa Marula secondary | y = -0.0374x + 19.935 | -0.0374 | y = 0.0909x + 19.742 | 0.0909 | y = -0.0642x + 21.133 | -0.0642 |



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Alon mosaic farm has an initial gradient of 0.1448 in 2013 which decreases to 0.052 in 2014 and further decreases to -0.095 in 2015. Similar decreasing pattern can be observed in farms such as Bombyx-Mori, which starts with a gradient of -0.0392 in 2013 and a final rate of -0.3376. Makosha Organic Farmers start with an initial value of 0.0021 and a final rate of -0.0633. Alon Mosaic, Bombyx-Mori, Makosha and Kuhestan make up 80% of the agro-ecological farms in the entire sample. Ba-Phalaborwa Marula does not follow the same trend as the rest of the Agro-ecological farms. Ba-Phalaborwa Marula has an initial value of -0.0374, increasing to 0.0909 in 2014 and decreasing to -0.0642 in 2015. This is an increasing pattern, as compared to the other agro-ecological farms which shows a decreasing pattern.

Bosveld Citrus plotted on Figure 4.2, reveals a decrease in annual average temperatures. Table 4.2 reveals that ZZ2 starts with an initial rate of -0.0252 and has a final rate of 0.025. This is an increase in the annual average temperatures. Mabunda has an initial value of -0.0881 in 2013, increasing to a still negative rate of -0.0486 and a final rate of -0.302. This is a complex pattern because the final rate of -0.0486 (2015) is a negative rate which means average temperatures are decreasing. However, the gradient of 2015 (-0.0486) is greater than the gradient of 2013 (-0.0881). This means the area is experiencing an increase in average temperatures. Bavaria Fruit estate follows an increasing trend with an initial value of 0.0608 in 2013 and a final rate of 0.0958 in 2015. Mangena has a final rate of -0.03817 (2015) and an initial value of -0.0465 (2013). Bosveld, ZZ2, Mabunda, Bavaria and Mangena make up 100% of the conventional farms, which show an increasing pattern. From this assessment, the agro-ecological farms collectively reveal a decreasing trend in the average temperatures. On the other hand, conventional farms show an increasing trend in the average temperatures.

A percentage variance was used to assess the change over the period of assessment. A percentage variance uses the initial value (2013) and the final value (2015) to estimate the overall percentage by which the rate has changed and also the direction of the change (Stanpenhurst, 2009).

The formula below was used to calculate the percentage change in the average temperature gradients over the period of 2013-2015.

$$Percentage\ Variance = 100 \times \left\{\frac{V1 - V2}{Abs\ (V1)}\right\}$$ **Equation 4.7: Percentage variance**

*V1 = the initial value (2013 gradient)*
*V2 = the new value (2015 gradient)*

*Abs = Microsoft Excel auto-correction function that corrects for zero division.*



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Table 4.3: Gradient Percentage Variance (2013 – 2015)

| Farm name | Initial value (2013) | New Value (2015) | Percentage Variance (%) |
|---|---|---|---|
| Kuhestan | 0.30 | -0.29 | -17.7 |
| Bosveld Citrus | 0.067 | 0.23 | 1.09 |
| ZZ2 | -0.03 | 0.03 | 213.10 |
| Alon Mosaic | 0.15 | -0.01 | -165.61 |
| Bombyx-Mori Silk Farm | -0.04 | -0.34 | -761.22 |
| Bavaria Fruit Estates | 0.06 | 0.10 | 57.56 |
| Makosha organic farmers | 0.002 | -0.06 | -3114.26 |
| Mabunda farmers' co-operative | -0.09 | -0.03 | 65.72 |
| Ba - Phalaborwa Marula secondary | -0.04 | -0.06 | -71.66 |
| Mangena Tomato farm | -0.05 | -0.04 | 17.92 |

The percentage variance does not give the rate at which the actual temperatures are changing. The output of the percentage variance is the percentile change in the rate of change of average temperatures. The trend line of each year gives the rate of change of average temperatures for that specific year. The percentage variance shows very high negative changes and low to moderate positive changes. Makosha Organic Farmers and Bombyx-Mori show the highest negative values, while Ba-Phalaborwa and Mabunda show the lowest positive values. We have already established the general patterns of both agro-ecological as well as conventional farms based on Table 4.2 and 4.1. Table 4.3 indicates that agro-ecological farms are experiencing a higher level of decrease in average temperatures while conventional farms are experiencing a lower increase in average temperatures. All the techniques and methods applied in this section 4.1 reveal that average temperatures are decreasing more rapidly over agro-ecological farms than they are increasing over conventional farms.



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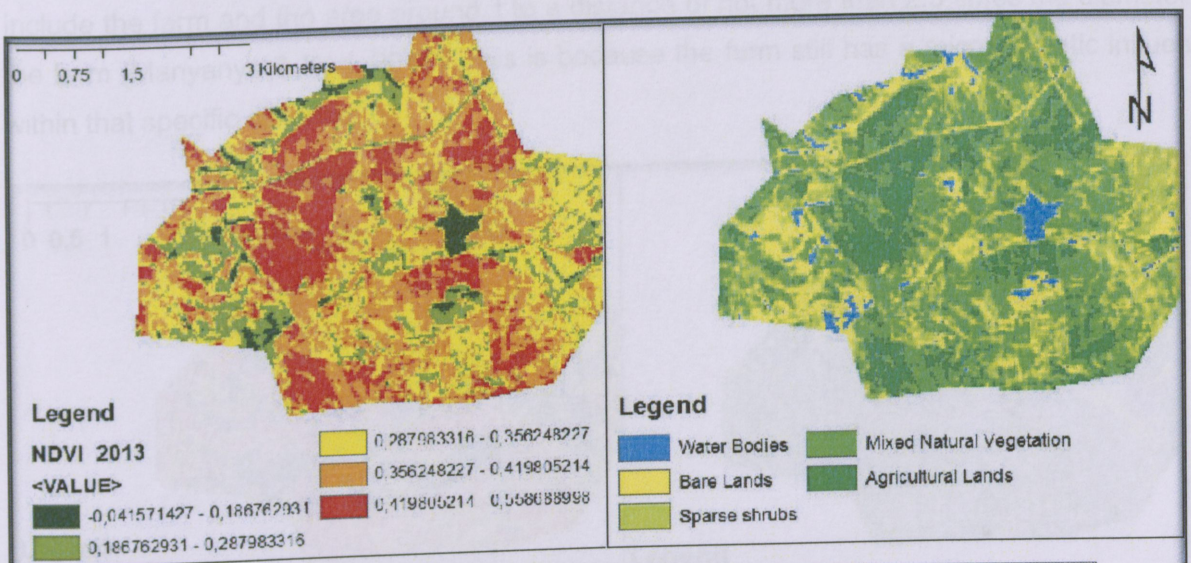
## 4.3. Changes in Crop Health and Soil carbon content

### 4.3.1. Crop Health

#### 4.3.1.1. NDVI and Re-classified outputs

- **Kuhestan Farm (Agro-ecological): Greater Tzaneen**

The pre-processing, processing and analysis of the images obtained from USGS and SANSA tec produced NDVI and re-classified images. The most important aspects of this output are, NDVI-red minimum and maximum values and the re-named classes according to land use. The Included table shows area percentages of the NDVI-reclassified image, all of which was performed in Arc GIS 10.2 to produce Figure 4.3.




| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percentage |
|---|---|---|---|---|
| Water bodies | 1 | 93 | 621794,482699 | 6,279798 |
| Bare Land | 2 | 463 | 2658560,161693 | 23,306949 |
| Sparse Shrubs | 3 | 768 | 6166559,194267 | 35,342844 |
| Mixed Natural Vegetation | 4 | 575 | 7609903,493214 | 26,461114 |
| Agricultural Lands | 5 | 274 | 3730144,448199 | 8,909296 |

**Figure 4.3: NDVI and Re-classified NDVI (Kuhestan Farm: 2013)**

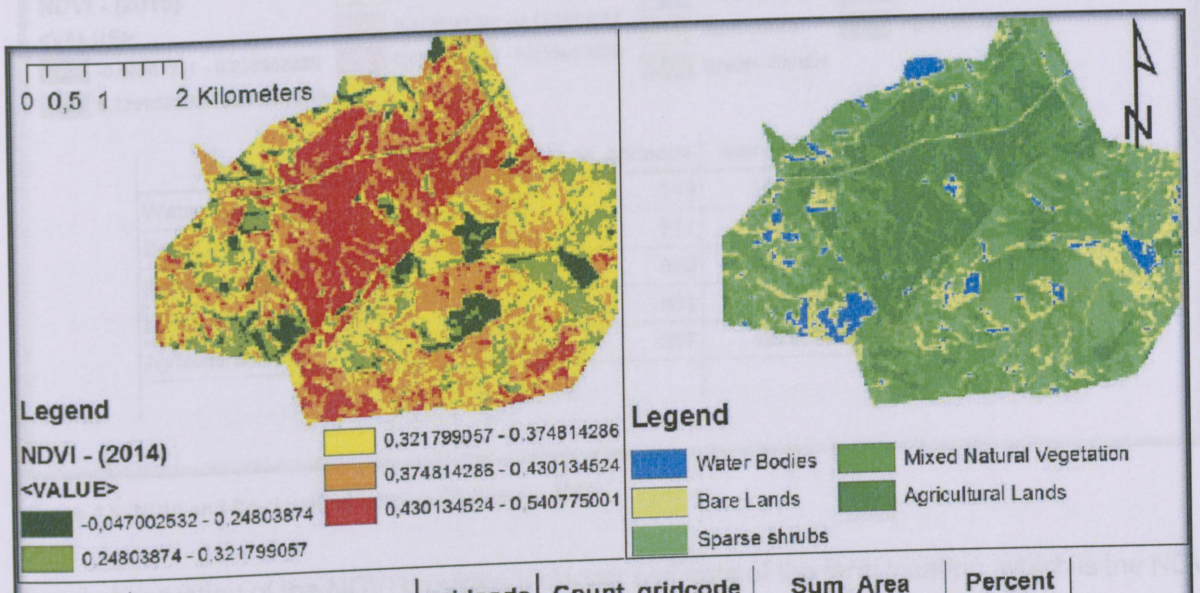
Initially, from visual observation of the two image outputs there is no clear distinction of the location of the farm area. According to the NDVI image, the farm area should be represented by the red colour which indicates dense vegetation or chlorophyll saturated vegetation (0.41 – 0.56).



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The NDVI shows random patches of dense vegetation spread across the entire image area. This region of the NDVI output will from here-on be referred to for the purposes of this study as NDVI-red. According to the NDVI output, the range of the NDVI-red has a minimum threshold value of 0.420 and a maximum of 0.559. Then the table of percentages calculated in Arc map using image grid code reveals that the percentage of the image occupied by Arable land was 8.910 in 2013. This percentage does not only indicate area but it is also governed by the NDVI-red output. It is thus an indication of area and mostly, crop health.

The challenge here becomes geographical location. Because the images are taken from space and cover a large swath width, this means that zooming in on the image to pixel extent produces a distorted image with low reliability. In order to maintain reliability, the images were zoomed in to include the farm and the area around it to a distance of not more than 2.5 times the diameter of the farm (Manyanya & Kori, 2014). This is because the farm still has a micro-climatic influence within that specific distance.



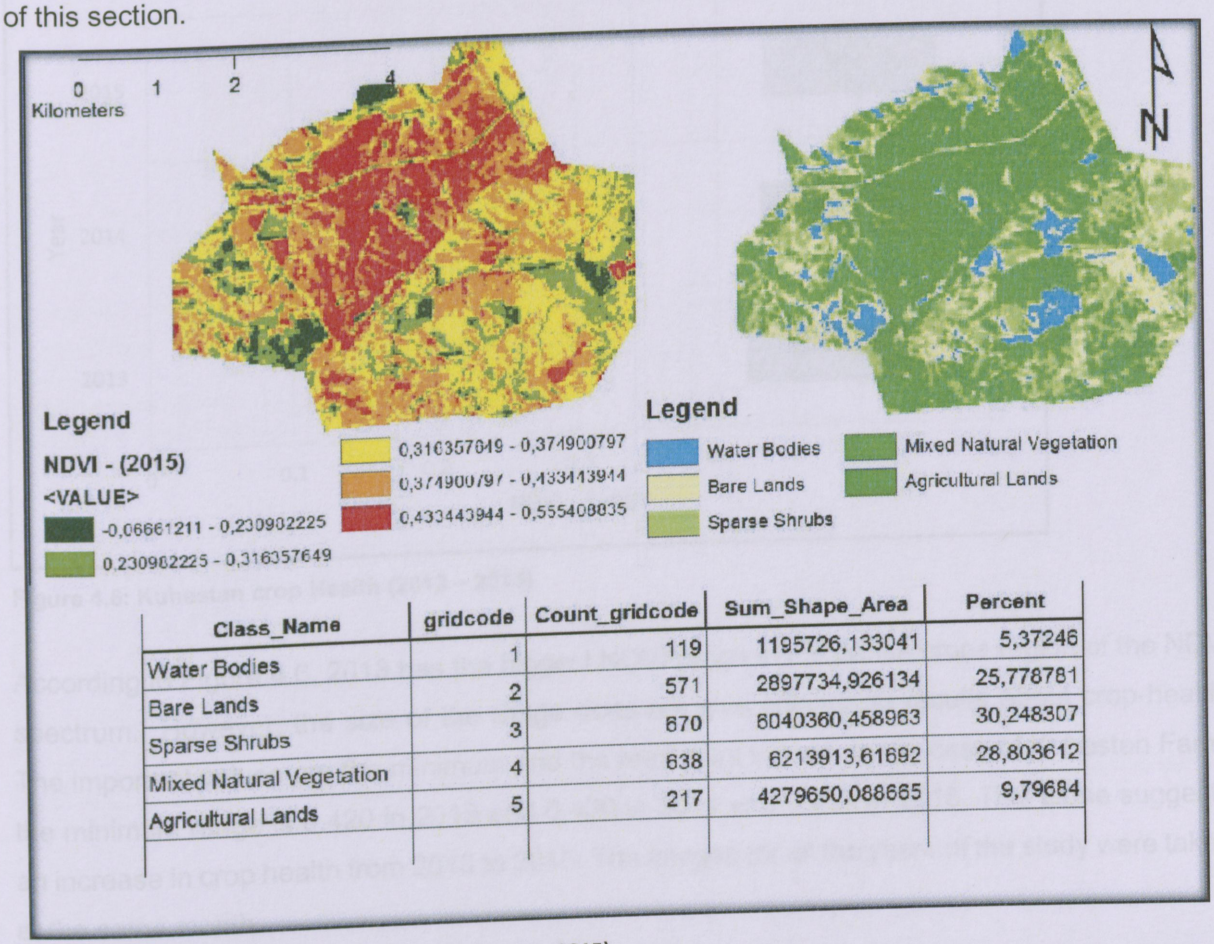

| Class_Name | gridcode | Count_gridcode | Sum_Area | Percent |
|---|---|---|---|---|
| Water Bodies | 1 | 128 | 940572,780437 | 5,451448 |
| Bare Lands | 2 | 558 | 2886484,942706 | 23,764906 |
| Sparse Shrubs | 3 | 752 | 6407358,820601 | 32,027257 |
| Mixed Natural Vegetation | 4 | 693 | 6419448,391582 | 29,51448 |
| Agricultural Lands | 5 | 217 | 3971540,592471 | 9,241908 |

Figure 4.4.: NDVI and Re-classified maps (Kuhestan, 2014)



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The year 2014, reveals an increase in the percentage occupied by arable land from 8.909 % to 9.242%. Also the NDVI range for arable land has shifted from 0.419 – 0.558 to 0.430 – 0.541 which seems like a small shift but NDVI ranges only from -1 to +1. This means that even the slightest shift is statistically significant. The significance of this shift is further explained at the end of this section.




| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Water Bodies | 1 | 119 | 1195726,133041 | 5,37246 |
| Bare Lands | 2 | 571 | 2897734,926134 | 25,778781 |
| Sparse Shrubs | 3 | 670 | 6040360,458963 | 30,248307 |
| Mixed Natural Vegetation | 4 | 638 | 6213913,61692 | 28,803612 |
| Agricultural Lands | 5 | 217 | 4279650,088665 | 9,79684 |

**Figure 4.5: NDVI and Re-classified outputs (Kuhestan: 2015)**

Visual observation of the NDVI provides a clearer estimate of the farm location, which is the NDVI-red region of the NDVI spectrum. The percentage has also increased from 8.9 in 2013 to 9.2 in 2014 and 9.7 in 2015. This means that there is an increase in arable land. We still cannot conclude on crop health patterns until we closely analyse the shifts in the NDVI-red from year to year. The floating bar graph in Figure 4.5 drawn from Microsoft Excel plots the NDVI- red range values from 2013 to 2015. From the NDVI output, the following formula yielded the results shown below on the graph.



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**Equation 4.5: Floating Bar Delta function**

Delta = Minimum value – maximum value (NDVI-red)




**Figure 4.6: Kuhestan crop Health (2013 – 2015)**

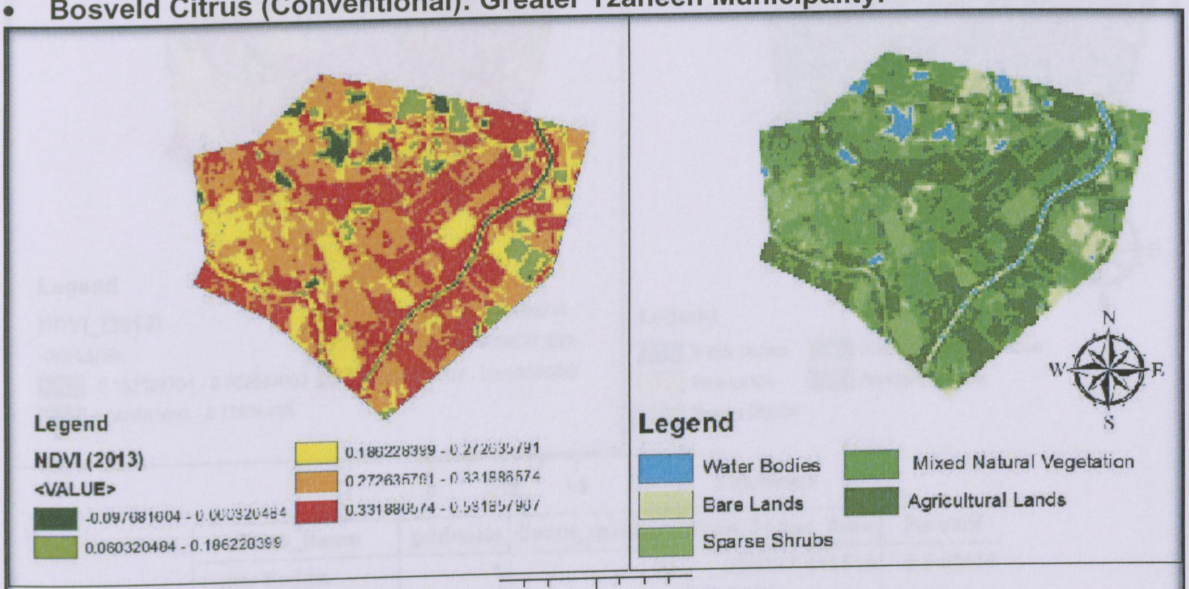
According to Figure 4.6, 2013 has the biggest NDVI range in the dense crops region of the NDVI spectrum. However, the size of the range does not give conclusive results about crop-health. The important values are the minimum and the maximum values. In the case of Kuhestan Farm, the minimum range is 0.420 in 2013 and 0.430 in 2014 and 0.433 in 2015. This alone suggests an increase in crop health from 2013 to 2015. The images for all the years of the study were taken at the same month.

However a conclusion cannot be made on the increase in crop health without a complete analysis of the entire NDVI-red range. The maximum value starts off at 0.559 in 2013, then 0.542 in 2014 and finally 0.555 in 2015. There was a dip in 2014 followed by an increase in 2015. As explained above, despite the dip of the maximum value of 2014, there is an increase in the minimum value. This means there is an increase in the minimum threshold for healthy crops. We can thus conclude that there is an increase in crop health over the period from 2013 – 2015.



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- **Bosveld Citrus (Conventional): Greater Tzaneen Municipality:**



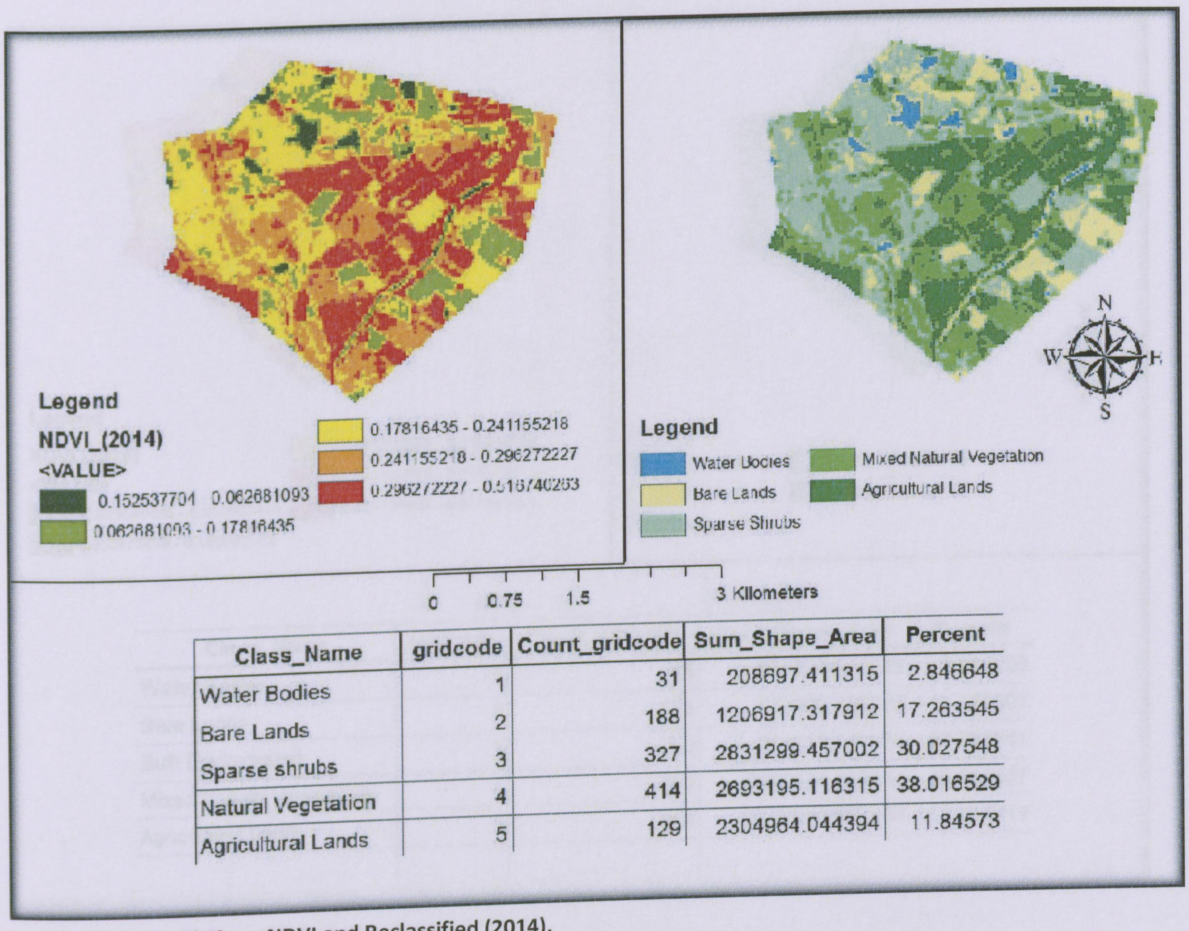

| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Water Bodies | 1 | 53 | 230763.495594 | 5.805077 |
| Bare Lands | 2 | 164 | 603288.157023 | 15.86854 |
| Sparse Shrubs | 3 | 328 | 1708454.995792 | 30.737081 |
| Mixed Natural Vegetation | 4 | 392 | 3656841.361105 | 35.539438 |
| Agricultural Lands | 5 | 166 | 3050698.219131 | 12.049864 |
| | | | | |

**Figure. 4.7: Bosveld Citrus NDVI and Reclassified (2013).**

NDVI reveals agricultural lands with healthy crops at a range of (0.332 – 0.532) occupying a percentage of 12.04 of the entire image. Also notable are the limited water bodies which currently are cumulatively at 5.8% of the entire image. This might explain some of the patterns which emerge later because of its significance in crop irrigation. The agricultural lands can be easily identified from the image but the distribution is more random than that of Kuhestan. The limited water supply poses a threat to agricultural production which might influence the NDVI output of 2014 presented in Figure 4.8.



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| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Water Bodies | 1 | 31 | 208697.411315 | 2.846648 |
| Bare Lands | 2 | 188 | 1206917.317912 | 17.263545 |
| Sparse shrubs | 3 | 327 | 2831299.457002 | 30.027548 |
| Natural Vegetation | 4 | 414 | 2693195.116315 | 38.016529 |
| Agricultural Lands | 5 | 129 | 2304964.044394 | 11.84573 |

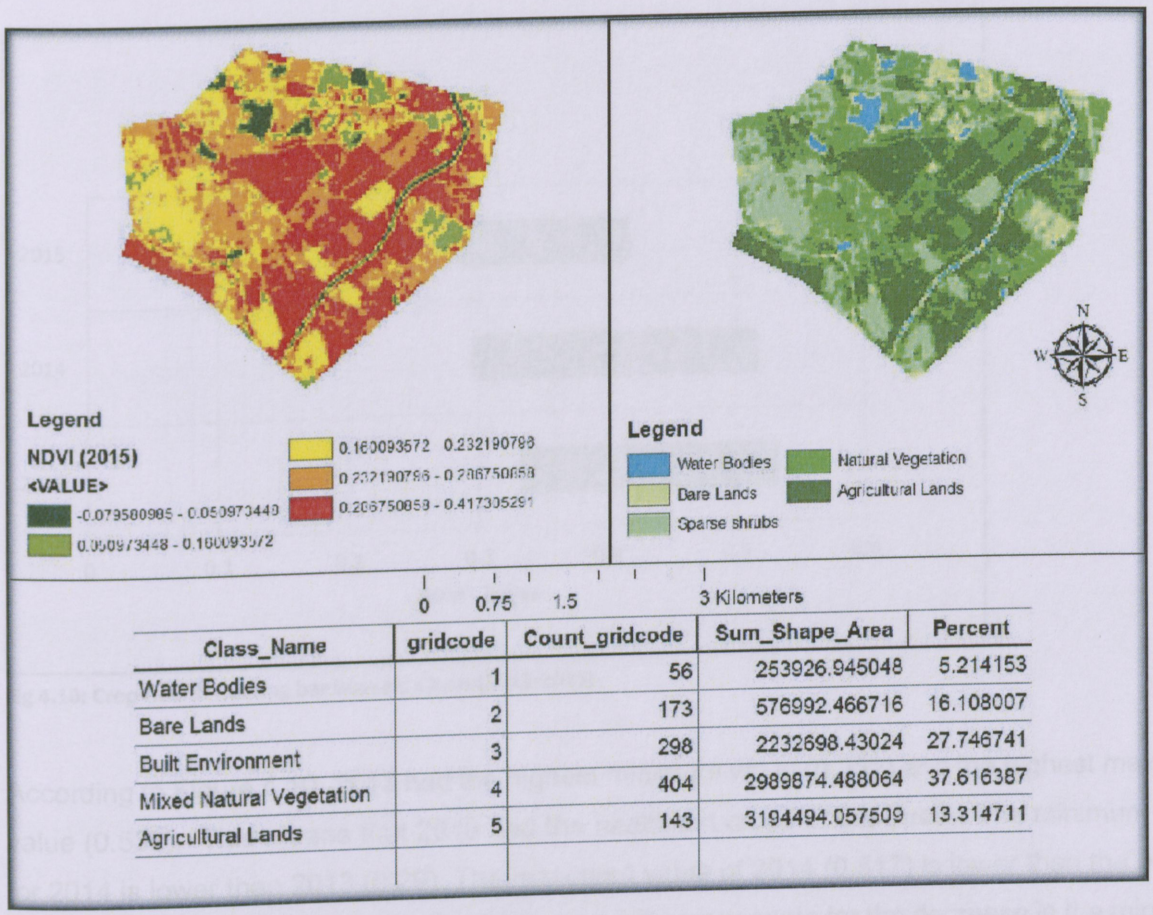
**Figure 4.8: Bosveld Citrus NDVI and Reclassified (2014).**

Despite the lack of a distinct grouping of land-use activities, the 2014 NDVI (Figure 4.8) shows an existence of a healthy agricultural system. The biggest concern as far as 2014 goes is the drastic decrease of the water supply. The portion of the image occupied by agricultural lands has also decreased from roughly 12% to 11%. This is also a factor which could have contributed to the decrease in crop health. This is further explored in Chapter 5.

The re-classified image shows that the majority of the isolated water bodies are surrounded by bare lands. Vegetation density seems to increase with increasing distance from the water source, which is contrary to what one would expect. An increase in the percentage occupied by bare lands and sparse shrubs automatically causes a decrease in the other classes. Overall, crop health has decreased from 2013 to 2014.



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| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Water Bodies | 1 | 56 | 253926.945048 | 5.214153 |
| Bare Lands | 2 | 173 | 576992.466716 | 16.108007 |
| Built Environment | 3 | 298 | 2232698.43024 | 27.746741 |
| Mixed Natural Vegetation | 4 | 404 | 2989874.488064 | 37.616387 |
| Agricultural Lands | 5 | 143 | 3194494.057509 | 13.314711 |

**Figure 4.9: Bosveld Citrus NDVI and Reclassified (2015).**

The year 2015 has the lowest minimum and maximum values. This means lower crop health, as compared to 2014 and 2013. The water bodies seem to have increased from 3% of the previous year to 5%. This however is contrary to expectations. The decrease in crop health prompts for an expectation of a reduction in water bodies' percentage as well. However this is the opposite, implying that the reduction of crop health is not attributed to irrigation. The area percentage occupied by agricultural lands (Class 5) has increased from 11% to 13% from 2014 to 2015. We can thus conclude that there is a decrease in crop health, which is not due to irrigation and also not due to an increased area percentage.



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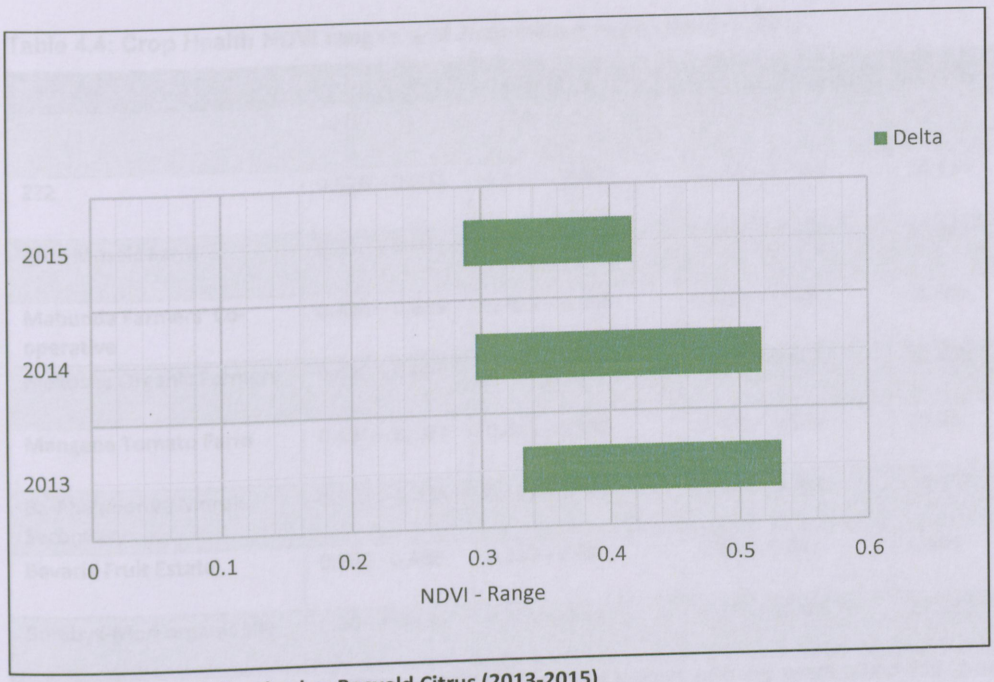



**Fig 4.10: Crop Health floating bar Bosveld Citrus (2013-2015)**

According to Figure 4.10, 2013 had the highest minimum value (0.332) and the highest maximum value (0.532). This means that 2013 had the healthiest crops of the three. The minimum value for 2014 is lower than 2013 (0.29). The maximum value of 2014 (0.517) is lower than the one for 2013. This means that the maximum value does not compensate for the decrease in the minimum value. This thus shows an overall decrease in crop health from 2013 to 2014. An even more drastic decrease happens in 2015 when the minimum drops to 0.287, which is a 3.04 % decrease. The maximum value decreases by 21.6 % to a value of 0.417 in 2015. This is a further decrease in crop health from 2013 through 2014 to 2015.

Table 4.4 below presents the NDVI and Re-classified data which would require more space in order to be included in this chapter as maps. The individual NDVI and Re-classified maps are attached at the back of this report as part of Appendix 1. The NDVI ranges for agricultural lands as well as the area percentage are shown below.



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**Table 4.4: Crop Health NDVI ranges and Area Percentages (2013 - 2015)**

| Farm Name | NDVI-red (range) | | | Area Percentage | | |
|---|---|---|---|---|---|---|
| | 2013 | 2014 | 2015 | 2013 | 2014 | 2015 |
| ZZ2 | 0.526 – 0.638 | 0.517 – 0.643 | 0.443 – 0.554 | 34.444 | 32.860 | 30.454 |
| Alon Mosaic Farm | 0.357 – 0.441 | 0.390 – 0.491 | 0.430 – 0.502 | 12.346 | 3.704 | 4.734 |
| Mabunda Farmers' Co-operative | 0.424 – 0.619 | 0.403 – 0.559 | 0.365 – 0.549 | 30.605 | 28.440 | 35.850 |
| Makosha Organic Farmers | 0.430 – 0.663 | 0.432 – 0.530 | 0.550 – 0.650 | 28.458 | 24.474 | 33.960 |
| Mangena Tomato Farm | 0.434 – 0.507 | 0.445 - 0.536 | 0.403 – 0.503 | 19.08 | 24.447 | 14.09 |
| Ba-Phalaborwa Marula Secondary | 0.372 – 0.438 | 0.493 – 0.584 | 0.321 – 0.377 | 19.812 | 24.503 | 21.124 |
| Bavaria Fruit Estate | 0.280 - 0.480 | 0.319 - 0.481 | 0.290 - 0.445 | 6.569 | 6.868 | 8.476 |
| Bombyx-Mori organic silk | 0.30 – 0.412 | 0.309 – 0.434 | 0.341 – 0.469 | 17.325 | 19.190 | 17.775 |
| Where the white cells represent CONVENTIONAL farms and Shaded cells represent AGRO-ECOLOGICAL farms | | | | | | |

According to Table 4.4 Alon Mosaic shows a crop health increase in both the minimum as well as the maximum values. This means that not only did the least healthy crops of the farm increase in the wavelength of reflection but also did the maximum value. This means there was an increase in crop health from 2013 to 2015. ZZ2, which is in the same general location, shows a decrease in both the minimum and maximum values, which indicates a crop health decrease. Notably, the area increased in size from 2013 to 2015.

Makosha Farm displays the same pattern in crop health as Alon Mosaic, Bombyx-Mori and Kuhestan (Figure 4.10). Mangena Tomato Farm shows the same trends as ZZ2; Mabunda, Bavaria and Bosveld (Figure 4.11). The tabular representation presents challenges in terms of a more detailed analysis of the NDVI range pattern irrespective of the changes in Area. A floating bar graph using a Delta function was plotted to give a more accurate interpretation of the emerging patterns.



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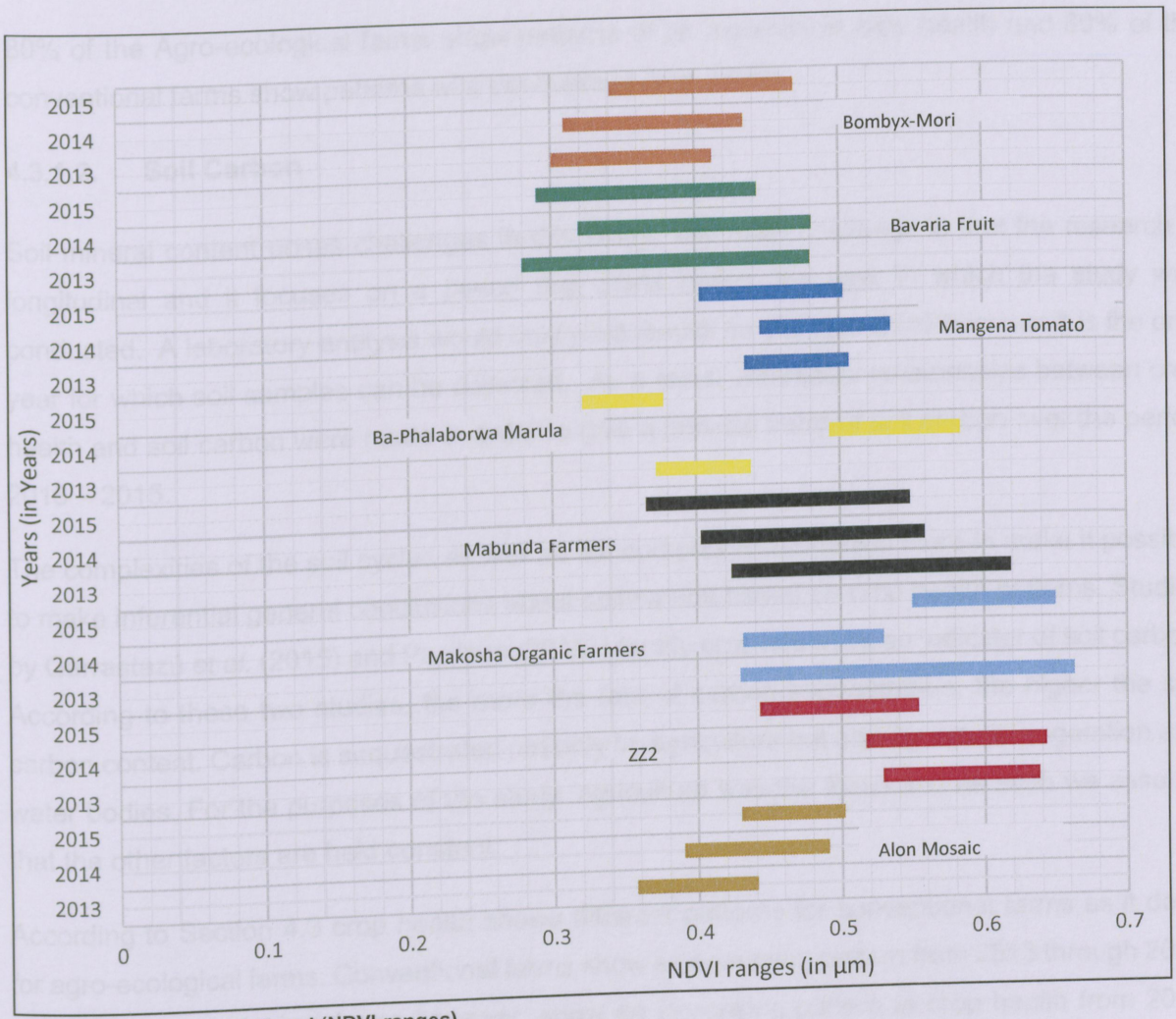



**Figure 4.11: Crop Health Trend (NDVI-ranges)**

The Delta function is a representative of both the minimum and the maximum values but it is still not a mean value. Thus it is more representative than a mean because it is a range rather than a single value mean. Stacking the NDVI ranges in succession indicates any kind of patterns that would emerge. The direction of the plot indicates the direction of the relationship if one exists at all. This works like to a trend-line analysis which performs an internal regression.

Initially, through a visual observation of the plot, a sinusoidal pattern can be spotted. Visual observation increases the chances of a higher Type 1 error. Thus a detailed examination of the output is needed. This is given by the individual directions of the stacked bars. Alon Mosaic, Makosha and Bombyx show an overall increasing pattern, indicating a positive gradient. ZZ2, Bavaria, and Mabunda show an overall decreasing pattern, indicating a negative gradient. Figures 4.10 and 4.11 show Kuhestan to be increasing and Bosveld to be decreasing. This means that



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80% of the Agro-ecological farms show patterns of an increase in crop health and 80% of the conventional farms show patterns of a decrease in crop health.

#### 4.3.1.2. Soil Carbon

Soil mineral content poses challenges in this study. The main challenge is that the research is longitudinal and it focuses on a period that starts before the year in which the study was conducted. A laboratory analysis would only yield results for the year 2015 because it is the only year for which soil samples can be collected. As a result, inferential relationships between crop health and soil carbon were made in order to give a general trend of soil carbon over the period 2013 – 2015.

The complexities of the soil cycles as well as the complex relationships there-in make it possible to make inferential general conclusions about soil carbon based on crop health patterns. Studies by Garrastazú *et al.* (2015) and Powlson (2016) identify crop health as an indicator of soil carbon. According to these two studies, the more the rate of carbon sequestration, the higher the soil carbon content. Carbon is sequestrated not only by agriculture but also by natural vegetation and water bodies. For the purposes of the study, agriculture was the focus and as such we assume that the other factors are held constant.

According to Section 4.3 crop health shows different patterns for conventional farms as it does for agro-ecological farms. Conventional farms show a decreasing pattern from 2013 through 2014 to 2015. Agro-ecological farms however, show an increasing pattern in crop health from 2013 through 2014 to 2015. Garrastazú *et al.* (2015) and Powlson (2016) provide an opportunity to make a general inference about soil carbon content. The soil carbon decreases from 2013 to 2015 on conventional farms and increases on agro-ecological farms. The limitations of making this inference is that we cannot measure just how much the soil carbon has changed. In this regard we are only interested in the general trend which makes the inference valid enough for a follow up detailed study.

### 4.4. Relationship between Crop Health, Soil and Temperature

This section links Section 4.1 with Section 4.2 in a relationship assessment. This is according to the third objective which was to: Assess the relationship between surface temperature patterns and crop health over the sampled farms of the study. Plotting the data graphically has the advantage that prevailing trends can be noted. The average temperatures and crop health (Delta)



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were plotted as histograms in order to accommodate the periodic x-axis. Traditionally the plotting method would be to plot individual histograms but that makes overall visual of the entire study as a whole challenging. This is the reason why the individual histograms were plotted next to each other on the same graph. The histograms were then shown as linear graphs in order to fit trend-lines through. The plots are shown in Figure 4.12 below

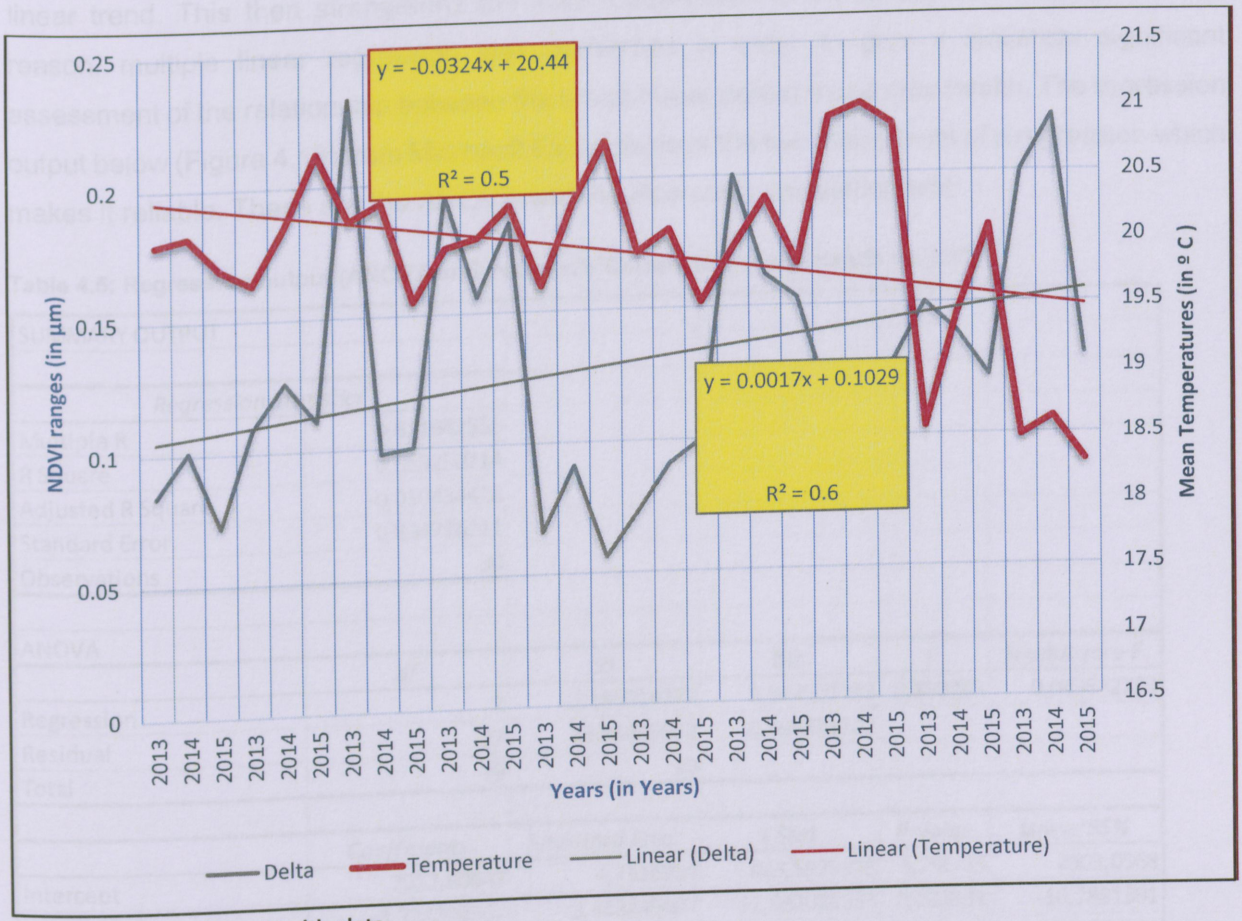



**Figure 4.12: LST and Crop Health plots.**

The Delta plots represent crop health while temperature represents the trends in annual land surface temperatures (LST). From observations of these two plots, a wave pattern emerges. The two plots seem to have an inverse relationship. This is however visual observation and cannot statistically prove the existence of a relationship between the two plots. The x-axis being a combination of periods means that the larger wave is a collective of individual wave functions for both crop health and LST respectively. This only poses a challenge where the individual periods which make up the X-axis are randomly distributed. This was overcome by arranging them in a linear increasing distribution. Thus we can then observe that the distribution of the peaks and troughs of the temperature curve tend to follow a pattern almost opposite to that shown by the



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Delta function. This is still not a statistical significant conclusion but it gives an idea of the kind of relationship to expect if one exists.

Trend lines were fitted into the plots in order to have a more accurate statistical idea of the kind of relationship expected. The trend lines are still individual graphs and cannot account for the entire plot. Temperature displays a negative linear trend while crop health displays a positive linear trend. This then strengthens the initial observation of an inverse relationship. For this reason, multiple linear regression was performed in order to give a statistical significant assessment of the relationship between the temperature patterns and crop health. The regression output below (Figure 4.13) from Microsoft Excel displays the two mains tests of a regression which makes it reliable. These are the ANOVA and the Pearson's correlation test.

**Table 4.5: Regression output (ANOVA and Pearson's Correlation) (Crop Health vs. LST)**

| SUMMARY OUTPUT | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| *Regression Statistics* | | | | | |
| Multiple R | 0,811942556 | | | | |
| R Square | 0,659250714 | | | | |
| Adjusted R Square | -0,010434418 | | | | |
| Standard Error | 0,834776211 | | | | |
| Observations | 30 | | | | |
| | | | | | |
| ANOVA | | | | | |
| | *df* | *SS* | *MS* | *F* | *Significance F* |
| Regression | 2 | 1,185014277 | 0,592507138 | 0,850263 | 0,043842733 |
| Residual | 27 | 18,81498572 | 0,696851323 | | |
| Total | 29 | 20 | | | |
| | | | | | |
| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* |
| Intercept | 2012,80647 | 4,7516936 | 423,5976978 | 3,78E-53 | 2003,0568 |
| X Variable 1 | -3,724824567 | 3,442445407 | -1,082028653 | 0,028881 | -10,7881391 |
| X Variable 2 | 0,084074001 | 0,23044888 | 0,364827119 | 0,037181 | -0,388768044 |

The relationship and strength of the relationship between crop health and annual LST averages is given by five (5) variables. These are P-value, R-square, Significance F and coefficients. The P-value of 0.029 means that the probability of the correlation being random is 2.9%. This thus means that there is a correlation between the regressed variables. The existence of a relationship means we can accept the Null Hypothesis. In this regression the Null Hypothesis was stated as follows:

*H0 = There is a correlation between LST and Crop Health.*



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Significance F of 0.043 is a statistical analysis which indicates that there is a probability of 4.3% that the correlation which is observed is a random occurrence. Thus implying a 95.7% probability that the correlation is statistically significant. The R-square value of 0.659 means that 65.9% of the variations in crop health can be explained by variations in LST. The co-efficient of the individual variables give the direction of the correlation with respect to each other.

Figure 4.11 and 4.12 suggest the existence of a linear inverse relationship. This is an inverse relationship, where an increase in one variable causes a decrease in the other. According to Table 4.5 temperature has a co-efficient of -3.725. This means that it is decreasing at a steady rate of -3.725 annually. Crop health has a co-efficient of 0.08, thus indicating an increase at a steady rate of 0.08 per year. These coefficients are identical to the gradients of the two trend-lines fitted into Figure 4.12. Thus confirming our initial observation of an inverse linear correlation. Thus the null hypothesis is accepted with statistical significance and a confidence level of 0.05

## 4.5. Farm crop yield statistics

Yield was calculated using the formula below and presented as percentages on Figure 4.13 below.

$$Seasonal\ Yield = \left[\frac{Amount\ of\ Crop\ Harvested\ per\ Season(kg)}{Total\ Area\ of\ Farm\ that\ Season(m^2)}\right] \text{ In Kg/m}^2$$

The yield statistics are shown as percentages of a total of 100%. Presenting the yield as percentages was due to some of the farmers discomfort with having the actual seasonal yield published for unknown reasons. This challenge was overcome by aggregating the seasonal yield for each of the three years to a perfect percentage of 100%. This was done for each of the farms individually. Instead of representing the yield as actual figures, the yield of each year presented as a percentage of the total yield of the entire period aggregated at 100 %. This also provides an advantage because it is easier to calculate the percentage variance of the yield from 2013 through 2014 to 2015. The yield percentages are presented on the stacked bar graph below (Figure 4.13).



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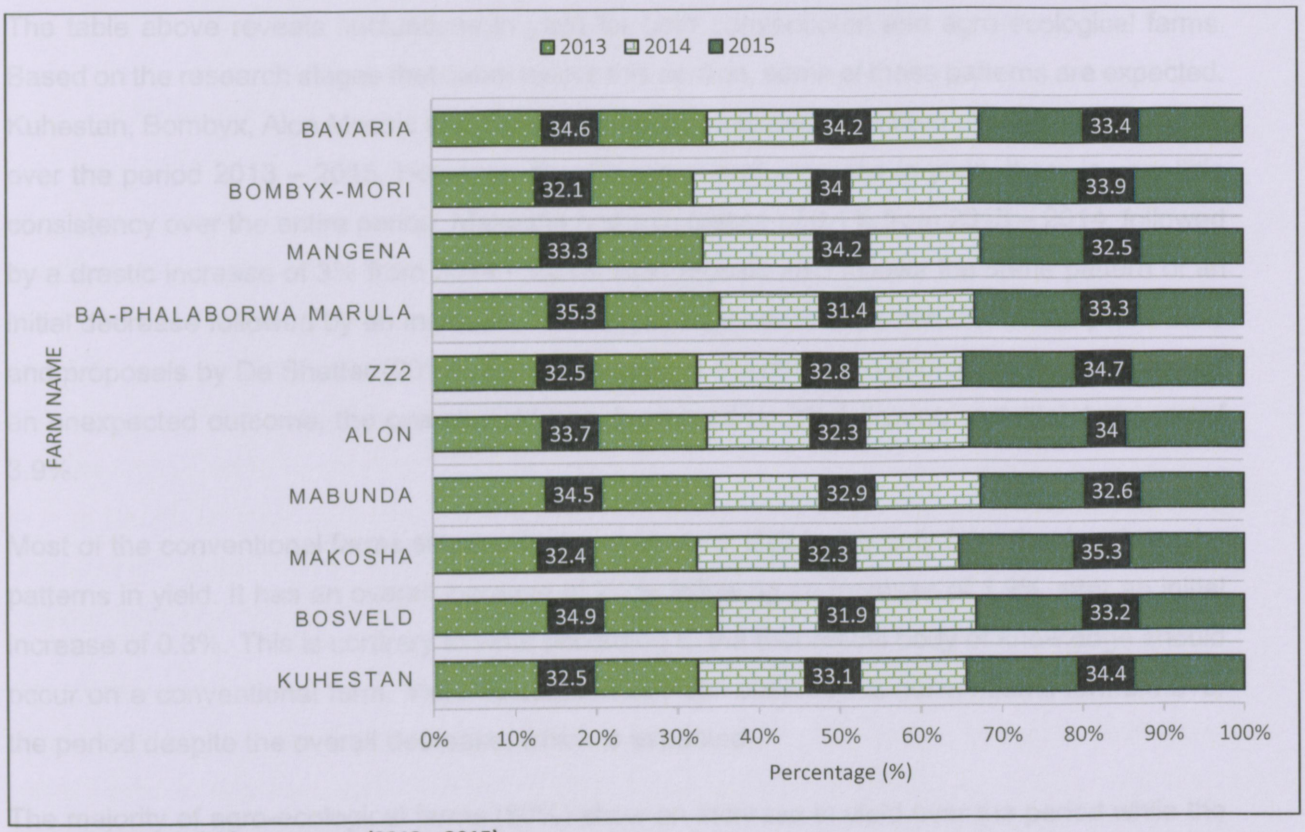



**Figure 4.13: Yield percentages (2013 – 2015).**

The bar graph above reveals that Bombyx-Mori has had an increase of 1.9% over the period from 2013 to 2015. Despite the increase in yield, it is still a 0.1% decrease as compared to the yield of 2014. Bavaria which occupies the same general location has had a slight decrease of 1.2%. This is also a decrease of 0.8% from the yield of 2014. The rest of the yield percentage variances over the period are presented in Table 4.6 below.

**Table 4.6: Yield percentage variance (2013 – 2015)**

| Farm Name | 2013 - 2014 | 2014 - 2015 | Overall Percentage variance |
|---|---|---|---|
| Kuhestan | 0,6 | 1,3 | 1,9 |
| Bosveld Citrus | -3 | 1,3 | -1,7 |
| Makosha Organic farmers | -0,1 | 3 | 2,9 |
| Mabunda farmers | -1,6 | -0,3 | -1,9 |
| Alon Mosaic | -1,4 | 1,7 | 0,3 |
| ZZ2 | 0,3 | 1,9 | 2,2 |
| Ba-Phalaborwa Marula | -3,9 | 1,9 | -2 |
| Mangena Tomato farm | 0,9 | -1,7 | -0,8 |
| Bombyx-Mori silk farm | 1,9 | -0,1 | 1,8 |
| Bavaria fruit estate | -0,4 | -0,8 | -1,2 |



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The table above reveals fluctuations in yield for both conventional and agro-ecological farms. Based on the research stages that came before this section, some of these patterns are expected. Kuhestan, Bombyx, Alon Mosaic and Makosha display an expected pattern of an increase in yield over the period 2013 – 2015. However, despite this overall increase in yield, there is very little consistency over the entire period. Makosha has a decrease of 0.1% from 2013 – 2014, followed by a drastic increase of 3% from 2014 – 2015. Alon Mosaic also follows the same pattern of an initial decrease followed by an increase. The overall increase is expected due to the predictions and proposals by De Shatter (2011). Ba-Phalaborwa is the only agro-ecological farm that shows an unexpected outcome, the overall yield has decreased by 2% following an initial decrease of 3.9%.

Most of the conventional farms show a decrease in yield. ZZ2 is the only farm that has irregular patterns in yield. It has an overall increase of 2.2% following an increase of 1.9% after an initial increase of 0.3%. This is contrary to what according to the theoretical body of knowledge should occur on a conventional farm. Yield fluctuations are still observed in conventional farmers over the period despite the overall decrease, which is expected.

The majority of agro-ecological farms (80%) show an increase in yield over the period while the majority (80%) of the conventional farms show a decrease in yield

### 4.6. Chapter summary.

The majority of conventional farms (80%) show increasing trends in surface temperatures. The majority of agro-ecological farms (80%) show the opposite patterns in surface temperatures. The NDVI outputs and analysis reveal increasing trends in crop health over agro-ecological farms and decreasing patterns over conventional farms. Soil carbon trends are similar to those revealed by crop-health. Crop yield also show increasing trends over agro-ecological farms and the opposite for conventional farms. A relationship analysis performed between surface temperatures through multiple linear regression gave an R-square value of 66%. This means that 66% of the patterns shown in crop health can be explained by trends in surface temperatures. These results are further discussed in the next chapter.



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# Chapter 5: Discussion of Results

## 5.1. Introduction

This chapter seeks to discuss and interpret the results presented in chapter four. These results are discussed and interpreted in line with the research's expected outcomes. This chapter also attempts to link the actual findings with the existing literature. The degree of accuracy of the methods used to address the specific objectives is also covered in this section. The first objective of the study was to examine the patterns in surface temperature readings over an agro-ecological farm as compared to a conventional farm. This was followed by characterisation of the changes in crop health and soil carbon content resulting from agro-ecological implementation. The third objective linked surface temperature patterns and crop health in a relationship assessment. The last objective was to evaluate the impacts of agro-ecological farming methods on yield capacity.

Based on the literature review, the following outcomes were expected for each objective. Average temperatures should have a decreasing pattern over an agro-ecological farm and an increasing pattern over a conventional farm. A decrease was expected in crop health over the conventional farm and an increase over the agro-ecological farm. Crop is a soil carbon indicator, as such soil carbon was expected be higher over an agro ecological farm due to increased carbon sequestration. Temperature and crop health are expected to have an inverse relationship. Yield capacity was expected to be increasing on an agro-ecological farm as compared to a conventional farm.

## 5.2. Patterns in surface temperature readings

From the existing literature, conventional farms are supposed to have little or no climate change mitigation potential. This is because the climate over a farm is greatly influenced by the agricultural vegetation (Valverde, 2015). Temperature is a dynamic variable which is affected by a number of factors. These include the microclimate, prevailing climatic conditions, and major meteorological phenomena among other things. The results of surface temperatures are thus subject to these influences, which are impossible to control in the field. However, using a regression makes the analysis statistical and thus there is less chance of a Type II error.



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The gradients of the trendlines reveal that in 2013, three of the five agro-ecological farms had surface temperatures that were gradually increasing. However, the trendline analysis for 2015 reveal that they have negative gradients. This means that temperatures are now decreasing. This trends are in line with expectations based on the literature review. These farms are Kuhestan, Alon-Mosaic and Makosha Organic Farmers. These three farms were not originally established as organic farms but retrofitted to organic from conventional. This means that surface temperatures would not immediately begin to lower. De schutter (2011) states that it takes a period of 3 – 10 years for agro-ecology to start showing positive expected results. This is dependent on the original condition of the soil.

An agro-ecological farm established on previously uncultivated lands is established on naturally organic soil. The practice of organic farming on such a land immediately begins to increase the already available organic matter in the soil and the rate of carbon sequestration. An agro-ecological farm established on previously conventionally cultivated lands will take longer to change the content of the soil to a purely organic state with high sequestration potential. This means an originally organic farm will take a shorter period of time to show decreasing LST trends as compared to a retroffited farm. For this reason, Kuhestan, Makosha, and Alon-Mosaic show positive gradients in 2013 despite them being all established in 2004. Kuhestan and Makosha start showing decreasing temperatures in 2015, 11 years after the retrofitting process was initiated. Makosha starts showing decreasing temperatures in 2014,10 years after the retrofitting process started.

Mangena Tomato Farm, Mabunda Farmers' Co-operative and ZZ2 are all conventional farms with decreasing gradients in 2013. All these three farms were established prior to 2010. As such, by 2013, they are expected to be showing increasing surface temperatures. However, all these farms are situated near large water bodies located in valleys. This means that the surface temperatures of the general area are lower. An initial negative gradient does not mean an increase. Mabunda still has decreasing temperatures in 2014, however at a much slower rate than 2013. This means that the area generally experiences low temperatures. For all these three farms, the rate of change gradually moves from a high decrease to a low decrease and in 2015 they are all experiencing a low increase, which is in line with the literature.

What is noteworthy is the percentage variance of the trend-line gradients. The percentage variance for farms which have decreasing patterns are much bigger values than those with



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increasing trends. This means that average temperatures are decreasing at a much faster rate than they are increasing.

However, as much as percentage variance is not an actual variation number, some of the values are too large to not warrant investigation. Mabunda farmers' co-operative shows a gradient percentage variance of - 3114.26% which means that the rate of increase has gone up by over 31 times the initial rate. This is not necessarily an indication of a Type I error. It can be an indication of irregular patterns in the overall climate of the general location.

### 5.3. Crop health and soil carbon patterns

Crop health does not only depend on the activities which take place on a farm such as pest control, farming methods and fertilisation. There is a dependence on external factors such as the quality of irrigation water, climatic conditions among others. All these internal and external factors influence the soil properties, which then influences crop health (Altieri, 1995; Gliessman, 2007). Focusing on agro-ecological farms assumes no input of chemical fertilisers and pesticides for all the organic farms. This means they cannot be used to explain the fluctuations in the patterns revealed by the crop health analysis.

The stacked bar graph in Figure 4.11 reveals unexpected fluctuations in the crop health of four farms over the period of 2013 - 2015. These farms are Makosha, ZZ2, Mangena and Ba-Phalaborwa Marula. Mangena and Ba-Phalaborwa Marula are located in the same general location. Mangena is a conventional farm and Ba-Phalaborwa is agro-ecological. They both show an overall decrease in crop health over the period 2013 – 2015. This is contrary to Gliessman (2007, 2011)'s observations. The crop health over an agro-ecological farm is expected to increase. For this reason, Ba-Phalaborwa Marula was expected to show an increase in crop health overall.

The temperature trend analysis show a decrease in average temperatures over Ba-Phalaborwa farm for the period 2013 – 2015. Marula is a tropical fruit that thrives in very high temperatures (Patterson *et al..,* 1979). The decrease in average temperatures can affect crop health if no compensation strategies are put into place. Mangena farm is in the same general location and experiences an increase in average temperatures, which causes a decrease in crop health. A study conducted by Adil *et al.* (2003) proved that tomatoes do not thrive under high temperatures, which is why they are mostly grown in the winter-spring period.



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Unlike Mangena, which is also a tomato farm, ZZ2 displays opposite patterns in crop health. Being a conventional farm, the crop health is expected to decrease over the 2013 – 2015 period; however, ZZ2 shows an increase. The two farms are not in the same general location; as such, the overall climatic conditions are not the similar. The availability of resources also plays a role in the overall crop health of a conventional farm. Mangena is a smaller corporation and a recently established farm whereas ZZ2 is a major conglomerate of farms with a vast availability of resources including a team of agricultural researchers. This means that ZZ2 has better response to potential crop health reducing temperature fluctuations.

Irrigation is a major contributor to crop health. This goes beyond the availability of water but also the quality of water. Water can bring toxins onto the farm acquired from an external source or as external inputs into the river before it reaches the farm (Wang, 2016). These toxins are trapped in the soil and ultimately making their way into the crops. Bavaria fruit estate displays expected trends in crop health. Being a conventional farm, crop health is supposed to decrease as it does. NDVI and Re-class outputs reveal fluctuations in water, which may have contributed towards the decrease in crop health. Water bodies decreased from 6.9% to 5.8% over the 2013 – 2015 period as shown in Appendix 1. This poses a threat to the irrigation process.

The real world is not as easy to control as an experiment in the laboratory. Because of this reason, even the farms, which show patterns explained by the literature, could have potentially been influenced by other factors. Mabunda and Makosha farms are in Giyani and both are near to the Mololotsi and the Great Letaba Rivers. Giyani is famous for its Greenbelt gold deposits, which are also known to leech acid drainage into the natural water systems (Murcott, 2012). These acidic minerals are carried in the water ultimately ending up on the farm in reduced concentrations. This lowers the pH of the soil, thus compromising crop health. An agro-ecological farm is developed on the utilisation of natural resources only; as such, there are methods, which would be applied to counteract the acidity of the irrigation water. These methods would not be as important in a conventional farm. This would explain the decrease in crop health over Mabunda while there is an increase over Makosha.

Despite Makosha displaying an expected increase in crop health, there are irregular fluctuations in the NDVI ranges, which are worth investigating. The minimum NDVI value for crop health in 2015 jumps to a value bigger than the maximum value of 2014. This is an irregularity since the ranges are usually expected to overlap. The NDVI and Re-classified outputs for both 2014 and 2015 reveal an increase in water supply provided by the adjacent river. In addition, 2015 reveals



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an establishment of a Dam next to the farms. This brings up a possibility that increased water supply could have increased the crop health instead of farming methods.

## 5.4. Relationship between Crop health and average temperature

Farms such as Makosha and Mabunda lie in very close proximity to each other. In an environment where the farm crops have no influence over climate, these two farms would be expected to show similar trends in temperature. The average temperatures support this expectation. However, the trendline gradients and percentage variances reveal the opposite. The gradients for 2015 for both farms are both negative revealing average temperatures decrease in both locations. Further analysis of the trendlines reveal that despite Mabunda's negative gradient, the rate of temperature decrease has decreased. This is an overall increase in average temperatures over the 2013 – 2015 period.

This increase in Mabunda's average temperature is an opposite trend to what Makosha shows. Makosha shows a gradually decreasing pattern. This means that since these two farms occupy the same general area, there must be a micro factor on the surface, which is causing the differences in average temperatures. The only difference between these two farms is the farming methods. Considering the trends in crop health that are displayed by Makosha and Mabunda, opposite patterns emerge. Makosha displays a decrease in average temperatures resulting in an increase in crop health. Mabunda shows an increase in average temperatures but a decrease in crop health. This reveals an inverse relationship between crop health and average temperature.

## 5.5. Yield patterns

Trends in yield capacity show a similarity to those observed in crop health. Most of the farms (80%) which have increasing temperature patterns have decreasing crop health trends and an increasing yield pattern. These are mostly agro-ecological farms. As much as this observation confirms the theoretical expected outcomes, the degree to which agro-ecology is practiced raises concerns. Without total implementation of agro-ecology from seed acquisition to trade, many of the trends, which seem to confirm literature, may have been influenced by other non-agro-ecological factors.



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Mixing of methods steals reduces full economic sustainability from an agro-ecological farm. A detailed analysis would include as assessment of the labour management system and the final destination for the crop harvest. This would also include an assessment of the farm's contribution towards human livelihoods improvement (Eghenter, 2013). A farm that produces a high yield without making contributions to human livelihoods and community engagement is not considered fully economically sustainable in agro-ecological terms (Altieri *et al.*, 2000).

The results reveal that 80% of the farms conform to the theoretical assumption that agro-ecology increases yield capacity. Some of the organic farms still have many conventional inputs introduced to the farm. This includes fertilisation and pesticides which then make it more difficult to conclude if the increase in yield was caused by fertilisation or agro-ecological farming methods. Fertilisation and pesticides have also been known to reduce yield in the long run due to soil poisoning and pest immunity development. This results in the law of diminishing returns. This is also another possible explanation for the decrease and increase in yield capacity over both conventional and agro-ecological farms.

## 5.6. Overall discussion

Agro-ecology is practiced with a lot of compromise in implementation of methods from the farmers. Some of the organic farms in this study are not wholly organic. They practice organic farming according to the availability of resources. This is mostly due to a lack of a standardized model for conversion from conventional farming to agro-ecology. The lack of a standardized conversion model creates room for compromise in implementation of the core organic agriculture principles. The community in general is also not aware enough of what organic products are. The increasing interest in organic produce creates a market where conventional farmers brand their conventional farms and products as organic.

Conversion to agro-ecology requires a pre-treatment of the soil before the cultivation process begins. A convention model should take these things into account. An organic farm is designed intellectually to integrate all the elements of the farm to function as a system. Any model of conversion should thus consider such facts. Agro-ecology is a climate sensitive agricultural practice. However, a design that was successfully implemented in one location does not necessarily work in the next. This is due to the differences in natural growth climatic conditions of certain crops. Climate does not always come with a direct link to the soil quality. This thus means



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that the same climatic conditions over different general locations will not always be linked to the same soil properties.

As such, a model of conversion should be designed for a particular crop in a particular area with its own unique soil and climatic conditions. This opens up a gap in the implementation practices of agro-ecology and conventional farming. There is thus a need for a model to be developed which governs implementation of agro-ecological conversion from conventional. This model must holistically comply with agro-ecological standards.

Certification is also another challenge when it comes to agro-ecology and organic farming. According to SAOSO, currently there is no legislation which governs organic farming in South Africa. This means a farm is as organic as the farmer claims. The lack of a standardized legislation means the degree of implementation will not be the same across the farms. The most recent draft is the SABS organic draft, which is not in implementation yet and is wanting, as far as content is concerned.

## 5.7. Chapter summary.

From the discussion of the results, there are issues, which arise. The theoretical body of knowledge puts all conventional farming methods as environmentally hazardous. In reality, farms have different levels of resources. Farmers that are more resourceful can compensate for some of the negative impacts of conventional methods better than those with limited resources. Agro-ecological farmers are also not strict enough in their level of implementation. The lack of a standardized legal framework on agro-ecology creates a compromise in the implementation of methods

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# Chapter 6: Conclusions and recommendations

## 6.1. Introduction

This chapter provides the conclusions of the entire study. This encompasses conclusions on the extent to which the objectives were addressed as well as the degree to which the aim was achieved. This is done in three sections, which include conclusions on the outcomes of the study, aspects for future research and recommendations.

## 6.2. Conclusions on the outcomes of the study

The study was a practical analysis of proposed and projected theoretical assumptions about agro-ecology. Most of these theories had not been tested on a large scale before but rather localized and tested by a single farmer. The challenge of location in terms of agriculture is that crops are climate-specific and therefore an adoption of a farming method practiced elsewhere should always have design modifications before implementation. The researcher aimed to test agro-ecology in climate change mitigation and economic sustainability as proposed and concluded the following.

- Surface temperatures are increasing over conventional farms while they are decreasing over agro-ecological farms.
- Crop health and soil carbon content are both increasing over agro-ecological farms as opposed to the decrease over conventional farms
- An inverse relationship exists between crop health and surface temperatures.
- Yield capacity is increasing over agro-ecological farms and decreasing over conventional farms.

The study confirmed that agro-ecology is an effective strategy in climate change mitigation and economic sustainability. The outcomes of this study support the projected assumptions by 80% in terms of crop health, temperature trends and yield. However, the discoveries which were made



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during the conduction of the study put these results into question. There is a large amount of compromise among agro-ecological farmers in implementation of agro-ecological principles. This can mean that other external factors influenced the positive results obtained. This could also mean that agro-ecology practiced at any scale can yield positive results.

### 6.3. Aspects for future research

After conducting the study, a large gap was noticed in the practice of both basic organic farming and advanced agro-ecological farming. The challenge is the lack of a standardised system of implementation for both basic organic farming and agro-ecological organic farming. There seems to be confusion between organic agriculture and agro-ecology among the farmers. This stems from the growing interest in organic products, thus creating a vulnerable environment where consumers purchase anything that is labeled as organic. A standardized method of implementation is important because organic agriculture is one of the methods of practicing agro-ecology. However, not all form of organic farming are agro-ecological (Lamine & Bellon, 2009).

There is thus a need for a standardized, region specific method of agro-ecological implementation. This must also be guided and also guide the agro-ecological policy framework. The challenge in the legislation is that agro-ecology is shelved under the organic concept. This is an easier approach to conversion from conventional farming to a simplified pseudo-agro-ecological farming. The challenge is that agro-ecology is the mother concept of organic farming, meaning that organic farming should be shelved under an overall agro-ecology policy, which South Africa still does not have. The result of the current situation is conventional farmers who apply one or two organic principle and claim to be entirely organic.

The research conducted for this study will be used as the basis for a PhD study in agro-ecology. The PhD study will aim at developing a GIS based model for conversion to agro-ecology through an adaptation of the Gliessman's method. This method approaches farming from a natural environment aspect. Every crop is grown in an artificially created environment that resembles the climatic and physical properties of its place of origin. This method entails highly designed permaculture systems like the corn-bean-squash system of South America or the coy fish and rice system of Asia. These permaculture systems replicate the conditions under which these crops were first discovered. These methods bring agriculture back to its pre-industrialisation state.

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Undertaking such a study will create awareness starting from the regional level and possibly even motivate the need for a highly specified organic legislation.

## 6.4. Recommendations.

From the literature review in chapter two, and the information coming up in the subsequent chapters, the following recommendations can be made.

- **A longitudinal study on soil composition assessment**

The challenge that arose in this study was that the initial year of the chosen 3-year period was 2013, which had already passed. The analysis of data was done in 2015, which means that the physical assessment of soil can only be done for the year 2015. Normalized Soil Difference Index (NDSI), which would be done from the satellite images, would also not reveal accurate results. This is because the soil is under the canopy formed by crops

- **Further development of the legal framework on agro-ecological practice.**

The lack of an individual policy which addresses agro-ecological practices compromises implementation by farmers. Conventional farmers brand their produce as organic because there is no legal system of inspection. Agro-ecology is shelved under the already limited organic farming policy. Agro-ecology is the mother concept to organic farming, meaning that organic farming should be shelved under agro-ecology.

- **Updating of the agriculture curricula in schools across institutions of all levels.**

Agro-ecology is a growing field and it has reached a stage where there is enough information make it a specialisation field in schools. An agriculture student in universities across the nation is taught agriculture as a whole. This limits the information taught to the student because other aspects of agriculture must be covered as well. Studies show that agro-ecology is more successful when practiced by small subsistence farmers. In reality, small-scale subsistence farmers are found in rural villages where they are not taught agro-ecology. Increasing the level of content in school syllabus will increase the interest in farming among young students. These students then have an option of taking up their parents' small farms and grow agro-ecologically.



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## 6.5. Chapter summary

Agro-ecology is an effective method of climate change mitigation, as revealed by this study. Economic sustainability can also be developed, maintained and improved by agro-ecological methods. In conventional farming, what eventually causes a decrease in the farm's economy is the methods of practice, which degrade the soil. The use of agro-ecology would thus keep the farm sustainable because the soil is kept healthy by the farming methods themselves. Overall, we can conclude that agro-ecology is an effective strategy for climate change mitigation and economic sustainability.

Agro-ecology, if practiced holistically can be an effective strategy in mitigating climate change and economic sustainability.

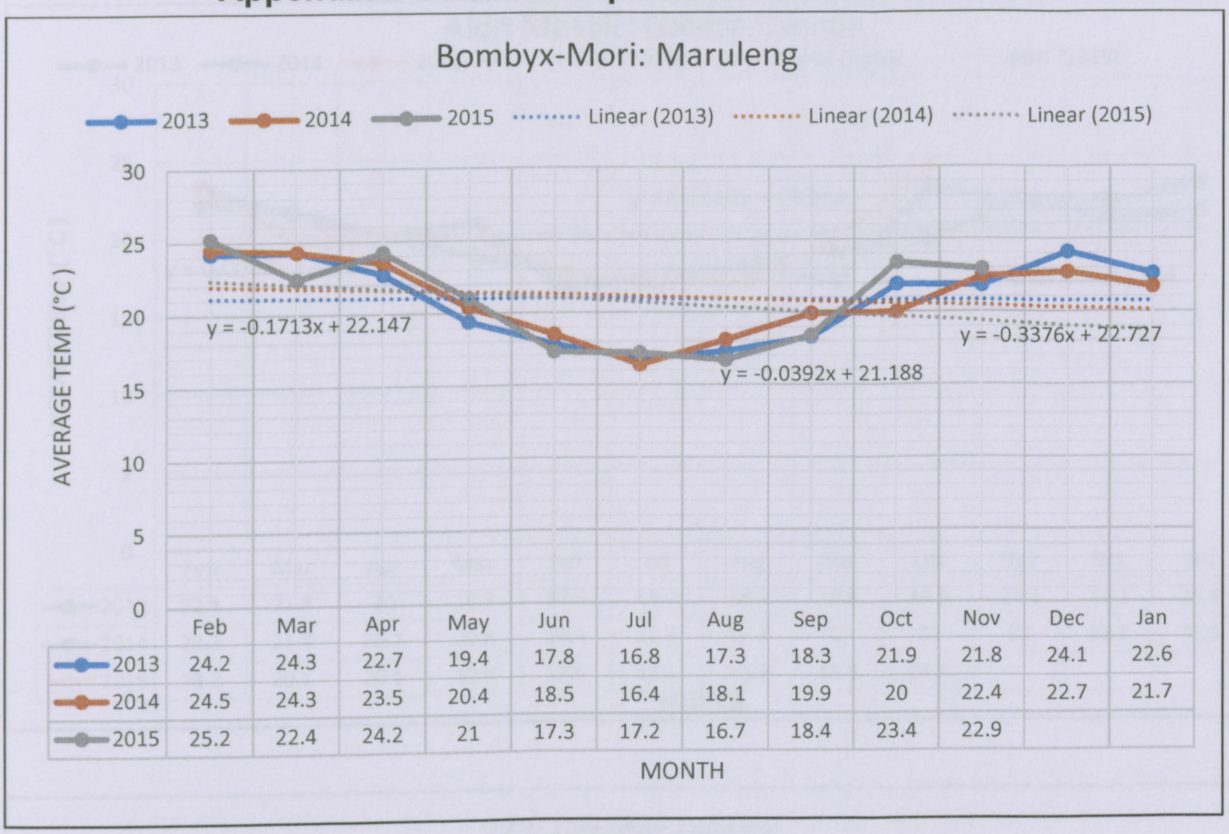
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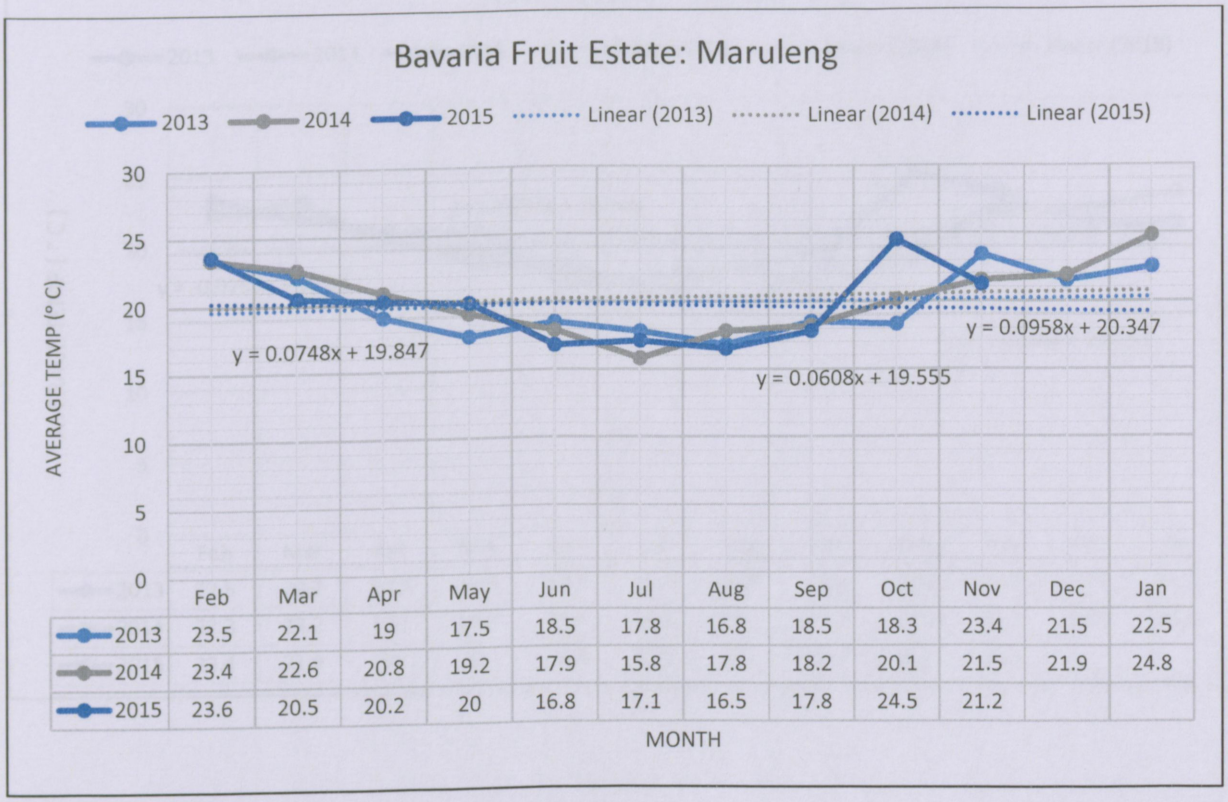


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## Appendix I: Surface temperatures and trend-lines



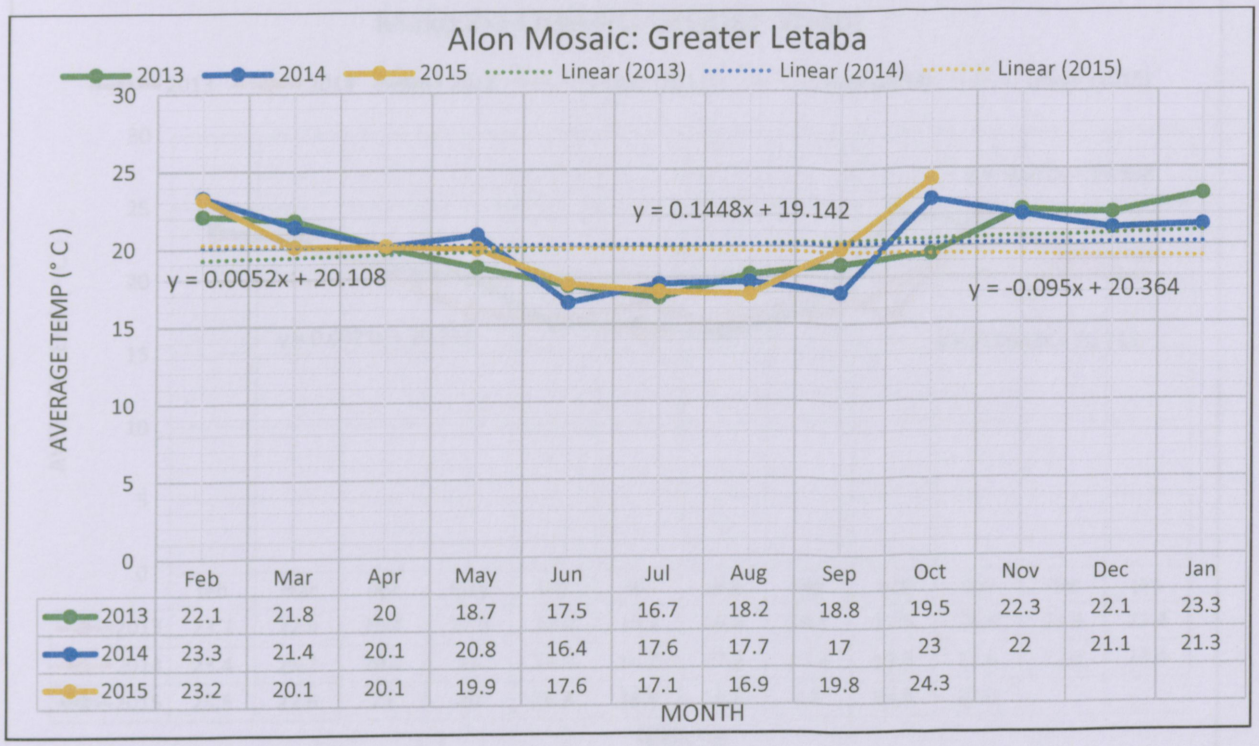

| | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | 24.2 | 24.3 | 22.7 | 19.4 | 17.8 | 16.8 | 17.3 | 18.3 | 21.9 | 21.8 | 24.1 | 22.6 |
| 2014 | 24.5 | 24.3 | 23.5 | 20.4 | 18.5 | 16.4 | 18.1 | 19.9 | 20 | 22.4 | 22.7 | 21.7 |
| 2015 | 25.2 | 22.4 | 24.2 | 21 | 17.3 | 17.2 | 16.7 | 18.4 | 23.4 | 22.9 | | |



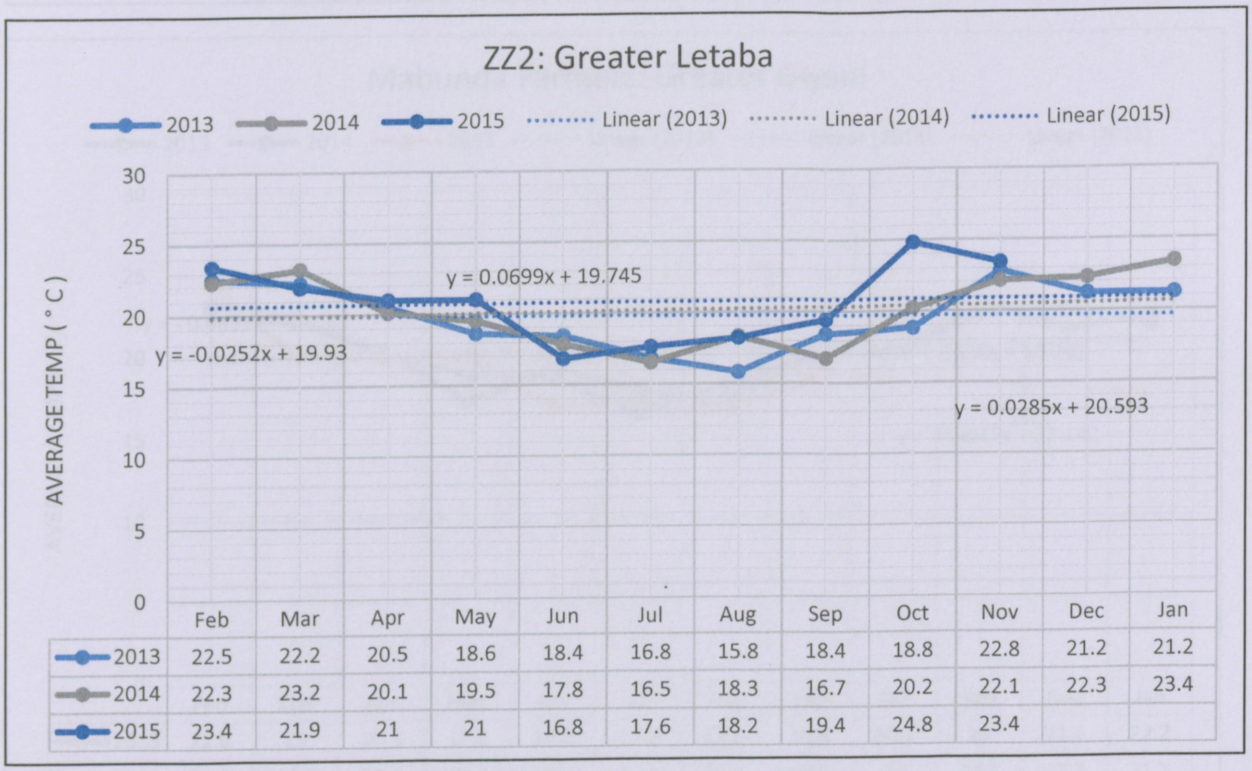

| | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | 23.5 | 22.1 | 19 | 17.5 | 18.5 | 17.8 | 16.8 | 18.5 | 18.3 | 23.4 | 21.5 | 22.5 |
| 2014 | 23.4 | 22.6 | 20.8 | 19.2 | 17.9 | 15.8 | 17.8 | 18.2 | 20.1 | 21.5 | 21.9 | 24.8 |
| 2015 | 23.6 | 20.5 | 20.2 | 20 | 16.8 | 17.1 | 16.5 | 17.8 | 24.5 | 21.2 | | |



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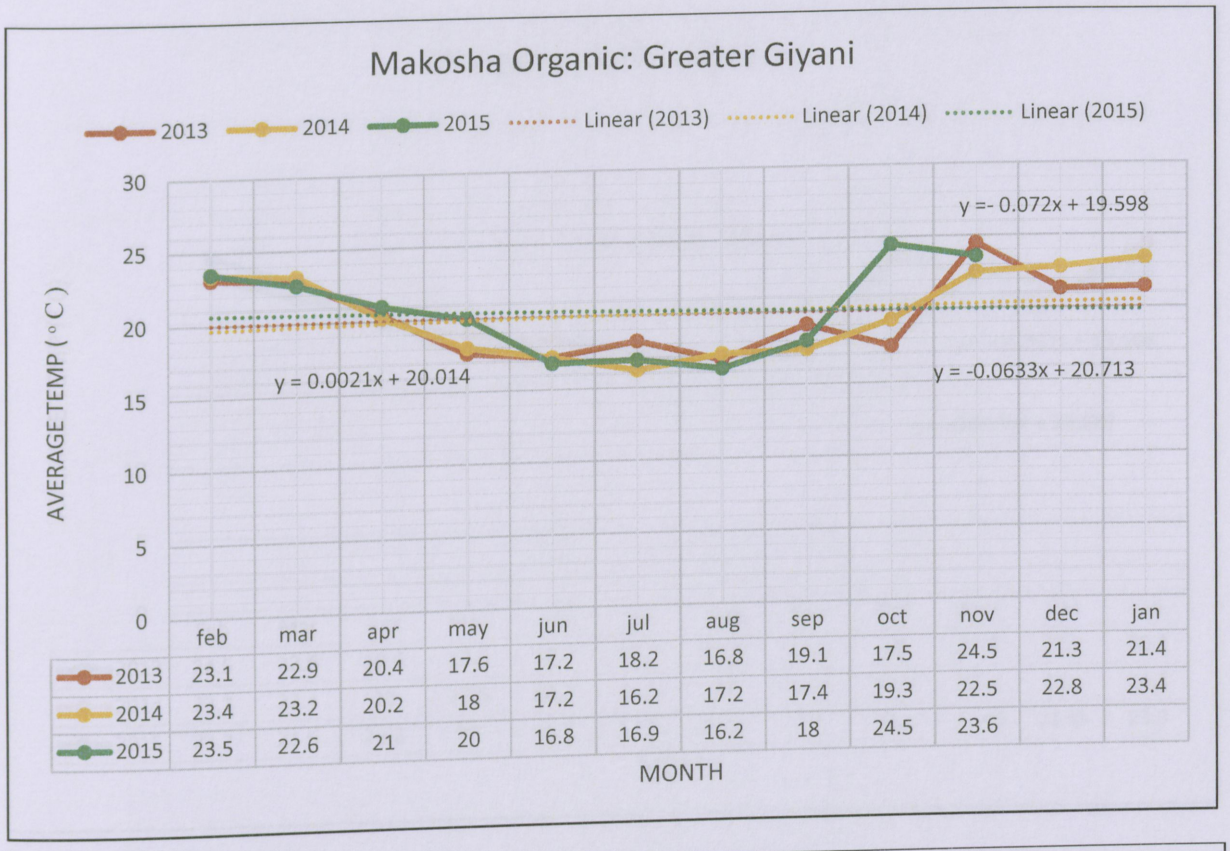

| | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | 22.1 | 21.8 | 20 | 18.7 | 17.5 | 16.7 | 18.2 | 18.8 | 19.5 | 22.3 | 22.1 | 23.3 |
| 2014 | 23.3 | 21.4 | 20.1 | 20.8 | 16.4 | 17.6 | 17.7 | 17 | 23 | 22 | 21.1 | 21.3 |
| 2015 | 23.2 | 20.1 | 20.1 | 19.9 | 17.6 | 17.1 | 16.9 | 19.8 | 24.3 | | | |



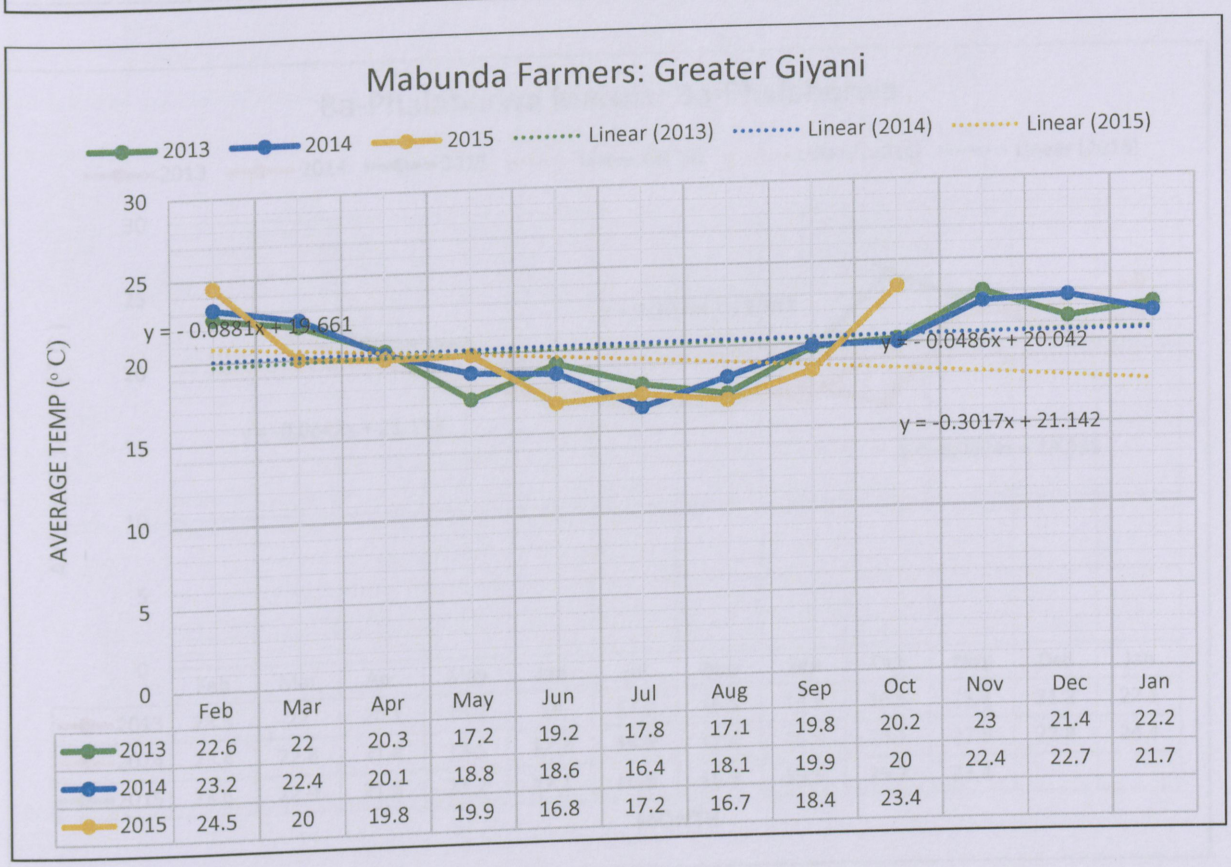

| | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | 22.5 | 22.2 | 20.5 | 18.6 | 18.4 | 16.8 | 15.8 | 18.4 | 18.8 | 22.8 | 21.2 | 21.2 |
| 2014 | 22.3 | 23.2 | 20.1 | 19.5 | 17.8 | 16.5 | 18.3 | 16.7 | 20.2 | 22.1 | 22.3 | 23.4 |
| 2015 | 23.4 | 21.9 | 21 | 21 | 16.8 | 17.6 | 18.2 | 19.4 | 24.8 | 23.4 | | |



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| | feb | mar | apr | may | jun | jul | aug | sep | oct | nov | dec | jan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | 23.1 | 22.9 | 20.4 | 17.6 | 17.2 | 18.2 | 16.8 | 19.1 | 17.5 | 24.5 | 21.3 | 21.4 |
| 2014 | 23.4 | 23.2 | 20.2 | 18 | 17.2 | 16.2 | 17.2 | 17.4 | 19.3 | 22.5 | 22.8 | 23.4 |
| 2015 | 23.5 | 22.6 | 21 | 20 | 16.8 | 16.9 | 16.2 | 18 | 24.5 | 23.6 | | |

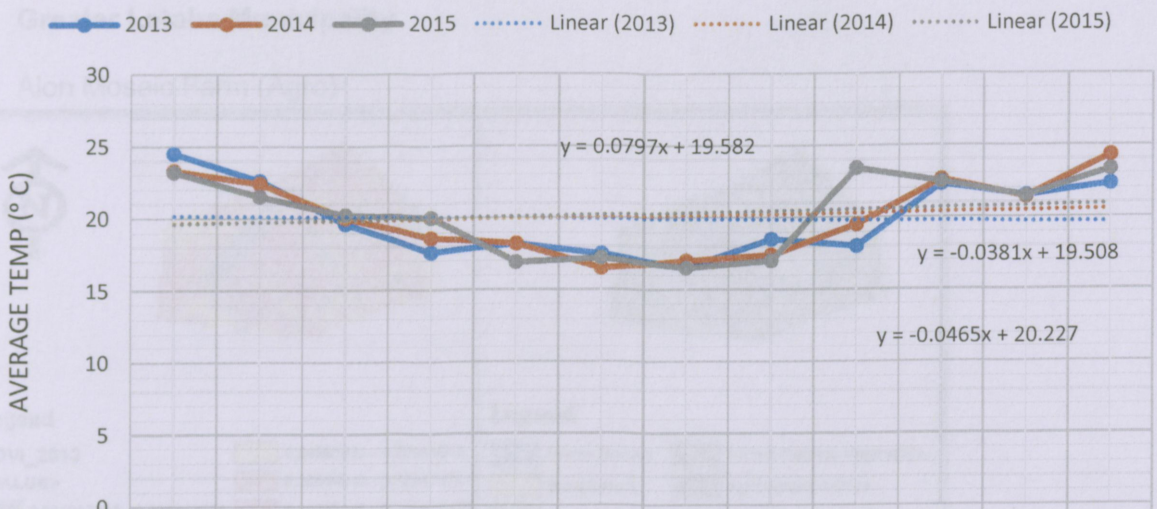



| | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | 22.6 | 22 | 20.3 | 17.2 | 19.2 | 17.8 | 17.1 | 19.8 | 20.2 | 23 | 21.4 | 22.2 |
| 2014 | 23.2 | 22.4 | 20.1 | 18.8 | 18.6 | 16.4 | 18.1 | 19.9 | 20 | 22.4 | 22.7 | 21.7 |
| 2015 | 24.5 | 20 | 19.8 | 19.9 | 16.8 | 17.2 | 16.7 | 18.4 | 23.4 | | | |



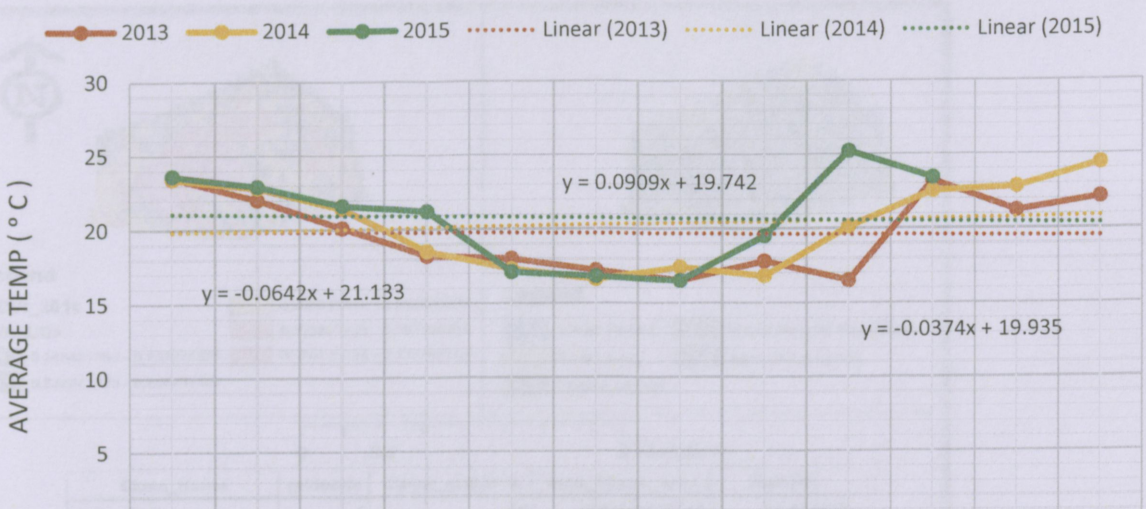
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## Mangena: Ba-Phalaborwa




| | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | 24.5 | 22.6 | 19.6 | 17.6 | 18.2 | 17.5 | 16.5 | 18.5 | 18 | 22.3 | 21.5 | 22.3 |
| 2014 | 23.3 | 22.4 | 20 | 18.6 | 18.2 | 16.5 | 17 | 17.4 | 19.5 | 22.6 | 21.4 | 24.3 |
| 2015 | 23.2 | 21.5 | 20.2 | 20 | 16.9 | 17.2 | 16.5 | 17 | 23.4 | 22.45 | 21.45 | 23.3 |

## Ba-Phalaborwa Marula: Ba-Phalaborwa




| | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | 23.5 | 22 | 20.1 | 18.2 | 18 | 17.2 | 16.5 | 17.8 | 16.5 | 23.2 | 21.2 | 22.1 |
| 2014 | 23.4 | 22.8 | 21.4 | 18.5 | 17.3 | 16.6 | 17.4 | 16.8 | 20.1 | 22.5 | 22.8 | 24.4 |
| 2015 | 23.6 | 22.9 | 21.6 | 21.2 | 17.1 | 16.8 | 16.5 | 19.5 | 25.2 | 23.4 | | |

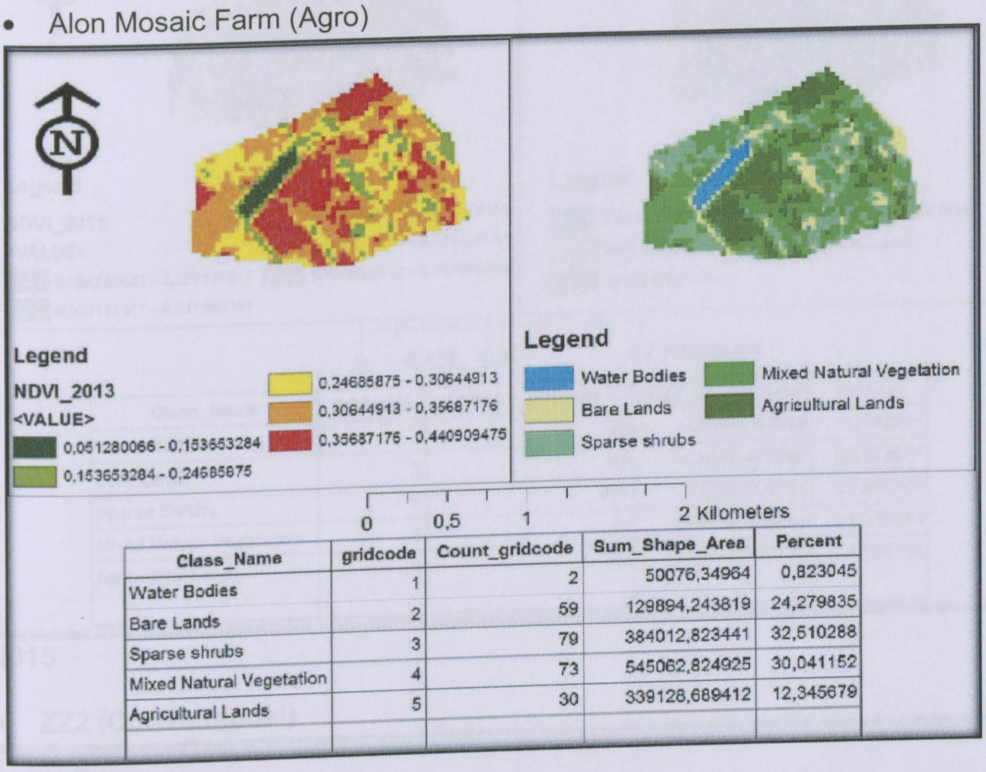


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# Appendix II: NDVI and Reclassified Image outputs.

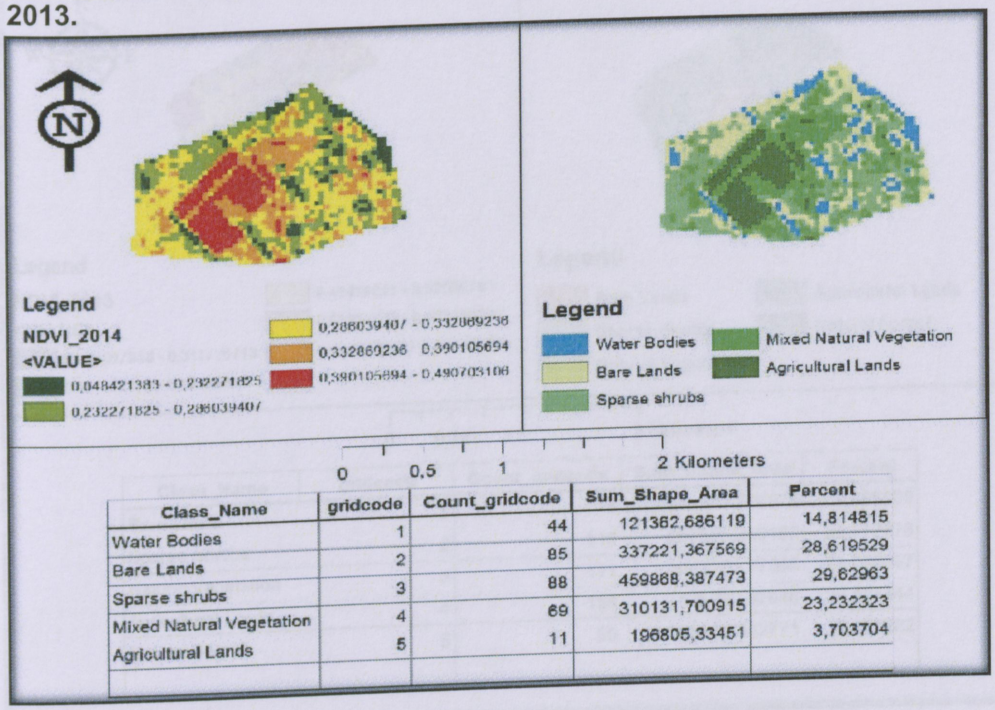
## a) Greater Letaba Municipality

- Alon Mosaic Farm (Agro)




| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Water Bodies | 1 | 2 | 50076,34964 | 0,823045 |
| Bare Lands | 2 | 59 | 129894,243819 | 24,279835 |
| Sparse shrubs | 3 | 79 | 384012,823441 | 32,510288 |
| Mixed Natural Vegetation | 4 | 73 | 545062,824925 | 30,041152 |
| Agricultural Lands | 5 | 30 | 339128,689412 | 12,345679 |

2013.

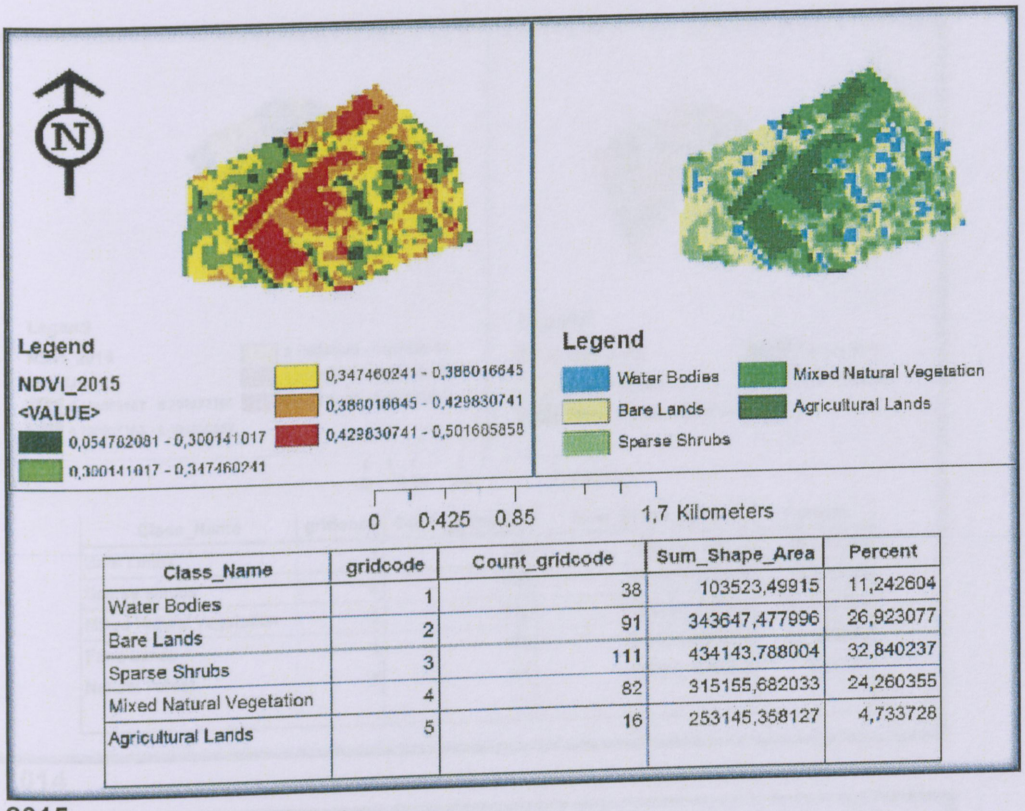



| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Water Bodies | 1 | 44 | 121362,686119 | 14,814815 |
| Bare Lands | 2 | 85 | 337221,367569 | 28,619529 |
| Sparse shrubs | 3 | 88 | 459888,387473 | 29,62963 |
| Mixed Natural Vegetation | 4 | 69 | 310131,700915 | 23,232323 |
| Agricultural Lands | 5 | 11 | 196805,33451 | 3,703704 |

2014.



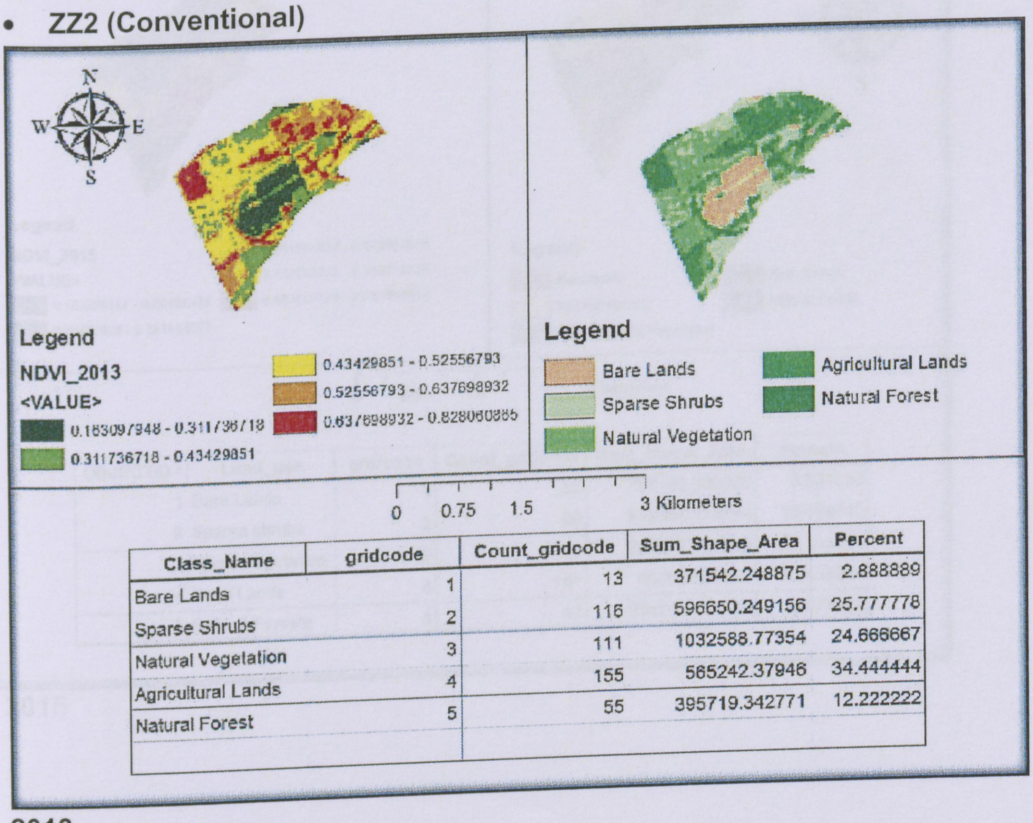
© University of Venda




| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Water Bodies | 1 | 38 | 103523,49915 | 11,242604 |
| Bare Lands | 2 | 91 | 343647,477996 | 26,923077 |
| Sparse Shrubs | 3 | 111 | 434143,788004 | 32,840237 |
| Mixed Natural Vegetation | 4 | 82 | 315155,682033 | 24,260355 |
| Agricultural Lands | 5 | 16 | 253145,358127 | 4,733728 |

2015

- ZZ2 (Conventional)




| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Bare Lands | 1 | 13 | 371542.248875 | 2.888889 |
| Sparse Shrubs | 2 | 116 | 596650.249156 | 25.777778 |
| Natural Vegetation | 3 | 111 | 1032588.77354 | 24.666667 |
| Agricultural Lands | 4 | 155 | 565242.37946 | 34.444444 |
| Natural Forest | 5 | 55 | 395719.342771 | 12.222222 |

2013

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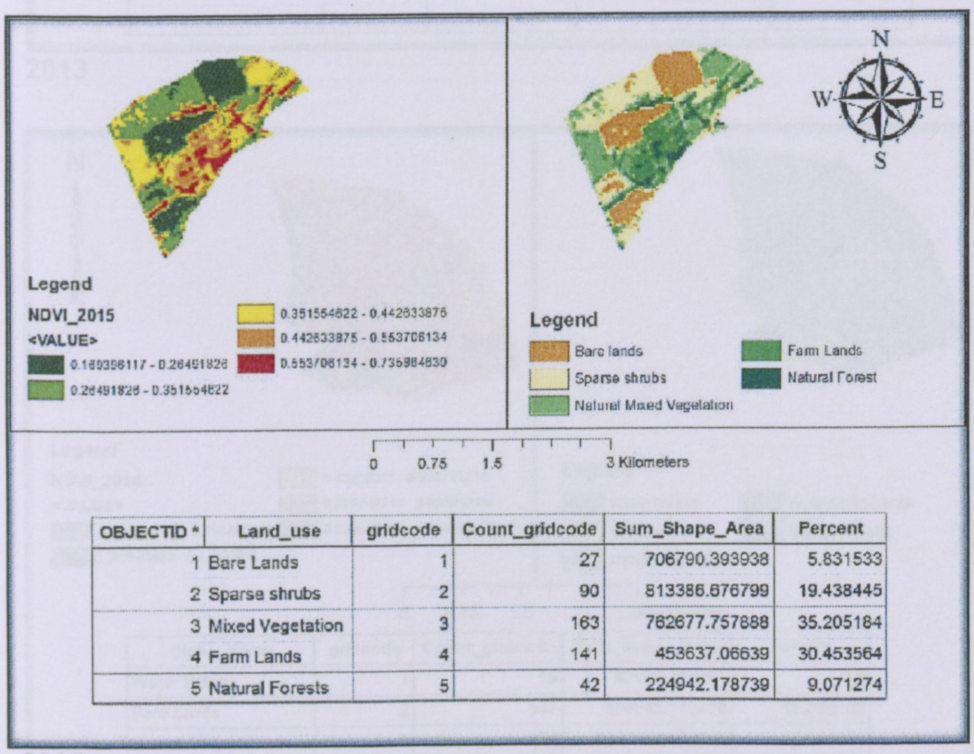


© University of Venda




| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Bare Lands | 1 | 29 | 769974.798712 | 5.882353 |
| Sparse shrubs | 2 | 149 | 577913.032509 | 30.223124 |
| Mixed Natural Vegetation | 3 | 112 | 1182256.428906 | 22.718053 |
| Farm Lands | 4 | 162 | 251075.830237 | 32.860041 |
| Natural Forest | 5 | 41 | 180607.446956 | 8.31643 |

2014




| OBJECTID * | Land_use | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|---|
| 1 | Bare Lands | 1 | 27 | 706790.393938 | 5.831533 |
| 2 | Sparse shrubs | 2 | 90 | 813386.676799 | 19.438445 |
| 3 | Mixed Vegetation | 3 | 163 | 762677.757888 | 35.205184 |
| 4 | Farm Lands | 4 | 141 | 453637.06639 | 30.453564 |
| 5 | Natural Forests | 5 | 42 | 224942.178739 | 9.071274 |

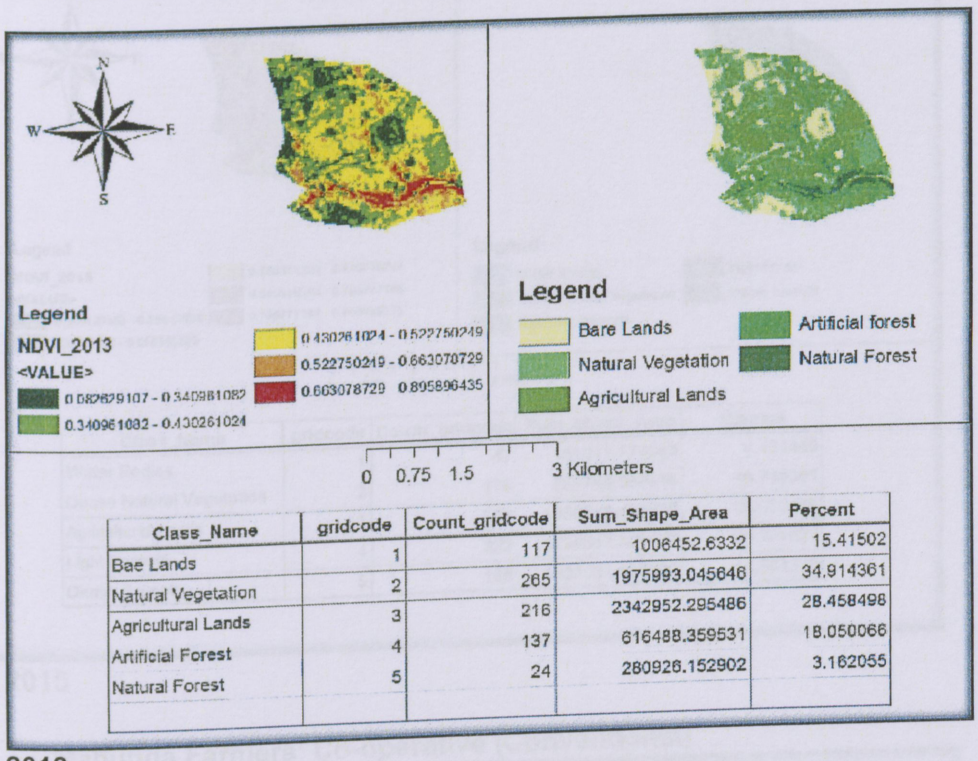
2015



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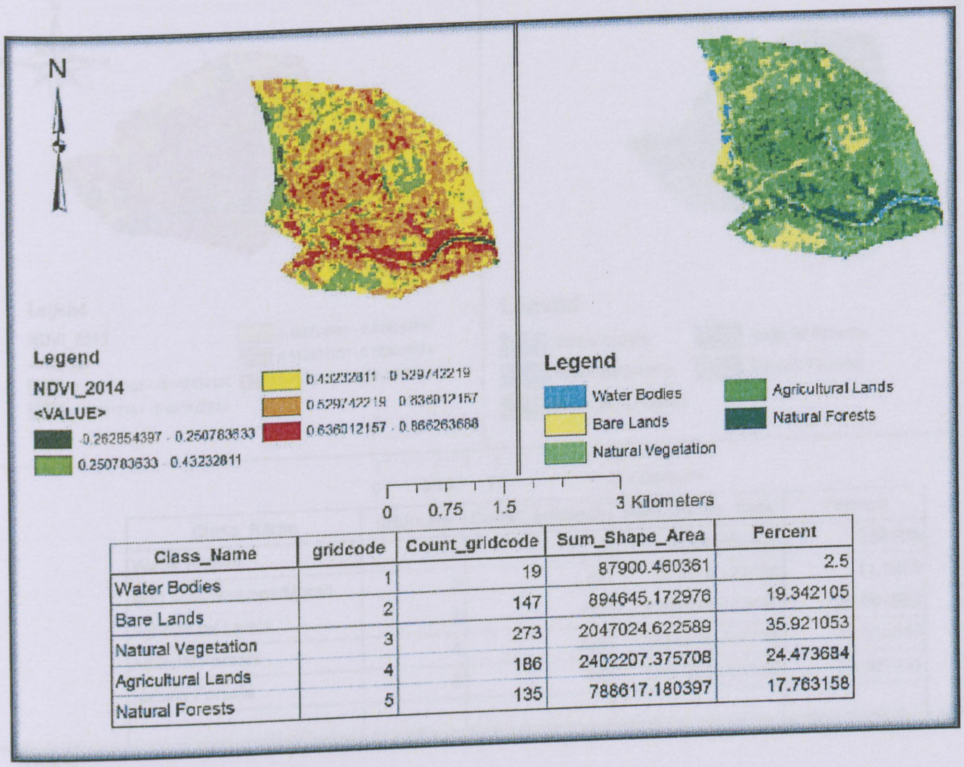
b) Greater Giyani Municipality.

- Makosha Organic Farmers (Agro)




| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Bae Lands | 1 | 117 | 1006452.6332 | 15.41502 |
| Natural Vegetation | 2 | 265 | 1975993.045646 | 34.914361 |
| Agricultural Lands | 3 | 216 | 2342952.295486 | 28.458498 |
| Artificial Forest | 4 | 137 | 616488.359531 | 18.050066 |
| Natural Forest | 5 | 24 | 280926.152902 | 3.162055 |

2013




| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Water Bodies | 1 | 19 | 87900.460361 | 2.5 |
| Bare Lands | 2 | 147 | 894645.172976 | 19.342105 |
| Natural Vegetation | 3 | 273 | 2047024.622589 | 35.921053 |
| Agricultural Lands | 4 | 186 | 2402207.375708 | 24.473684 |
| Natural Forests | 5 | 135 | 788617.180397 | 17.763158 |

2014

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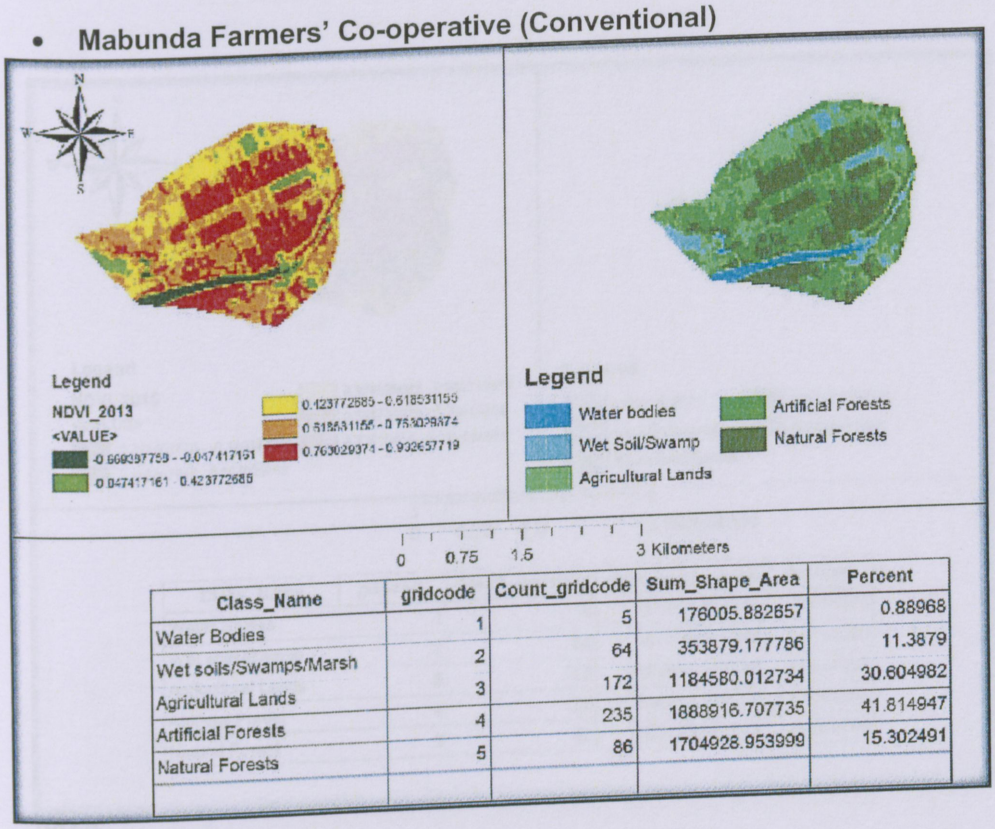
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| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Water Bodies | 1 | 47 | 151011.774883 | 4.421449 |
| Dense Natural Vegetation | 2 | 178 | 858744.389618 | 16.745061 |
| Agricultural Lands | 3 | 361 | 1336596.490915 | 33.960489 |
| Light Forests | 4 | 322 | 2239887.503177 | 30.291627 |
| Dense Forests | 5 | 155 | 1837001.586306 | 14.581373 |

2015

- **Mabunda Farmers' Co-operative (Conventional)**

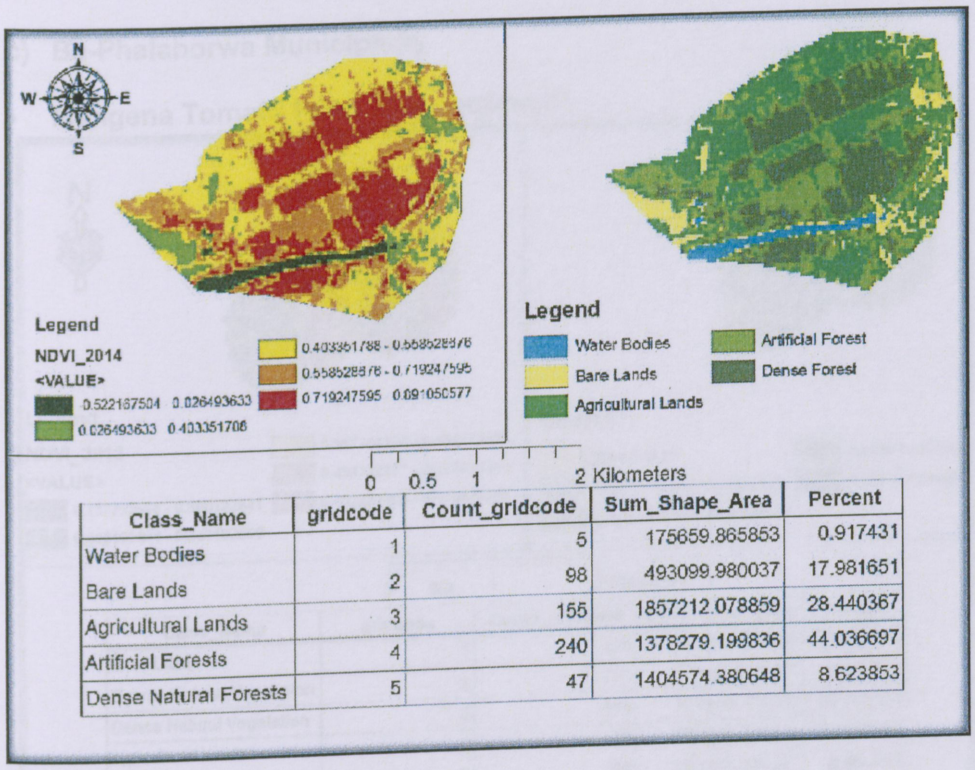



| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Water Bodies | 1 | 5 | 176005.882857 | 0.88968 |
| Wet soils/Swamps/Marsh | 2 | 64 | 353879.177786 | 11.3879 |
| Agricultural Lands | 3 | 172 | 1184580.012734 | 30.604982 |
| Artificial Forests | 4 | 235 | 1888916.707735 | 41.814947 |
| Natural Forests | 5 | 86 | 1704928.953999 | 15.302491 |
| | | | | |

2013

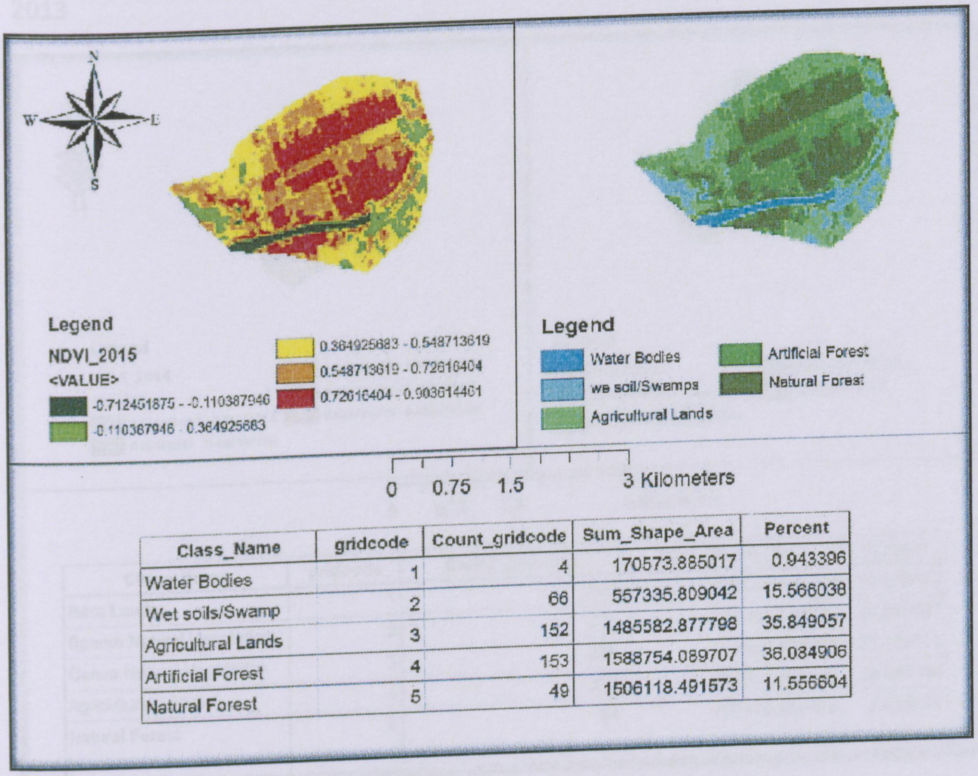


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| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Water Bodies | 1 | 5 | 175659.865853 | 0.917431 |
| Bare Lands | 2 | 98 | 493099.980037 | 17.981651 |
| Agricultural Lands | 3 | 155 | 1857212.078859 | 28.440367 |
| Artificial Forests | 4 | 240 | 1378279.199836 | 44.036697 |
| Dense Natural Forests | 5 | 47 | 1404574.380648 | 8.623853 |

2014




| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Water Bodies | 1 | 4 | 170573.885017 | 0.943396 |
| Wet soils/Swamp | 2 | 66 | 557335.809042 | 15.566038 |
| Agricultural Lands | 3 | 152 | 1485582.877798 | 35.849057 |
| Artificial Forest | 4 | 153 | 1588754.089707 | 36.084906 |
| Natural Forest | 5 | 49 | 1506118.491573 | 11.556604 |

2015

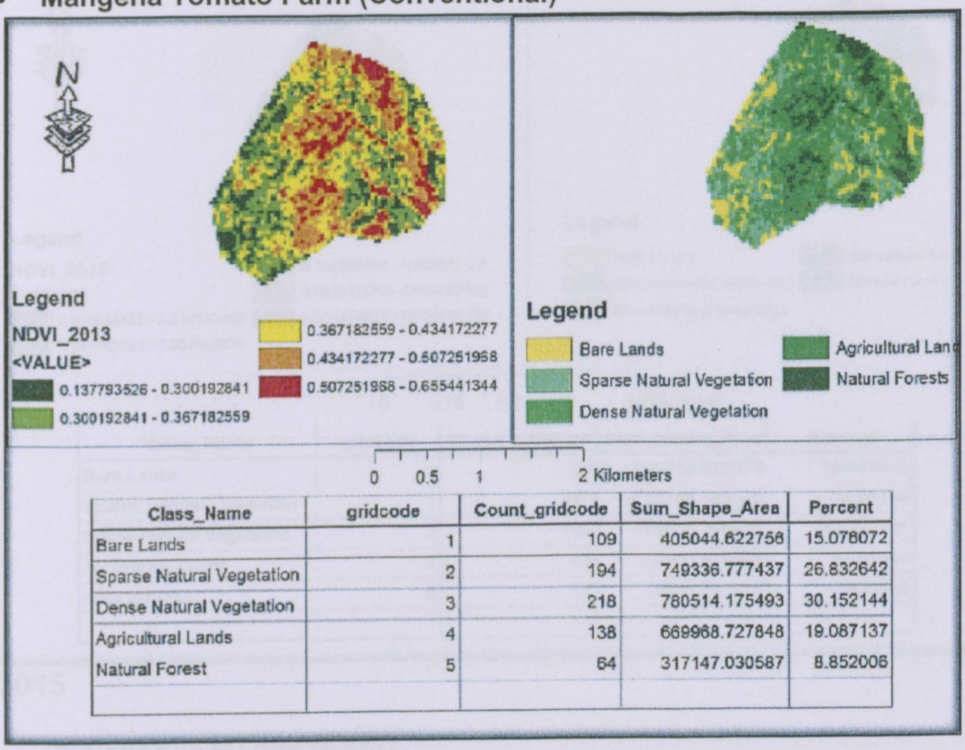
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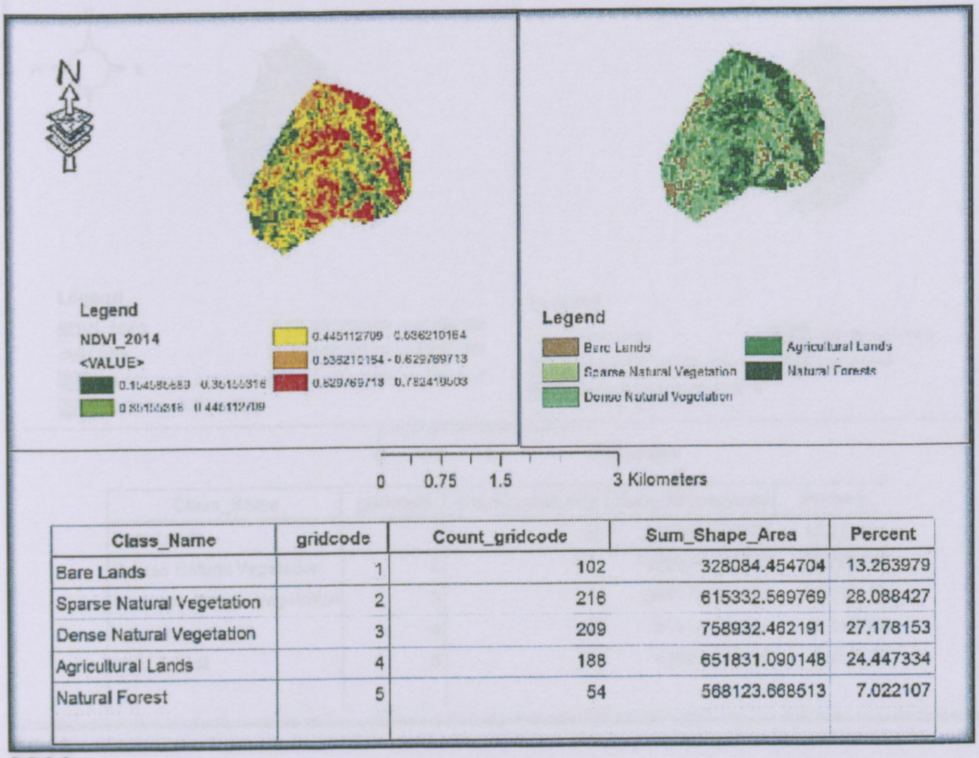
## c) Ba-Phalaborwa Municipality

- **Mangena Tomato Farm (Conventional)**




| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Bare Lands | 1 | 109 | 405044.622758 | 15.078072 |
| Sparse Natural Vegetation | 2 | 194 | 749336.777437 | 26.832642 |
| Dense Natural Vegetation | 3 | 218 | 780514.175493 | 30.152144 |
| Agricultural Lands | 4 | 138 | 669968.727848 | 19.087137 |
| Natural Forest | 5 | 64 | 317147.030587 | 8.852006 |

2013



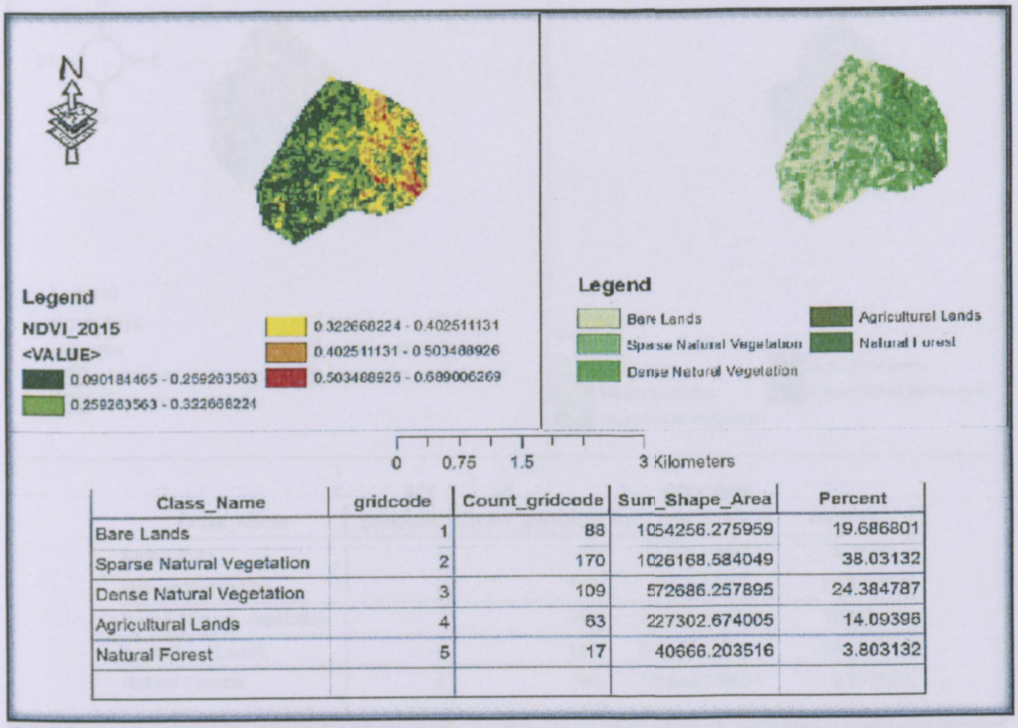

| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Bare Lands | 1 | 102 | 328084.454704 | 13.263979 |
| Sparse Natural Vegetation | 2 | 216 | 615332.569769 | 28.088427 |
| Dense Natural Vegetation | 3 | 209 | 758932.462191 | 27.178153 |
| Agricultural Lands | 4 | 188 | 651831.090148 | 24.447334 |
| Natural Forest | 5 | 54 | 568123.668513 | 7.022107 |

2014

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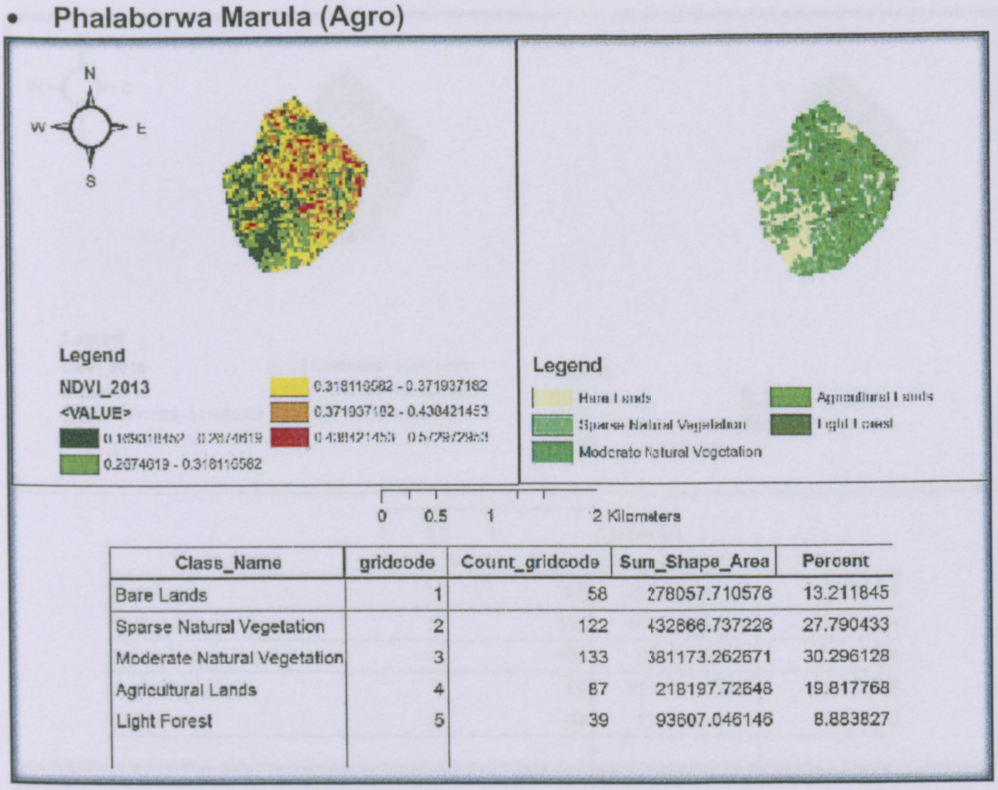
© University of Venda




| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Bare Lands | 1 | 88 | 1054256.275959 | 19.686801 |
| Sparse Natural Vegetation | 2 | 170 | 1026168.584049 | 38.03132 |
| Dense Natural Vegetation | 3 | 109 | 572686.257895 | 24.384787 |
| Agricultural Lands | 4 | 63 | 227302.674005 | 14.09396 |
| Natural Forest | 5 | 17 | 40666.203516 | 3.803132 |

2015

- **Phalaborwa Marula (Agro)**



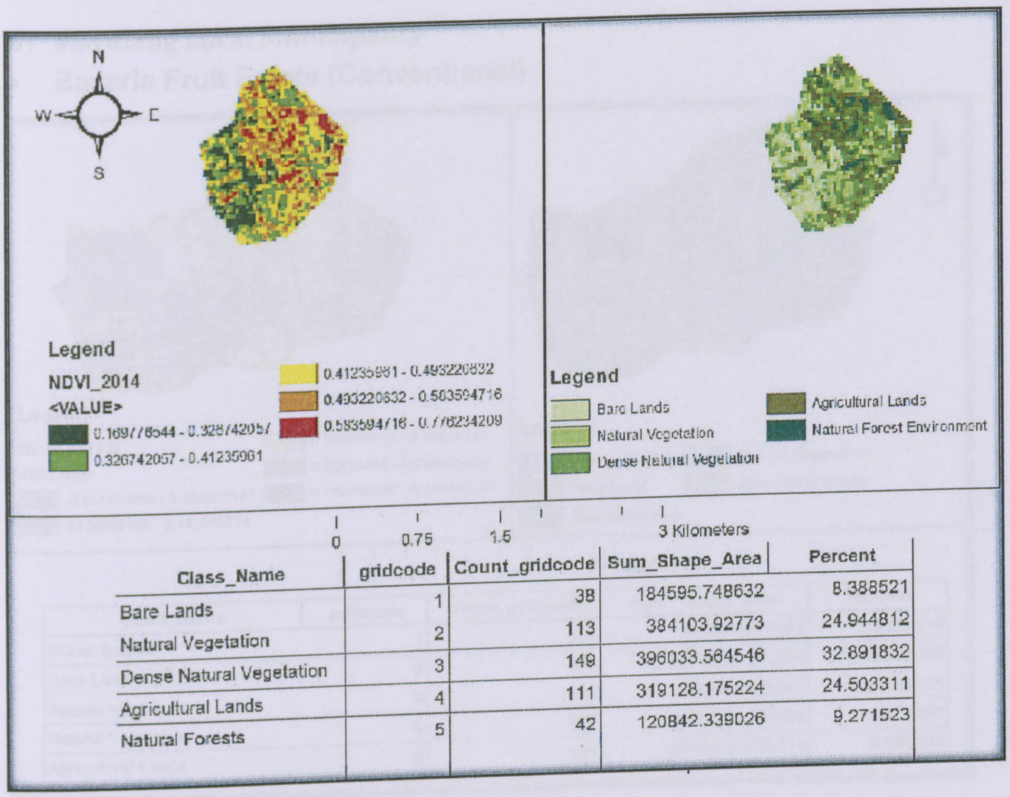

| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Bare Lands | 1 | 58 | 278057.710576 | 13.211845 |
| Sparse Natural Vegetation | 2 | 122 | 432866.737226 | 27.790433 |
| Moderate Natural Vegetation | 3 | 133 | 381173.262671 | 30.296128 |
| Agricultural Lands | 4 | 87 | 218197.72648 | 19.817768 |
| Light Forest | 5 | 39 | 93607.046146 | 8.883827 |

2013

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| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Bare Lands | 1 | 38 | 184595.748632 | 8.388521 |
| Natural Vegetation | 2 | 113 | 384103.92773 | 24.944812 |
| Dense Natural Vegetation | 3 | 149 | 396033.564546 | 32.891832 |
| Agricultural Lands | 4 | 111 | 319128.175224 | 24.503311 |
| Natural Forests | 5 | 42 | 120842.339026 | 9.271523 |

2014




| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Bare Lands | 1 | 62 | 299360.541772 | 13.932584 |
| Sparse Natural Vegetation | 2 | 118 | 464570.439083 | 28.516854 |
| Dense Natural Vegetation | 3 | 133 | 320809.90124 | 29.88764 |
| Agricultural Lands | 4 | 94 | 226363.115453 | 21.123596 |
| Light Forest | 5 | 38 | 92774.016178 | 8.539326 |

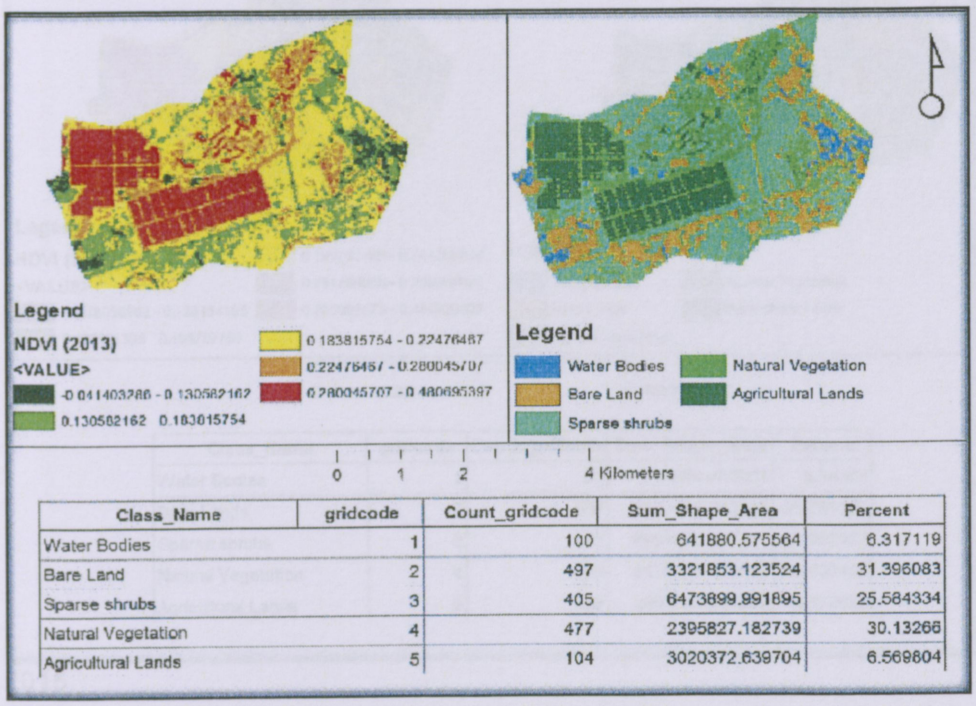
2015



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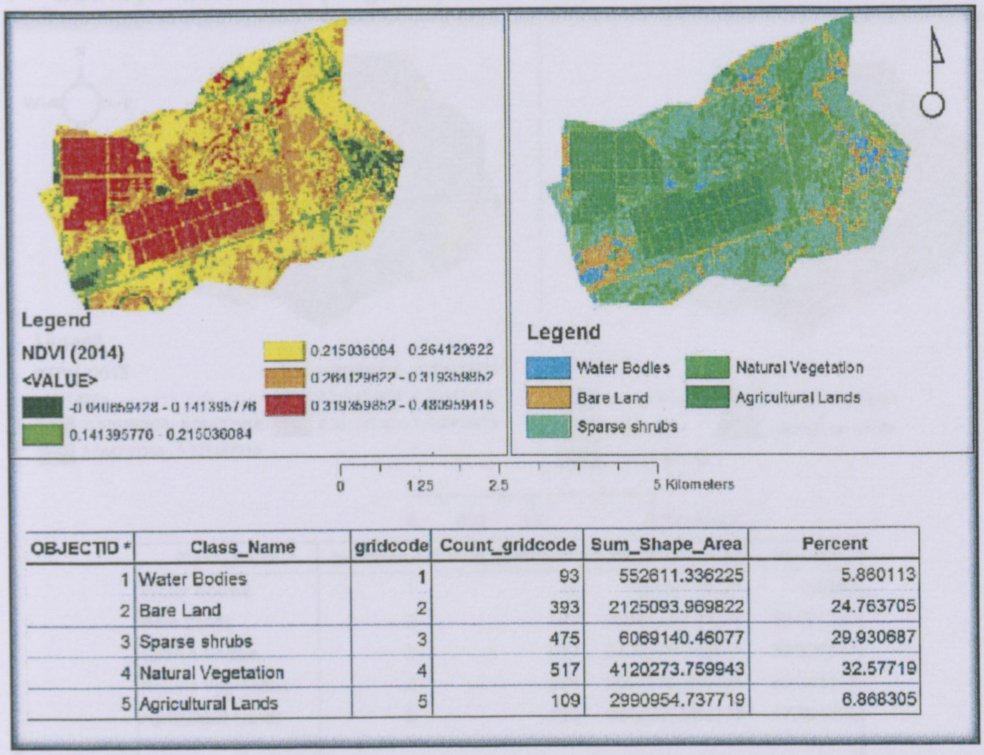
## d) Maruleng Local Municipality

- **Bavaria Fruit Estate (Conventional)**




| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Water Bodies | 1 | 100 | 641880.575564 | 6.317119 |
| Bare Land | 2 | 497 | 3321853.123524 | 31.396083 |
| Sparse shrubs | 3 | 405 | 6473899.991695 | 25.564334 |
| Natural Vegetation | 4 | 477 | 2395827.182739 | 30.13266 |
| Agricultural Lands | 5 | 104 | 3020372.639704 | 6.569804 |

2013

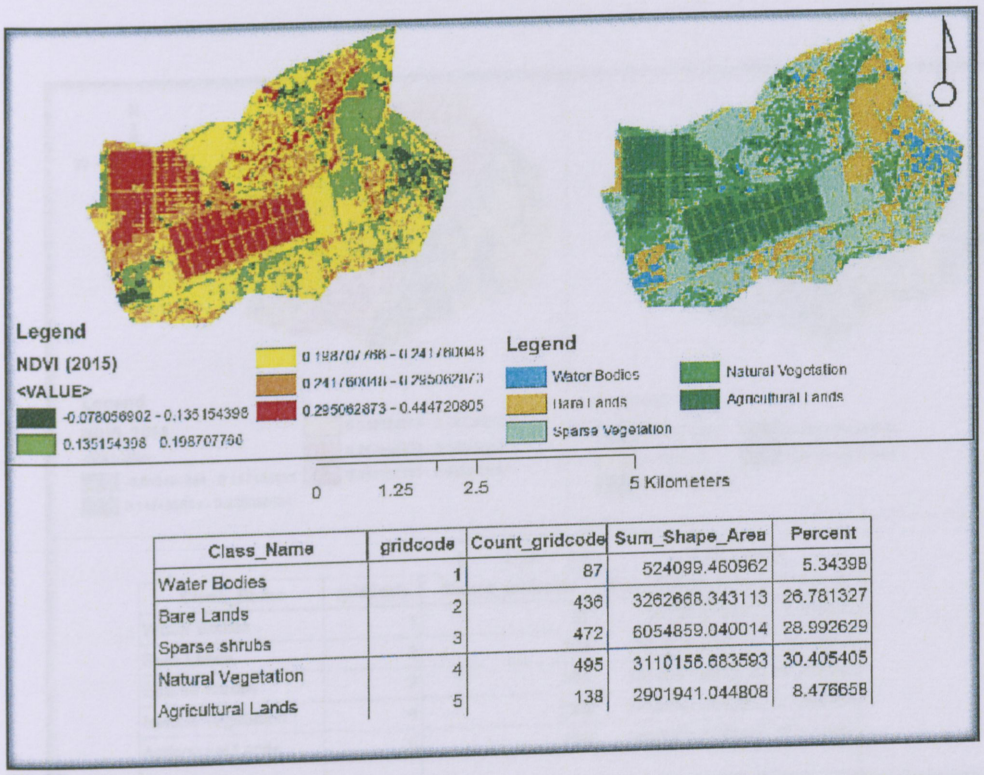



| OBJECTID * | Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|---|
| 1 | Water Bodies | 1 | 93 | 552611.336225 | 5.860113 |
| 2 | Bare Land | 2 | 393 | 2125093.969822 | 24.763705 |
| 3 | Sparse shrubs | 3 | 475 | 6069140.46077 | 29.930687 |
| 4 | Natural Vegetation | 4 | 517 | 4120273.759943 | 32.57719 |
| 5 | Agricultural Lands | 5 | 109 | 2990954.737719 | 6.868305 |

2014



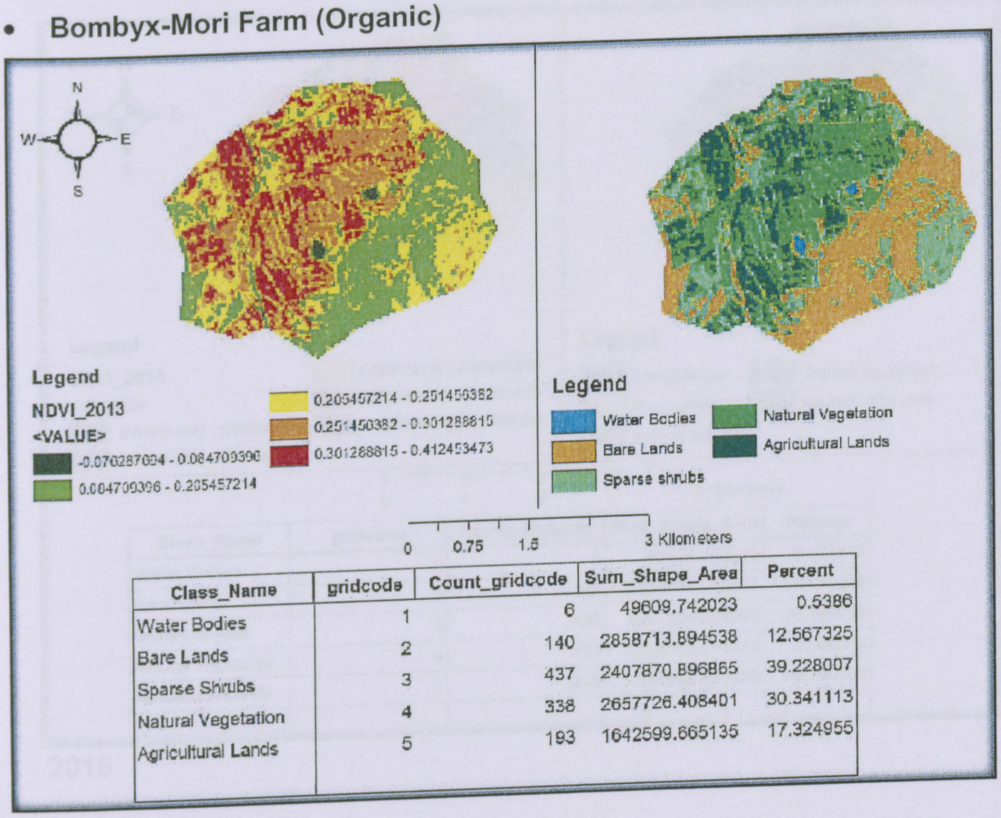
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| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Water Bodies | 1 | 87 | 524099.460962 | 5.34398 |
| Bare Lands | 2 | 436 | 3262668.343113 | 26.781327 |
| Sparse shrubs | 3 | 472 | 6054859.040014 | 28.992629 |
| Natural Vegetation | 4 | 495 | 3110156.683593 | 30.405405 |
| Agricultural Lands | 5 | 138 | 2901941.044808 | 8.476658 |

2015

- **Bombyx-Mori Farm (Organic)**




| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Water Bodies | 1 | 6 | 49609.742023 | 0.5386 |
| Bare Lands | 2 | 140 | 2858713.894538 | 12.567325 |
| Sparse Shrubs | 3 | 437 | 2407870.896865 | 39.228007 |
| Natural Vegetation | 4 | 338 | 2657726.408401 | 30.341113 |
| Agricultural Lands | 5 | 193 | 1642599.665135 | 17.324955 |

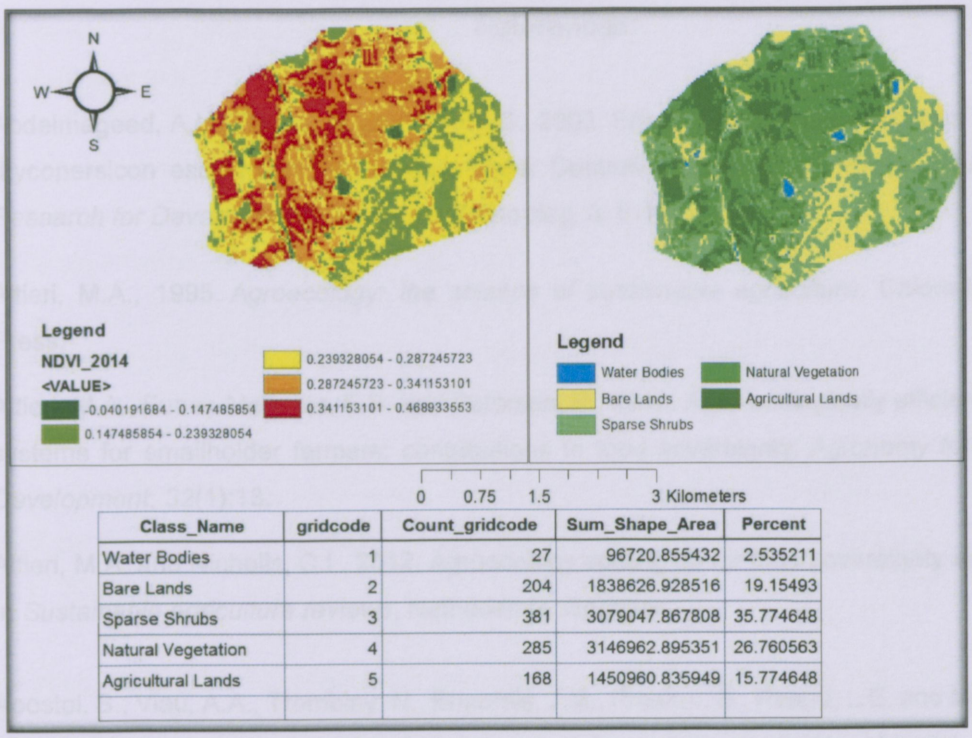
2013

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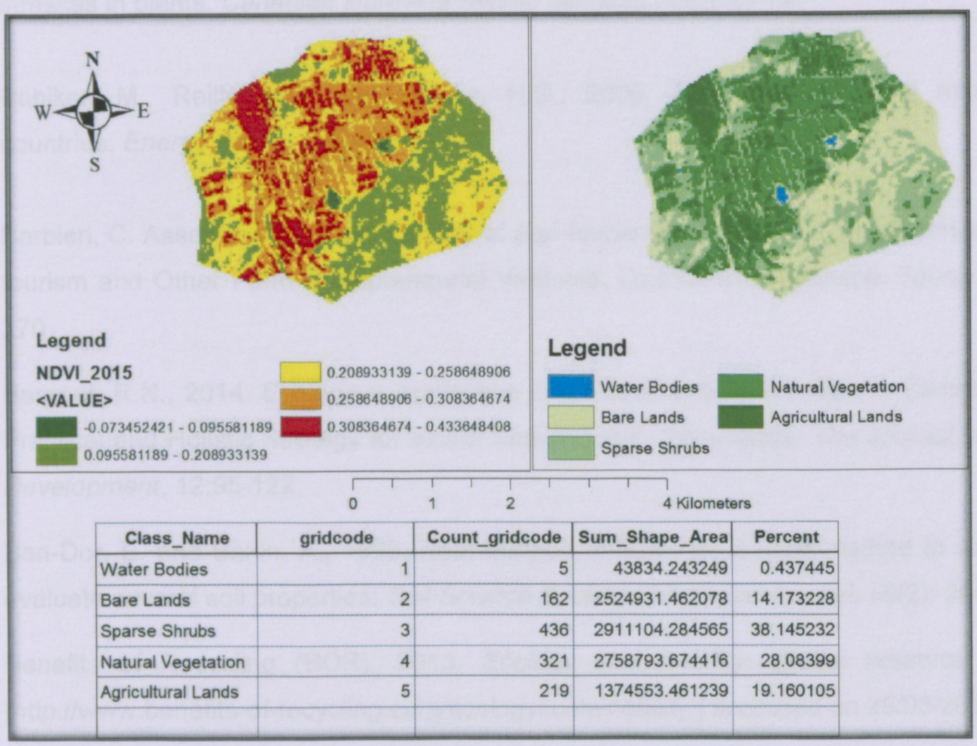
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| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Water Bodies | 1 | 27 | 96720.855432 | 2.535211 |
| Bare Lands | 2 | 204 | 1838626.928516 | 19.15493 |
| Sparse Shrubs | 3 | 381 | 3079047.867808 | 35.774648 |
| Natural Vegetation | 4 | 285 | 3146962.895351 | 26.760563 |
| Agricultural Lands | 5 | 168 | 1450960.835949 | 15.774648 |

2014




| Class_Name | gridcode | Count_gridcode | Sum_Shape_Area | Percent |
|---|---|---|---|---|
| Water Bodies | 1 | 5 | 43834.243249 | 0.437445 |
| Bare Lands | 2 | 162 | 2524931.462078 | 14.173228 |
| Sparse Shrubs | 3 | 436 | 2911104.284565 | 38.145232 |
| Natural Vegetation | 4 | 321 | 2758793.674416 | 28.08399 |
| Agricultural Lands | 5 | 219 | 1374553.461239 | 19.160105 |

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