

**Increased Water Productivity in irrigated Tomato production in the smallholder farming community of Giyani**

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## ABSTRACT

The availability of water for irrigation purposes is becoming a serious concern for smallholder farmers in the former homeland areas of South Africa. Not only because of global weather change and the occurrence of more erratic weather events, but also due to competition for fresh water between the agricultural, industrial and domestic sectors (Hamdy et al., 2003). Food production increases in smallholder agriculture is seen as a possible solution to the food security challenges in the rural areas of the Limpopo Province (Altman et al., 2009). Smallholder farmers in Giyani mostly use traditional furrow irrigation systems and their farm crop productivity remains very low, compared to commercial farms in the same area.

The objective of this study is to utilize and test various innovation technologies aimed at increasing Water Productivity (WP) in order to facilitate better irrigation management of the available water resources. The study was conducted on two farms, Zava Cooperative Garden and Mzilela Cooperative Garden, in the rural areas of Giyani over a two year period from 2012-2013. This study seeks to achieve the objective in three distinct ways. Firstly, the use of NIR technology is used to evaluate the prediction ability of soil chemical parameters for fertilizer requirement calculations. Secondly, WP trials were conducted on smallholder tomato (*Solanum lycopersicum*) production for three consecutive seasons, evaluating their current tomato crop production systems and also testing new innovations for WP increases. Thirdly, applying the MonQI methodology, inputs and outputs of all crop production sites were done to monitor the cropping systems throughout the period of the research.

The results from this study indicate the importance of applying new innovations amongst smallholder production systems. Important findings from the NIR technologies indicated that this innovation can improve soil nutrient management in a more affordable, user friendly manner. The results showed that good prediction models were obtained for pH (KCl), electrical conductivity (EC), P, K, Mg, Na and CEC, with  $R^2$  and RPD values larger than 0.60 and 1.4 respectively. The prediction of exchangeable Ca was less successful with a  $R^2$  value of 0.43. Results from the WP trials suggest that drip irrigation performed better than furrow irrigation in terms of yield and WP. Yield and WP were very low for all treatments, being below 32 t/ha and 5.2 kg/m<sup>3</sup> respectively. Improved management practices, such as soil nutrient management and mulching were introduced in the 2<sup>nd</sup> and 3<sup>rd</sup> seasons of tomato trials in order to increase WP at field level at Mzilela farm. Results showed tomato yield increased from an average of 26.5 t/ha to 120.9 t/ha and WP increases from 4.61kg/m<sup>3</sup> to 17.69 kg/m<sup>3</sup>. Deep drainage of water out of the rootzone decreased with better irrigation management. The results from the monitoring of inputs and output of their cropping systems revealed that smallholder farmers, using traditional farming practices, yielded very low and

mostly below 5 t/ha for all crops. Some crops were totally lost due to hail and heat-waves. NPK balances for conventional cropping by the smallholder farmers at Mzilela was in the range of 0 to -70 kg/ha. The tomato production fertilized treatment of the 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> WP trials, showed positive nutrient balance results for P and K in the range of 80 to 140 kg/ha. N balances were mostly negative for all plots. NFI was R2768 and R4740 for season 1 and 3 respectively, while the 2<sup>nd</sup> season results showed a loss of - R5176. With the improved yield from the WP trial sites, and the fruits being sold to the Spar, the NFI increased to R42486 in the final season. The study concludes that great improvements in yield, WP and NFI are attainable and sustainable amongst smallholder farmers in the Giyani area.

## OPSOMMING

Die beskikbaarheid van water hulpbronne vir besproeiings doeleindes onder kleinskaalse boere in die voormalige tuislande is besig om ernstige bekommernisse te wek. Nie net as gevolg van globale weer veranderinge en meer gereelde ekstreme weer toestande nie, maar ook as gevolg van die kompetisie tussen die landbou, industriële en huishoudelike sektore vir water gebruike (Hamdy et al., 2003). Verhoogde voedsel produksie onder die kleinskaalse landbou sektor word gesien as 'n moontlike oplossing vir die voedsel sekuriteit uitdagings in die platteland areas van die Limpopo Provinsie in Suid-Afrika (Altman et al., 2009). Kleinskaalse boere in Giyani gebruik meestal tradisionele voor-besproeiings stelsels en hul produktiwiteit bly steeds baie laag wanneer dit met kommersiële boerderye vergelyk word.

Die hoofdoel van hierdie studie is om Water Produktiwiteit (WP) te bestudeer en verskeie innovasie tegnologieë te toets om beter besproeiing bestuur van kosbare water bronne te fasiliteer. Die studie was uitgevoer op twee plase, naamlik Zava Koöperatiewe Tuin en Mzilela Koöperatiewe Tuin, wat in die plattelandse areas van Giyani geleë is en die studie is gedoen oor 'n periode van twee jaar vanaf 2012 tot 2013. Om hierdie doelwit te bereik was die navorsing in drie eenhede uitgevoer. Eerstens sal Naby-Infra Rooi (NIR) tegnologie gebruik word om die voorspelling vermoë van grond chemiese eienskappe te toets vir meer effektiewe grond voedingstof bestuur deur kleinboere. Tweedens sal WP proewe uitgevoer word op kleinskaalse tamatie (*Solanum lycopersicum*) produksie. Die huidige tamatie gewasproduksie stelsels was getoets om die WP statusse te evalueer van hul tradisionele bestuurs praktyke van beide drip- en voorbesproeiings stelsels. Laastens, is insette en uitsette van die kleinboere se produksie stelsels met die MonQI metodologie bestudeer om die huidige produksie sisteme te evalueer, sowel as die WP proef persele, deur opbrengs, grond voedingstof balanse en netto plaas inkomste (NPI) te monitor en te bereken vir 4 half jaar seisoene gedurende die navorsings periode.

Die resultate van die navorsing voer aan dat die gebruik van innovasie tegnologieë onder kleinskaalse boerderystelsels ontsettend belangrik is vir verbeterde produksie. Hoofbevindings van die NIR tegnologie dui dat meer doeltreffende grond voedingstof bestuur moontlik is en wat goedkoper en meer gebruikersvriendelik is vir kleinboere. Hierdie tegniek het goeie voorspelbaarheid-modelle getoon vir pH (KCl), Elektriese Geleiding (EG), P, K, Mg, Na en kation uitruilings kapasiteit (KUK) met  $R^2$  en RPD waardes hoër as 0.60 en 1.4 onderskeidelik. Die voorspelbaarheid van Ca was minder suksesvol met 'n  $R^2$  waarde van 0.43. Die resultate van die WP toetse wys dat drip besproeiing beter as voorbesproeiing presteer het in terme van opbrengs en WP. Opbrengs en WP was baie laag vir

alle behandelings van seisoen 1, met waardes laer as 32 t/ha en 5.2 kg/m<sup>3</sup> onderskeidelik. Verbeterde bestuurspraktyke, soos grond voedingstof bestuur asook die gebruik van 'n deklaag, was in die 2de en 3de seisoen toegepas om opbrengs en WP te verhoog op plaas-skaal op Mziela plaas. Resultate het gewys dat opbrengs verhoog het van 'n gemiddelde van 26.5 t/ha tot 120.9 t/ha en WP verhoging van 4.61 kg/m<sup>3</sup> tot 17.69 kg/m<sup>3</sup>. In terme van die insette en uitsette van die produksie sisteme het opbrengste van alle gewasse, wat nog van tradisionele metodes gebruik, laer as 5 t/ha getoon. Soms van die totale oeste verloor deur hael of hittegolwe. Die NPK balanse vir die gewasverbouing met konvensionele kleinboer metodes was in die orde van 0 tot -70 kg/ha. Die kunsmis behandelings van die tamatie proewe van die 1ste, 2de en 3de WP seisoene het positiewe balanse getoon vir P en K in die orde van 80 tot 140 kg/ha. Die N balanse was meestal negatief vir alle verbouings persele. Die NPI was R2768 en R4740 vir seisoen 1 en 3 onderskeidelik, terwyl die 2de seisoen 'n verlies van -R5176 getoon het. Die verbetering in opbrengs met die WP proewe en met die verkoop van die tamaties aan die Spar was die NPI vir die 4de seisoen R42486. Die studie sluit dat daar groot moontlikehede is vir verhoging in opbrengs, WP en NPI onder kleinboere in die Giyani area.

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## LIST OF ABBREVIATIONS

ARC	Agricultural Research Council
BD	Bulk Density
BGDB	Background data base
CAF	Central Analytical Facility
CEC	Cation Exchange Capacity
DAFF	Department of Agriculture, Forestry and Fisheries
EC	Electrical Conductivity
ET	Evapotranspiration
LAI	Leaf Area Index
LDA	Limpopo Department of Agriculture
Mamsl	Meters above mean sea level
MonQI	Monitoring for Quality Improvement
PCD	Pressure compensated drippers
RMSEE	Root mean square error of estimation
RMSEP	Root mean square error of prediction
RPD	Ratio of performance to deviation
SSA	Sub-Saharan-Africa
SWC	Soil water content
TA	Titrateable Acidity
USLE	Universal soil loss equation
WP	Water Productivity

## CHAPTER 1 INTRODUCTION

### 1.1 General Introduction

Smallholder farmers in South Africa's rural former homeland areas are characterized by a very basic way of life and considered by many to be the poorest of the poor and therefore highly at risk in terms of food security. It is also interesting that many have noted the potential of smallholder agriculture as a solution for poverty alleviation and improved food security for the people of South Africa at the bottom of the poverty line (Altman et al., 2009). The thinking of late has been to invest government supported projects to develop these resource poor smallholder (mainly subsistence) farmers into commercial farmers in order to increase income at household level. In the Western (commercial agriculture) paradigm, this seems like the obvious solution, but has this way of thinking been successful and sustainably implemented as an accepted solution for the farmers on ground level? What are the needs of these farmers and how can agriculture attend to these needs? The founder of the new South Africa, former, late, President Nelson Mandela once stated that:

*“Overcoming poverty is not a task of charity; it is an act of justice.*

This research looks at the smallholder farmers at ground level in the Limpopo Province of South Africa to see how basic innovations, specifically designed with and for the smallholder farmers, can affect the lives of many household members. There are however many challenges facing the smallholder farmers in South Africa, which includes depleted water resources, increased erratic weather events and the shortages of other production resources to ensure sustainable food production increases (Mukherji et al., 2009) The smallholder sector therefore needs smallholder agriculture focused solutions and not commercial agriculture focused solutions, which has mostly failed in the past.

Water is one of the most precious resources on earth and without it life on earth would be impossible. In agriculture, and especially smallholder agriculture, the application of water on the soil surface is one of the most effective ways to increase crop production in developing countries. Concerns are growing about the future “global water crisis” that humanity is facing. Not only because the scarcity of clean water is affecting food production, but also because it is affecting the conservation of ecosystems (Pretty et al, 2006). Water shortages and increasing population in the developing world is giving rise to an ever growing competition for water between the agricultural, domestic and industrial sectors as each seeks more water for development (Hamdy et al., 2003). According to the Food and Agricultural Organization FAO (2001), agricultural food production must be increased by

70% world-wide, while the developing countries must double their production in order to meet a 40% population increase by 2050 with regards to the consumptive need.

The so called 'yield gap' between commercial farmers and smallholder farmers remains quite large and it is specifically in the smallholder farming communities where most of the world's poor and hungry people are found. According to Keating et al., (2010), the lack of inputs for these poor farmers, especially in the areas of irrigation and nutrient management is the main reason for the continuing large yield gaps in South Africa. With hunger and starvation being a major problem in Sub-Sahara Africa (SSA), increases in crop productivity, while ensuring that the available resources efficiently and sustainably, is the logical solution. The main challenge is thus to develop affordable, water efficient technologies, which can be easily implemented by the smallholder farmers in Africa. Pretty et al., (2006), states that this will help poor farmers to increase their food production as well as raising their income.

### **1.1.1 Near Infrared Spectroscopy as innovation for fertility management**

Soil nutrient mining is a common practise in the smallholder farms of SSA, and it leaves fertile land areas bare after decades of successive farming. Taking out nutrients from the soil every season through the continuous production of food crops, without any nutrient input, means that smallholder farm productivity is decreasing over time. Soil nutrient mining is most prevalent in areas of low agricultural production and low productivity, because of harsh limitations through poverty which includes physical capital (infrastructure) and human capital (health and education). The result of continuous nutrient mining is increased poverty, food insecurity, environmental damage and social and political instability (Henaio & Baanante, 2006). Nutrient mining can be estimated through the nutrient balance approach by determining the sum of the inputs and outputs from the soil. A methodology is proposed in this research to monitor the nutrient flows in the smallholder areas of Giyani.

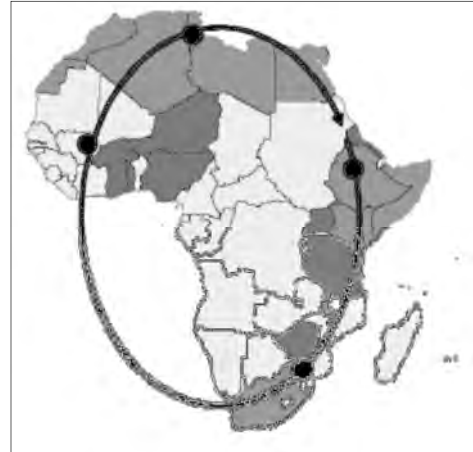
A new innovation for soil chemical characterization is studied with the use of NIR technology to predict main fertility parameters for fertilizer requirement calculations. There is a need for a more speedily soil test, more cost-effective and less labour some method for soil chemical characterization to give smallholder farmers better direction in terms of fertility management on their farms. This will also address soil nutrient mining problems.

### **1.1.2 Water Productivity**

Water Productivity (WP) in agriculture can broadly be defined as the ratio of net benefits from crop, livestock, fishery, forestry and mixed agricultural systems, to the amount of water used in producing these benefits (Molden et al., 2010). In SSA, the challenge remains to

increase yields of smallholder agriculture in resource-poor, low-external input farming systems.

Food security had become a focal point in many developing countries. Water resources are mostly exploited and populations are growing rapidly. According to the FAO (2012), there are 16 million undernourished people in the developing countries of Africa. Climate change brings about new challenges for water users and poor farmers are doing everything they can to meet the consumptive needs of their households. The solution to these growing challenges seems simplistic in nature: to produce more food crops with the same amount of water (Hamdy, et al., 2003). This is the reality for future smallholder farmers, as many African counties will suffer water scarcity by the year 2025 (EAU4food Collaborative partners, 2012)



*Figure 1.1: African countries expected to experience water stress (dark grey) to scarcity (light grey) in 2025 (EAU4food Collaborative partners, 2012).*

Water availability and irrigation management plays a vital role in the outcome of smallholder production in Giyani. Successful production will mean that the produce will not only supply enough food for their households, but also that the excess production can possibly be sold for extra household income. With groundwater resources that may become depleted during the dry season, the food security risks are becoming much greater with the more unexpected weather events that may occur. With most smallholder farmers still using traditional furrow irrigation, there are great possibilities to produce more food with the same amount of available water. Water productivity increases will not only ensure better use of valuable water resources, but also improve the efficiency of the farm as a whole. As water resources will become scarcer and more expensive in the future, it is becoming imperative to use water in a more productive way at farm level.

### **1.1.3 Smallholder monitoring**

In order to increase smallholder crop production in the former homeland areas, the true extent of the current productivity at farm level needs to be known. Research done on the smallholder crop production is very limited and generally there are no production averages for the former homeland areas of South Africa. According to Svendsen et al., (2009), the performances of smallholder irrigation in Africa are reported to be below expectation. In South Africa, the Government has made genuine efforts to promote smallholder

development with investment in initiatives such as land reform, agricultural credit, infrastructure and comprehensive farmer support services (Machethe, 2004). Doing research on farms in the Limpopo Province, in the heart of the former homeland area of Gazankulu (now Giyani), will aid in gaining a better understanding of the current situation of rural farmers in the area. A methodology is proposed to monitor smallholder farms in order to evaluate current production performance and also to evaluate if the implemented innovation through this research was successful or not. Scientific monitoring of the farming system and the irrigation methods are essential in order to understand the reasons for poor results in the production of various crops and specifically tomatoes. Most smallholder farmers are untrained and use traditional management practices for irrigation, fertilization, pest control, crop management and soil preparation.

### **1.2 Hypothesis**

Monitoring of a smallholder farm in the Giyani area will provide an effective way to evaluate current production performances, as well as establishing success indicators on farm level over 4 seasons of production. Water productivity increases in tomato production through better irrigation management, and better farming practices will bring about yield increases and better use of the available water. NIR Spectroscopy techniques for indicating soil chemical characterization, will aid addressing soil nutrient mining on smallholder farms.

### **1.3 Aims of the study**

The main aim of this research project is to monitor a smallholder farm in the community for 4, half year seasons of crop production. Implementation of innovations to improve water productivity will be done at field scale in 3 consecutive seasons of tomato production. The introduced innovations aim to be fully accepted by the local farmers and must be easy to implement. Better water resource management and decreasing negative effects on the environment can be achieved through better decision making and monitoring. The farmers play an integral role in the research and the aim is to develop the smallholder farmers through training in the usage of effective innovations. In the case of successful innovations, the aim is that this model be introduced to more smallholder farmers in the area, with continued monitoring by the Department of Agriculture in Giyani. NIR technology for soil chemical characterization was tested and aims at having a prediction accuracy greater than 60%.

### **1.4 Transdisciplinary approach**

The EAU4food research project follows a transdisciplinary approach. This comprises of an integration of scientific and non-scientific knowledge by the participation of all the involved stakeholders such as the farmers, water managers, retailers, policy makers and NGO's

(EAU4food Collaborative partners, 2012). This approach is at the forefront of genuine participatory interaction of multiple stakeholders at all levels. It is used in order to ensure that the successes will stay in the community and continue to grow in the lives of the smallholder farmers. By a growing rate of adopting in the use of the newly introduced, successful innovations, other farmers in the region will also start to benefit through this approach. This approach instructed the research to be done.

### **1.5 The thesis content**

The following chapter's contains the research work done as follow:

Chapter 2: "Literature review"

Chapter 3: "Study area"

Chapter 4: "NIR Spectroscopy for Soil Chemical Characterization"

Chapter 5: "Water Productivity"

Chapter 6: "Farm scale monitoring using MonQI"

Chapter 7: "Conclusion"



## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Introduction

The rapid growth of the world population is pressurising the limited fresh water resources that is available in the world. Irrigated agricultural sector in developing countries consume 70 to 80 % of the fresh water resources (Hamdy et al., 2003) and is therefore the largest consumer of freshwater with increasing competition from the industrial and domestic sectors. Wallace (2000) argues that the current global issue is the challenge to produce enough food for the increasing population where water resources are limited and already highly exploited, particularly in those areas where the population increase is the greatest.

Monitoring smallholder farms is essential in order to understand current production challenges. Several methodologies have been developed in order to effectively monitor smallholder farms across the world. The recording of production figures and the inputs and outputs of each farm provides valuable information of farm productivity as a whole, but also to see where the main productivity increase constraints are within a certain farm. There remains a massive gap, known as the yield gap, between commercial farms and smallholder farms in South Africa.

Increasing WP in agriculture is at the forefront of the solution to the rising need to feed the growing population with the same amount of water. The future thinking regarding irrigated agriculture must shift from a 'maximum irrigation-maximum yield' strategy to a 'less irrigation-maximum crop water productivity' as water will become the main driving force of production (Zwart & Bastiaanssen, 2004).

The environmental impact of continuous soil nutrient mining must be addressed to limit land areas becoming degraded in the future. Smallholder farmers need a method for soil nutrient management decisions with regards to fertilizer requirements before planting their crops. NIR spectroscopy is seen as a possible replacement for soil chemical characterization in order to give smallholder farmers access to site specific advice for fertilizer recommendations.

#### 2.2 NIR Spectroscopy for soil chemical characterization

##### 2.2.1 General

Soil nutrient depletion in sub-Saharan Africa is another major factor that limits sustainable agriculture and rural development. The cause for concern has been stated at household level, as well as at government level with policy makers and developers of these countries

(Smaling et al., 1996). Net soil exploitation is the result of deteriorating relative price relations between the farm inputs and outputs. This places the poor farming households under an ever increasing pressure to produce more with no or little replacement of nutrients into the soil (De Jager et al., 1998).

Most smallholder farmers in South Africa do not value soil nutrient additions to the soil or even nutrient saving techniques. The crops are usually low yielding and according to Stoorvogel et al., (1993), the average nutrient losses in 38 SSA countries by the year 2000 will be 26 kg N, 3 kg P and 19 kg K per hectare per year lost due to gross nutrient mining.

### **2.2.2 Near Infra-red Spectroscopy**

In the past, our understanding of soil assessment and of its quality has been determined by routine soil chemical and physical laboratory analysis and there is a global drive to develop more time- and cost efficient methodologies for soil analysis (Viscarra Rossel et al., 2006). Diffuse reflectance spectroscopy provides a possible alternative for soil chemical characterization to evaluate soil fertility in terms of fertilizer requirements. This can have a major effect on crop yields on farms where no particular method is used to determine fertilizer requirements. A 60 – 80% accurate prediction, based on the  $R^2$  value of prediction models, of the soil chemical characteristics may have a large economic return in terms of yield on the investment made for soil testing expenses. Sheppard & Walsh (2002), noted that more soil testing laboratories are closing in Africa at a time when they should be getting ready for the challenge of agricultural development and increased production. There is therefore a growing need, especially for smallholder agriculture, for a more affordable soil testing method to guide fertilizer application. The challenge is to maintain environmental management in agricultural systems while controlling the costs and increasing productivity. Thus according to Dunn et al., (2002) a cost-effective soil analysis method is needed to guide farmers in the application of inputs to best fill their purpose, in order to obtain better responses from inputs in agriculture.

Spectroscopy techniques such as mass spectroscopy (MS), nuclear magnetic resonance (NMR), visible (VIS), near infrared (NIR) and mid infrared (MIR) spectroscopy can possibly be used as an alternative method to improve or replace conventional laboratory methods for soil chemical analysis (Viscarra Rossel et al., 2006). NIR is accepted worldwide as an analysis method for many constituents in various plant species (Batten, 1998) and has been investigated for its prediction abilities for soil chemical parameters such as organic C, EC, pH, N, C, P, S, Ca, Mg, Na, K, Fe and Mn (Dunn et al., 2002). NIR spectroscopic techniques can be relevant in soil because of a high sensitivity to both the organic- and inorganic phases (Viscarra Rossel et al., 2006). NIR diffuse reflectance analysis utilizes the

wavelength range of 400-2500 nm or 1797.5-112340.375  $\text{cm}^{-1}$ . The radiation of the chemical bonds of any chemical compound in the samples, such as C-H, N-H, S-H and O-H, is absorbed in the NIR region in accordance to the concentration of those compounds (Zornoza et al., 2008). In order to predict and relate spectral information to the soil property in question, a calibration is developed using a process known as chemometrics (Beata et al., 2006). The NIR scans of the soil sample are used to establish a regression model with which the significant information that is contained in the spectra is concentrated into a few variables and optimized to produce fitting correlations with a certain property. A large number of samples are needed to build these regression calibrations to ensure better reliability of this technique (Chodak, 2008).

The benefits of NIR as an alternative method for soil chemical characterization is noted by many authors include i) minimal samples preparation, ii) fast analysis, iii) cost effectiveness, iv) several constituents can be analysed simultaneously, v) it is a non-destructive method, vi) no hazardous chemicals used and vii) results can be very accurate (Batten, 1998; Janik et al., 1998; Dunn et al., 2002). According to Malley et al., (2004) three approaches have been used to analyse soils using NIR. Firstly, it is used as remote sensing instrumentation in the laboratory and in the air, which started in the 1970's. The second approach focusses on the use of laboratory NIR instruments to predict soil chemical characteristics of soil samples, which dates back to the 1980's. The last approach is termed landscape analysis of soils, which finds its application in precision agriculture. The use of NIR spectroscopy on soils, have been viewed by many authors who tested NIR spectroscopy's ability to predict various soil chemical parameters and these can be seen in Table 2.1.

*Table 2.1: A literature review of quantitative prediction of various soil chemical attributes using multivariate statistical techniques and spectral response in the ultra violet (UV), visible (VIS) and near infrared (NIR) regions of the electromagnetic spectra*

Soil chemical attribute	spectral region	spectral range (nm)	Multivariate method	n (cal)/n (val)	RMSE	R <sup>2</sup>	Authors
Acid (exch.) cmol/kg	VIS-NIR	400-2498	PCR(11)	30/119	24.40	0.65	(Chang et al., 2001)
C (inorg.) g/kg	NIR	1100-2498	PLSR (19)	177 60		0.87	(McCarty et al., 2002)
C (inorg.) g/kg	VIS-NIR	400-2498	PLSR (6)	76/32	0.15	0.96	(Chang & Laird, 2002)

C (total) g/kg	NIR	1100-2498	PLSR (16)	177/60	0.86		(McCarty et al., 2002)
C (total) g/kg	NIR	1100-2498	PLSR (7)	120/59	0.96		(Reeves et al., 1999)
C (total) g/kg	VIS-NIR	400-2498	PLSR (5)	76/32	0.65	0.91	(Chang & Laird, 2002)
C (total) g/kg	VIS-NIR	400-2498	PLSR (7)	30/119	0.79	0.87	(Chang et al., 2001)
C:N ratio	VIS-NIR	400-2498	PLSR (6)	76/32	0.21	0.88	(Chang & Laird, 2002)
CEC; cmol(+)/kg	NIR	1000-2500	MRA (63 bands)	35/56	0.64		(Ben-Dor & Banin, 1995)
CEC; mmol(+)/kg	NIR	700-2500	PCR	121/40	0.67		(Islam et al., 2003)
CEC; cmol(+)/kg	VIS-NIR	400-2498	PCR (8)	30/119	38.20	0.81	(Chang et al., 2001)
CEC; cmol(+)/kg	VIS-NIR	350-2500	MARS	493/247	38.00	0.88	(Sheppard & Walsh, 2002)
CEC; mmol(+)/kg	UV-VIS-NIR	250-2500	PCR	121/40	0.64		(Islam et al., 2003)
Ca; mmol(+)/kg	NIR	700-2500	PCR	121/40	0.72		(Islam et al., 2003)
Ca; g/kg	VIS-NIR	400-2500	modified PLSR	309	0.90		(Cozzolino & Moron, 2003)
Ca (exch.);cmol(+)/kg	VIS-NIR	350-2500	MARS	493/247	28.00	0.88	(Sheppard & Walsh, 2002)
Ca (exch.);cmol(+)/kg	VIS-NIR	400-2498	PCR (12)	30/119	40.00	0.75	(Chang et al., 2001)
Ca; mmol(+)/kg	UV-VIS-NIR	250-2500	PCR	121/40	0.67		(Islam et al., 2003)
Ca (exch.);cmol(+)/kg	NIR	800-2500	PLSR	49	0.34	0.66	(Mashimbye, 2013)
EC; microS/cm	VIS-NIR	400-2400	SMLR (456, 984, 1014)	15/10	0.65		(Shibusawa et al., 2001)
EC; mS/m	NIR	700-2500	PLSR	49	0.22	0.22	(Mashimbye, 2013)
EC; mS/cm	UV-VIS-NIR	250-2500	PCR	121/40	0.10		(Islam et al., 2003)
K; g/kg	VIS-NIR	400-2500	modified PLSR	317	0.72		(Cozzolino & Moron, 2003)

K; mmol(+)/kg	UV-VIS-NIR	250-2500	PCR	121/40	0.00	(Islam et al., 2003)
K (avail.)mg/kg	VIS-NIR	400-1100	NN	41	0.80	(Daniel et al., 2003)
K (exch.) cmol(+)/kg	VIS-NIR	400-2498	PCR (13)	30/119	4.20	0.55 (Chang et al., 2001)
Mg; mmol(+)/kg	VIS-NIR	400-2498	PCR	121/40	0.59	(Islam et al., 2003)
Mg (exch.); cmol(+)/kg	NIR	800-2500	PLSR	49	0.29	0.78 (Mashimbye, 2013)
Mg; g/kg	VIS-NIR	400-2500	modified PLSR	315	0.90	(Cozzolino & Moron, 2003)
Mg (exch.); cmol(+)/kg	VIS-NIR	350-2500	MARS	493/246	11.00	0.81 (Sheppard & Walsh, 2002)
Mg (exch.); mg/kg	VIS-NIR	400-2498	PCR (9)	30/119	12.80	0.68 (Chang et al., 2001)
Mg; mmol(+)/kg	UV-VIS-NIR	250-2500	PCR	121/40	0.63	(Islam et al., 2003)
N (total); %	NIR	1100-2500	MLR (1702, 1870, 2052)	72/48	0.92	(Dallal & Henry, 1986)
N (total); mg/kg	NIR	1100-2300	PLSR (10)	180 x-val	0.94	(Reeves & McCartney, 2001)
N (total); mg/kg	NIR	1100-2498	PLSR (8)	120/59	0.95	(Reeves et al., 1999)
N (total) ; g/kg	VIS-NIR	400-2498	PLSR (7)	76/32	0.04	0.86 (Chang & Laird, 2002)
N (total) ; g/kg	VIS-NIR	400-2498	PCR	30/119	0.06	0.85 (Chang et al., 2001)
Na (exch.); cmol(+)/kg	VIS-NIR	400-2498	PCR (7)	30/119	1.30	0.09 (Chang et al., 2001)
Na; mmol(+)/kg	UV-VIS-NIR	250-2500	PCR	121/40	0.34	(Islam et al., 2003)
Na (exch.); cmol(+)/kg	NIR	800-2500	PLSR	49	0.29	0.86 (Mashimbye, 2013)
P (avail.); mg/kg	VIS-NIR	400-1100	NN	41	0.81	(Daniel et al., 2003)
pH	NIR	1100-2300	PLSR (8)	180 x-val	0.74	(Reeves & McCartney, 2001)
pH	NIR	1100-2498	PLSR (11)	120/59	0.73	(Reeves et al., 1999)
pH	VIS-NIR	350-2500	MARS	505/253	0.43	0.70 (Sheppard & Walsh, 2002)
pH	NIR	800-2500	PLSR	49	0.34	0.66 (Mashimbye, 2013)

## 2.3 Water Productivity

### 2.3.1 General overview of Water Productivity in Agriculture

Water Productivity (WP) in this study reflects on the productive use of irrigation and rainfall water in smallholder agriculture, which denotes increased returns from the water used to produce their food crops. WP can broadly be defined as the net return from a certain unit of water used to produce that return (Molden, et al., 2010). The concept of WP has its roots in the classical concept of irrigation efficiency and consequently, many definitions are found based on the background of the researcher or stakeholder. The WP concept evolved from the crop physiology field that termed the carbon assimilated or crop yield per unit of transpiration as *Water Use Efficiency (WUE)*. Later, WUE was defined as the amount of marketable crop yield per unit of evapotranspiration (ET). The irrigation sector has also used the term to describe how effectively water is delivered to the crop (Molden, et al., 2010).

Due to the several interrelated definitions, Molden et al, (2003) proposed some general definitions to set up a framework for research into the concept of water productivity across different spatial scales namely crops, fields, farms, irrigation systems, basins, nations and the globe. At each scale, different processes will take primary interest and each set of processes are internally linked and affect the hydrological system as a whole. The ultimate aim of WP is therefore to increase the 'crop per drop' in responding to the need of feeding the growing population world-wide, while also aiming to decrease negative impacts on sensitive water ecosystems.

WP should be preferred over WUE and also irrigation efficiency (IE), because of the cross scale application rather than a scale specific approach. Van Halsema and Vincent (2012) argue that the widespread use of WUE in its application of a comparative measure of efficiency is null and void because of irregular use of the components of the water balance. Looking from the crop physiologist point of view, the terms  $WUE_{crop}$  actually refers to WP, which is production over the sum of the ET. It is also important to note that practices not directly related to water management which improves soil fertility, pest and disease control, crop selection and access to better markets, also affects WP interactively. WP or Crop Water Productivity (CWP) can thus be referred to as the marketable crop yield ( $Y_{act}$ ) over the actual evapotranspiration ( $ET_{act}$ ) (Zwart & Bastiaanssen, 2004).

$$WP = Y_{act}/ET_{act} \quad (\text{kg/m}^{-3}) \quad [2.1]$$

Where  $Y_{act}$  is the actual yield determined by weighing the marketable crop in kg, and  $ET_{act}$  is the actual evapotranspiration in cubic meters used by the plant. For the latter, careful considerations must be made when calculating the water balance for an accurate view of the

amount of water used to produce the corresponding crop yield. WUE defined in the same way as equation 1, is used by other authors in the quest to optimize the amount of water that is transpired per unit of crop production (Wallace, 2000; Gregory et al., 1997).

$$WUE = \frac{Y}{ET} = \frac{w/t}{\{1+(L+E_s+R+D)/E_t\}} \quad [2.2]$$

Where WUE is defined as the biomass(W) produced per plant transpiration (W/T), produced per unit of water resource consumed (either as rainfall, surface, groundwater): L the losses in storage and conveyancy,  $E_s$  evaporation from soil surface, R Runoff water, D drainage from root zone of crop and  $E_t$  crop transpiration consumed.

### 2.3.2 Components of Water Productivity

The goal of increasing WP is to increase the 'crop per drop' of the agricultural crop production system. For this purpose one must define 'which crop' and 'which drop' and also the scale of the application (Molden et al., 2003).

i) The Numerator: Which crop?

Firstly, the numerator (kg of marketable yield) of the WP equation needs to be defined in terms of the type of crop being produced. In both WP and WUE, the specific crop plays a large role in the equation as, for example, a certain WP value for maize, wheat and tomatoes are not comparable. The ability of the crop to convert transpiration into biomass is the main consideration. This ability of the plant is based on the breed, cultivar type and nature of the crop and thus the crop physiology is the key factor that will affect the yield. According to Gregory et al, (1997), biomass production by annual plants is mostly directly proportional to the amount of water transpired, nutrient uptake and radiation intercepted. Biomass or plant dry matter production is the result of the conversion of radiant energy to chemical energy in the process of photosynthesis.

$$W = \int qfS\delta t \quad [2.3]$$

Where the efficiency,  $q$  is the intercepted radiation converted into dry matter,  $f$  is the fraction of the incoming radiation intercepted by the plant canopy,  $S$  is the amount of incoming radiation per unit area, and  $T$  is the time (Monteith & Greenwood, 1986). When there are water, nutrient and disease limitations,  $q$ , tends to be very conservative for certain crops in the given growing environment (Gregory et al., 1997). When  $CO_2$  is exchanged between the atmosphere and the crop canopy, there is a related exchange of water vapour. The outflow of water vapour is crop specific and it depends strongly on the biochemistry pathway of photosynthesis. Accordingly, carbohydrates are formed but is also further elaborated into

more structural assimilates with the aid of other elements such as Nitrogen (N), Phosphorous (P) and Magnesium (Mg) as the structural materials of the plant is produced. The nutrient uptake decreases over time as the structural components are produced (Gregory et al., 1997). It is thus clear that nutrient and pest management plays an important role in the biomass production, and not only sufficient water supply. The transpiration water use ratio is therefore:

$$W = \int \frac{k}{d} T \partial t \quad [2.4]$$

Where  $k$  is the crop specific constant for a given crop and depends mainly on the biochemistry of photosynthesis, while  $d$  is the mean saturation deficit of the atmosphere weighed in favour of time when the transpiration is highest and  $T$  is the amount of water transpired (Gregory et al., 1997). The efficiency in terms of the ratio between biomass and transpiration is different according to the type of plant. To increase biomass production, it requires more transpiration through the stomata which means that more  $\text{CO}_2$  enters the plant for photosynthesis and biomass production and more water escapes from the leaves. The stomata in the leaf play a very important role in the plant as the cooling regulator. Liquid movement is also needed for nutrient transport. During long hot, dry spells, the stomata will close and therefore limit transpiration which in turn will limit the process of photosynthesis and will ultimately affect the yield (Molden et al, 2010). Heat-waves can therefore have a severe effect on crop yield if water supply to the plant root is insufficient for an extended period.

The crop types such as C3, C4 and CAM (crassulean acid metabolism) is more water efficient respectively (Molden et al, 2010). The crop productivity is thus primarily determined by i) the crop type and genetics, ii) nutrient deficiencies in the growth cycle and iii) to a lesser extent the irrigation application and cultivation techniques (de Wit, 1992; van Halsema and Vincent, 2012; Steduto et al, 2007)

Plant management practices from here on will denote to the aspect of the WP denominator which is to improve marketable yield.

ii) The denominator: Which drop?

Secondly, the denominator of WP, the amount of water used, must also be defined and also the method used to calculate this amount must be clearly stated. It is difficult to separately measure transpiration (water beneficially used) from the plant and evaporation (water not used beneficially) from the soil surface. Thus to define WP in terms of ET and not transpiration alone makes sense at field level (Kijne et al., 2002). Water balance calculation



is crucial in understanding the measure of water used by the plant and to provide a means to generalize water use across scales. At the very basic level of in-field crops, a set of defined domain boundaries is required in three the dimensional space and time. This domain is considered to be from the top of the crop canopy to the bottom of the root zone (Molden et al., 2003). In order to calculate the amount of water used in this domain during the growing period to produce the crop (marketable yield), it is important to understand the soil water balance, as well as the soil-plant-atmosphere continuum.

Actual ET determination has to be done with the use of effective measuring and a good understanding of the soil water balance. The soil balance is defined as the inflow and outflow from the soil root zone in the equation:

$$ET_{act} = I + P - R - D - \Delta S \quad [2.5]$$

Where  $I$ , is the irrigation water applied,  $P$  the rainfall,  $R$  runoff,  $D$  drainage or deep percolation and  $\Delta S$  is the change in soil moisture storage over time. Many studies of WP and WUE do not accurately account for the whole water balance, as they introduce simplified conditions that lead to assumptions that  $R$  and  $D$  equals zero. The ET is then calculated as the sum of rainfall and irrigation minus the change in seasonal soil moisture storage. It also assumes that all the rainfall and irrigation water was stored in the soil root zone and used by the plant (van Halsema and Vincent, 2012).

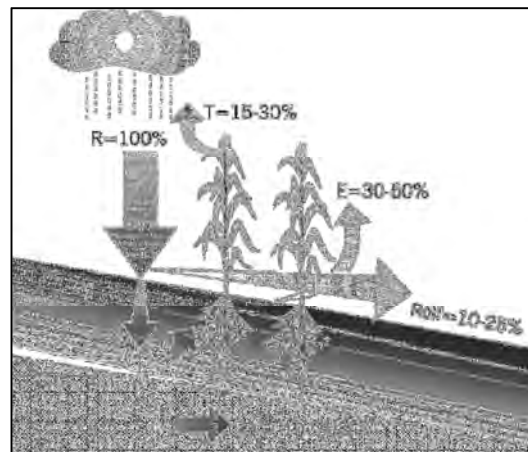


Figure 2.1: The water balance components of a crop at field level (Rockstrom et al., 2002).

It is therefore imperative that proper water accounting is done and soil water content is measured correctly using accurate soil water measuring equipment. Effective soil water balance monitoring can be done during the season by the use of gravimetric soil moisture measurements, neutron scattering equipment or time-domain-reflectometry (TDR) (Zwart & Bastiaanssen, 2004). Another method for accounting for the actual ET is in the use of lysimeter measurements or  $ET_a$  modelling. According to Sun et al, (2006), 22 of 24 recent publications provided WUE values in which the fraction of total water applied over water actually utilized is not accurately accounted. In a paper looking at numerous CWP studies over the last 25 years, Zwart and Bastiaanssen (2004) noted that many of these studies do not measure actual ET but rather estimated it. Very few studies give the moisture content at which the yield was measured, which ultimately gives errors in the end results.

### 2.3.3 Increasing water productivity

Molden et al (2010), discusses some priority areas where fairly large increases in WP is possible, which include i) high poverty areas with low WP, ii) water scarce areas where there is high water competition between users, iii) areas with little water resource development where little extra water can have a great effect, and iv) areas of water driven eco-system degradation (e.g. falling water tables and water desiccation).

To increase WP in agriculture and specifically at farm-scale, there needs either to be an increase in the WP denominator or a decrease in the numerator of the WP equation. Both of these factors are in some degrees inter-linked and thus a change in yield or ET may either be from the soil management or better agronomic management of the crop. We will focus and treat both cases separately and later discuss the main pathways of improving WP. The plant management practices, such as soil fertility management by adding N and P and other agronomic practices have an indirect effect on the physiological efficiency in which a plant can use water to create biomass (Hatfield et al., 2001). The management of the soil can improve the numerator, while the agronomic management improves the denominator of the WP equation. Soil management practices by the smallholder farmers will affect the processes of ET through the modification of the available energy, the available water in the profile, or the exchange rate between the soil and the air.

Plant or agronomic management practices affects WP and mostly the marketable yield. As previously discussed in section 1.2.2, the biomass/transpiration ratio is plant specific. Steduto et al (2007), reminds us that it is very important to note that there is a limit to the amount of biomass that a crop can produce per unit of water consumed. While these relationships are mostly fixed, there is considerable variability in crop yield relative to transpiration because of the differences in evaporation, harvest index (HI), climate conditions, cultivars, water stress, pest and diseases, nutrient and soil status and other agronomical farm management practices (Molden et al, 2010). The strategy here is found in the producers 'water domain' of plant production and mostly relates to the agronomic practice that determines the crop choice, nutrient and pest management (van Halsema & Vincent, 2012). Plant management practices that affects WP includes timeline of sowing, an even established crop, use of pesticides and also the role of the previous crop on that land. Any plant management practice that brings about a fast development and enables the plant to cover the soil surface, shade out weeds and reduced air movement may bring about increases in WP (Cooper & Gregory, 1987).

Soil management practices have its effect mostly in the numerator of the WP equation. Evaporation losses from the soil surface play an important role in the amount of water

available during the growing period. Water losses from the root zone through drainage and evaporation makes less water available to the plants. The strategy here is to reduce ET while increasing productive transpiration which will increase WP at field level. The soil storage capacity will be affected by the soil texture and organic matter content and also affect the release of water to the plant. Yield and WP will thus also be affected by rapid drying of the soil as the plant does not get the opportunity for osmotic regulation and adjustment (Ali & Talukder, 2008). Nutrient status of the soil also affects the development of the plant. The irrigation system and scheduling will also affect the WP status as the wetting area differs for different systems and thus affects the evaporation from the surface.

The term, 'increasing water productivity' implies that there is a more effective way of improving the yield of a crop with the water that is currently being used. Passioura (2005), and Kijne et al (2002) concluded that there are three main pathways or principles for improving WP namely, i) improving marketable yield for each unit of transpiration, ii) reducing non-beneficial atmospheric depletions and outflows from the water domain and iii) improvements in the effective-use of rainwater, water with marginal quality and water stored in the water domain.

*Table 2.2: Field level strategies to improve WP: (modified from Kijne et al., 2002)*

<b>Strategies</b>	<b>Options and Practices: Field level</b>
<i><u>Principle 1: Enhancing marketable yield of the crop for each unit of crop transpiration</u></i>	
Increasing yield or value of the product	Crop and residue management for enhancing yield Synchronizing water application with crop water demand Changing to higher value crops
Reducing transpiration	Crop scheduling to match season with low evaporation demand Deficit irrigation
<i><u>Principle 2: Reducing non-beneficial atmospheric depletions and the outflow from the domain of interest</u></i>	
Reducing evaporation from soil and water	Crop scheduling to reduce evaporation during fallow period Plant spacing and row orientation Tillage and soil management (eg. Minimum tillage, mulching) Irrigation techniques (eg. drip, subsurface irrigation) Saturated culture with rice on bed
Reducing transpiration from	Weed management

weeds	
Reducing percolation	Levelling and precision irrigation Water saving irrigation in rice
Reducing runoff	Water harvesting Tillage to increase infiltration
<i><u>Principle 3: Enhancing the effective-use of rainfall, water with marginal quality water stored in the domain of interest</u></i>	
Effective use of rainwater	Water harvesting and supplementary irrigation
Effective use of water with marginal quality	Mixing marginal water with water of good quality Crop management to reduce salinity effects

### 2.3.4 WP research in Tomato production

A study was conducted by Rashidi & Gholami, (2008), where they did a review on tomato WP values for eleven publications of research on WP and WUE in Iran. The reported values ranged from 2.58-11.88 kg/m<sup>-3</sup> for tomato production. The highest values was measured for micro irrigation and deficit irrigation study sites. In a study on the effect of irrigation methods, mulching and soil water suction on tomato growth, Ramalan & Nwokeocha (2000) reported WP values between 1.80 and 6.70 kg/m<sup>-3</sup>. They found the highest WP values for plots that were irrigated with the conventional furrow method, unmulched and irrigated at 30 kpa soil water suction. They concluded that WUE can be increased significantly by mulching and that a 5-day irrigation interval was more effective in enhancing yields and WUE than irrigating at the 30 kPa or 60 kPa respectively. Katerji et al (2003), studied the effects of salt tolerance on different crops and reported WP values ranging from 4.30 to 8.60 kg/m<sup>-3</sup> for tomatoes grown on loam and clay textured soils.

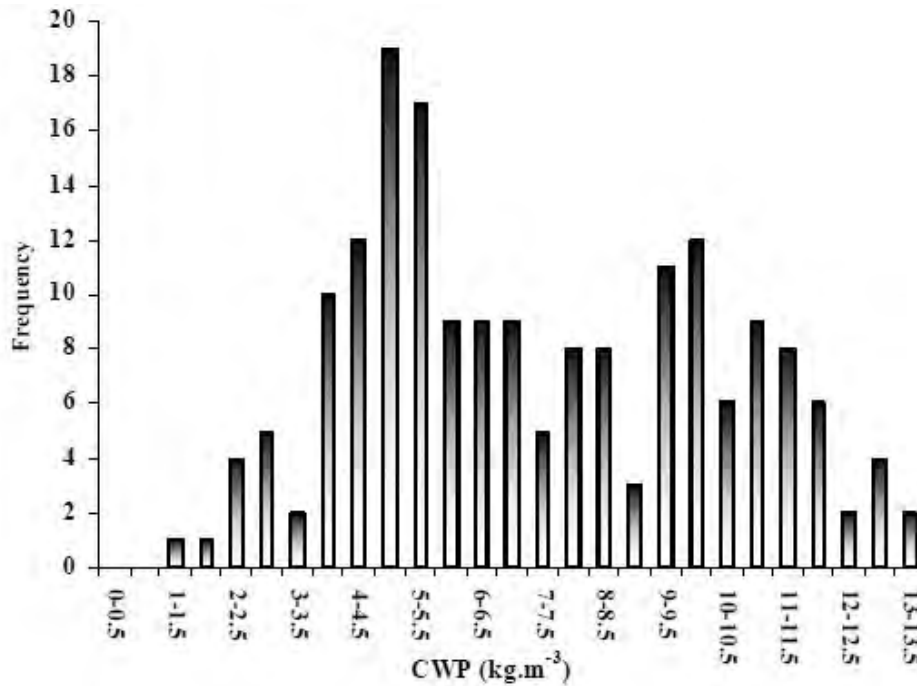


Figure 2.2: Tomato WP values for studies done across Iran (Rashidi & Gholami, 2008).

## 2.4 Smallholder monitoring

### 2.4.1 Smallholder Agriculture in South Africa

The South African agricultural sector can be divided into two components. The larger of the two are the established, highly capitalised commercial sector and on the other hand the poorly established, fluctuating smallholder farming sector. Smallholder farming in South Africa is common in the former homeland areas of the country (May & Carter, 2009). These smallholder farmers are mostly unskilled and untrained with regards to effective agricultural practices. Farming in the former homeland areas of South Africa is characterized by smallholder farming units that are 1.5 ha in size on average, whereas a plot in the commercial sector will average at 42 ha (Van Averbek, 2008).

There is no standard definition found in literature for the term smallholder or small-scale farmer. Smallholder farming in South Africa can be defined as producers who are black and otherwise farmers that are distinct from the dominant (white) large-scale commercial sector. Characterized by a small farm size or plots, they are only partially linked to the larger economic sector and is further classified according to the criteria which include land size, reason for produce (subsistence or commercial), income (poor or rich) level and race group (Fanadzo, 2012). The total area of land that is under irrigation in South Africa is approximately 1.3 million hectare of which about 100 000 ha is in the hands of smallholder farmers (Van Averbek, 2008). Smallholder farming amount to approximately 10% of the

total irrigated agricultural sector in South Africa and increases in overall production can have a significant effect on the food security status of the rural South African farming households.

A household is said to be food secure when the members of that household have access to safe food. When this is not so, the household will be food insecure. This will result in inadequate food intake of the household members and the outcome can either be hunger or mal-nutrition. According to Altman et al (2009) expanding employment opportunities, social grants and **small-scale agriculture** are three contributing solutions to the food security problem. The question remains whether or not smallholder farming, especially in SSA, can contribute and aid in solving the currently growing food security problem. There have been some successes in this regard in some of the African counties. The Agricultural Input Support Programme (AISP) was successfully implemented in Malawi and resulted in yields increases across a large number of staple foods produced by smallholder farmers (Baiphethi & Jacobs, 2009).

After the 1950's, the best way of commercializing the African smallholder farmers was thought to be irrigation development. Beside a lot of effort to realize this by means of irrigation schemes, the homeland areas still did not produce sufficient amounts of crops and food quality many times remained lacking.

There are many challenges facing the smallholder farmers. Past research shows some of the factors contributing to failures of smallholder irrigation projects. Machethe et al, (2004) proposed some of these factors, which include i) total dependency on government; ii) dilapidated irrigation water supply infrastructure; iii) ineffective water management; iv) low production levels; v) lack of knowledge in irrigation and crop management; vi) ineffective extension services; vii) lack of market credit; viii) difficulty in sourcing production inputs; ix) lack of mechanization services; x) broken fences and xi) degraded soils.

*Table 2.3: Categories of the Food Security status, according to district and municipality, of households in the Limpopo Province (De Cock et al., 2013).*

District	Municipality	Food secure	Mildly food insecure	Moderately food insecure	Severely food insecure
	%				
Capricorn	Blouberg	9.1	1.5	27.3	62.1
	Molemole	13.5	5.8	21.2	59.6
<b>Mopani</b>	<b>Giyani</b>	<b>8.2</b>	<b>6.6</b>	<b>23.0</b>	<b>62.3</b>
	Maruleng	6.7	3.3	25.0	65.0
Sekhukhune	Fetakgomo	29.3	13.8	31.0	25.9
	Tubatse	18.6	11.9	37.3	32.2

Whembe	Mutale	13.3	5.0	40.0	41.7
	Thulamela	20.7	3.4	25.9	50.0
Waterberg	Mookgopong	10.3	1.7	20.7	67.2
	Mogalakwena	18.6	6.8	10.2	64.4
Overall		14.8	5.8	26.4	53.1

#### 2.4.2 The yield gap and Food security

The concept of 'yield gap' was established in the 1970's after research was done by the International Rice Research Institute (IRRI) (Mondal, 2011). Yield gap is commonly defined as the difference between the potential yield for the best farm in terms of spatial and temporal scale of interest, and the actual average farmers' yield (Lobell et al., 2009; Mondal, 2011). Smallholder tomato production in the former homeland areas are characterized by low yields and poor quality, while farming by commercial producers in the same region are very productive and very profitable. There are many reasons for the continuing large yield gaps in SSA, while the main areas for improvements are said to be in crop nutrient management and irrigation management (Keating et al., 2010).

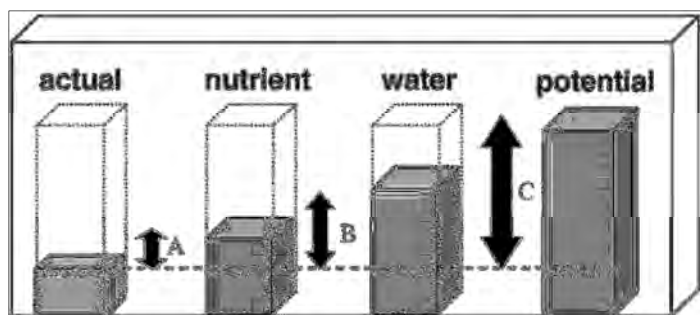


Figure 2.3: Three yield levels distinguished in order to define gaps in terms of potential using land quality indicators. (Bindraban et al., 2000)

In 2000, there were an estimated 5515 ha of tomatoes planted in South Africa, while some sources estimate that this number has decreased to approximately 4875 ha in 2011 (NDA, 2000; Van Zyl, 2011). The average yield for South African tomato production in 2011 was approximately 54.3 ton/ha, yet a yield of 60-80 ton/ha can be achieved with good management. In a case study survey on smallholder tomato production in the Limpopo Province, Chikazunga (2013), found that the average tomato production area is 3.55 ha and average yield is 19 ton/ha. For the Vhembe and Mopani district, the farmers supplying to the agro-processors in the area, have the highest yields with an average of 26 ton/ha. The smallholder farmers in these districts produces two cycles of tomatoes per year.



### **2.4.3 Monitoring smallholder farms**

The monitoring of yields and crop production inputs and outputs are mostly an unknown concept for smallholder farmers in the former homeland areas. Most of the smallholder farmers are old and uneducated and thus to record information regarding their farming practices is a challenge and seen by them as not worth doing. There is however progress in this regard but the use of new technologies to facilitate this process could speed up the farmer adoption rate.

MonQI (Monitoring for Quality Improvement; Alterra, Wageningen) is a multi-scale and multi-disciplinary approach developed to improve the monitoring, management and performance of small-scale agricultural entities world-wide. Nutrient depletion results from successive crop production without proper soil fertilization. This is the results of ineffective farm management practices (eg. irrigation), which leads to high erosion and high levels of leaching (drainage). Decreasing fallow rates and also the inefficient recycling of nutrients that are already in the farming system are among the contributors of poor farm productivity. Fertilization and irrigation are two practices that work interchangeably and can be managed to increase WUE and nitrogen use efficiency (NUE) (Singandhupe et al., 2003). There are thus many aspects of farm practices that influence these processes. In addressing these causes of depletion one needs an appropriate methodology or “basket of technology options” that will aid in understanding the complex farming systems (De Jager et al., 1998).

MonQi is developed and aims to improve the quality of farm management, crop production, the quality of produce, livelihoods and the negative effects of farming on the environment. The aim is reached through a research framework for systematic (financial) analysis of agricultural systems at farm level and describes the existing management situation.

The MonQI Toolbox is a set of materials (questionnaire, software and manuals) for the application of methodology which includes monitoring of the inputs and outputs at farm level. The methodology is a modification of the existing NUTMON approach, a methodology for monitoring nutrient flows and economic performance in tropical farming systems. It has been used successfully for more than ten years in a wide range of farming systems and countries, including China, Vietnam, Indonesia, Kenya, Uganda, Ethiopia, Burkina Faso and Ghana.

### **2.5 Conclusion**

Through the reviewing of applicable literature, relating to the research themes of this study, we conclude that the proposed study will aid in improving smallholder agriculture in the former homeland areas of Giyani. Due to fact that research reports and production potential data for this area is mostly non-existing, the research is needed. NIR spectroscopy



technology for soil chemical property prediction has shown successful results in above mentioned previous studies from many authors. WP increases can be achieved at field-scales and many approaches from various authors were noted. The monitoring and nutrient balance calculations for smallholder farms in SSA are essential in order to evaluate smallholder farming practices in Giyani.

## CHAPTER 3

### STUDY AREA

#### 3.1 Introduction

Giyani is a small town situated in the Limpopo Province, the northern most province of the Republic of South Africa. This province is one of the major producers of vegetable crops and contributes to about 18% of the total vegetable production in the country. Potato and tomato production are the two largest produced vegetable crops in South Africa for both the local and export markets. Tomato, *Solanum lycopersicum*, production is a common crop grown by smallholder farmers in this region and is done so by the use of the conventional furrow irrigation systems. In total, 227 990 tons of tomatoes is produced in the Limpopo Province which accounts for about 66% of all tomato production in South Africa (NDA, 2009). Because of the economic importance and a short growing period, tomato was selected as the chosen crop for research on smallholder agriculture in the Giyani area. The region is also home to one of the largest commercial tomato producers, namely ZZ2.

The villages in and around Giyani are still home to some of the most rural areas in South Africa, where village life and farming goes hand in hand. Farming is a way of life and a means to supply food for the households and to the village community. Agriculture in these communities are characterized by subsistence production which is mostly done using ineffective, conventional practices passed on from generation to generation.

#### 3.2 The study area

The Giyani area is governed by the Greater Giyani Municipality and was established in 1969 as the commercial capital centre of the former Gazankulu homeland and now heads the Mopani district. The area is known for its rich cultural history and is characterized by smallholder agriculture and African village life (Municipality, 2007). Majority of the people in this area speak an African language known as Tsonga.

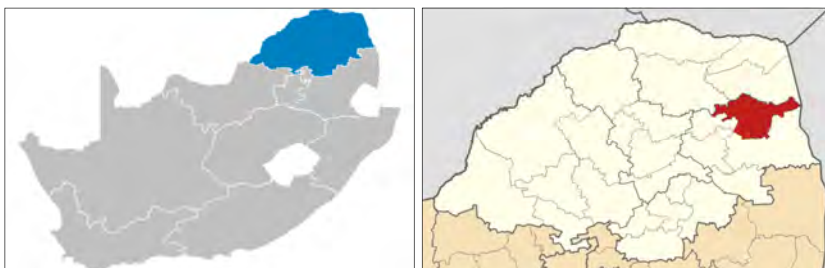


Figure 3.1: The location of the Limpopo Province (Blue), South Africa (Bizzorg, 2012) and the location of the study area of Giyani in the Mopani district (red), Limpopo Province (Commons, 2011).

### 3.2.1 Climate

The Limpopo Province is one of the richest agricultural crop production areas in the country. The climate ranges from sub-tropical to semi-arid in some areas. Because of the great changes in topography, it gives rise to a wide variety of climatic characteristics.

The study area is located in the lowveld, which is characterized by a dry to semi-arid savannah climate. The summer months (October to March) have long sunshine-hour days with occasional thunderstorms, while the winter (April to August) is mostly dry with mild temperatures and frost-free (M'Marete, 2003). The mean annual precipitation (MAP) for the study area is approximately 350 to 500 mm per annum, of which 80% occur during the summer months (Scheffler, 2008).

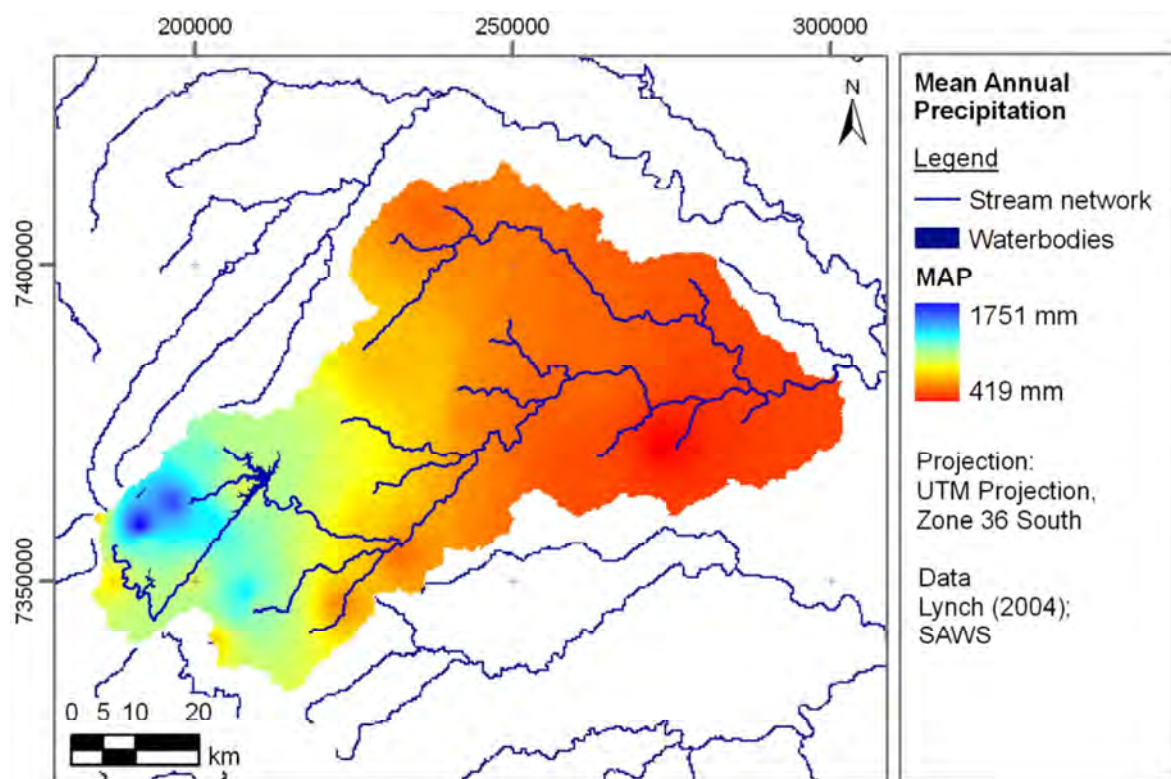


Figure 3.2: Mean annual precipitation for the Great Letaba River and the Molototsi River catchments (Scheffler, 2008).

The average daily maximum temperature varies from about 25 to 30°C, while the daily minimum temperature ranges between 18 to 23°C. Summer heat-waves may occur and this extreme weather event is a common production challenge affecting their yields. There is generally no frost, with farmers being able to plant the whole year round. Daily evaporation is mostly high because of high temperatures with the average ET ranges between 70 to 110 mm per month.

Weather data from the Masalale Packhouse gives a good overview of the crop production potential throughout the study period. This station is located approximately 12 km from both of the farms in the study. The rainfall data, as seen in Figure 3.1, shows that very little rain was received in the winter months of 2012 and 2013. Heavy rains and flooding occurred in February, 2013.

*Table 3.1: Summary of the weather data for the study period, from the Masalale Packhouse weather station (ARC, 2013).*

Year	Month	Temperature (°C)			mm		N Rad (MJ/m <sup>2</sup> )	Wspd (ms <sup>-1</sup> )	R hum (%)	Cold Units	Heat Units
		min	max	ave	Rain	ETO					
2011	9	11.30	30.60	20.79	1.27	97.49	13.97	0.99	57.50	48.86	10.79
2011	10	17.09	30.38	23.45	37.34	99.72	13.50	1.05	61.56	57.25	13.45
2011	11	19.11	31.16	24.74	59.95	94.03	12.97	0.91	57.98	62.27	14.74
2011	12	19.96	31.33	25.45	58.92	97.73	13.02	0.87	58.88	62.99	15.45
2012	1	20.96	32.03	26.27	81.54	110.68	14.70	1.08	66.84	61.63	16.27
2012	2	21.91	33.62	27.14	9.13	98.27	14.29	0.75	68.49	61.35	17.14
2012	3	19.38	33.02	25.78	40.37	97.33	12.62	0.92	64.91	56.82	15.78
2012	4	14.11	28.73	20.92	2.03	75.82	11.25	0.73	71.28	59.87	10.92
2012	5	10.61	29.13	19.32	0.00	66.60	9.89	0.57	67.15	55.81	9.32
2012	6	6.37	26.36	15.73	0.00	57.25	8.95	0.57	62.37	53.43	5.73
2012	7	6.46	26.04	15.74	0.76	68.72	8.44	0.61	59.28	54.78	5.74
2012	8	7.89	29.02	18.03	2.28	102.01	16.69	0.66	53.19	44.39	8.03
2012	9	14.66	28.08	21.11	21.59	200.69	15.54	1.03	51.61	57.50	11.11
2012	10	17.34	29.16	23.03	41.40	108.33	16.20	0.90	55.92	61.56	13.03
2012	11	17.97	31.43	24.45	50.04	238.37	19.95	0.99	57.98	57.98	14.45
2012	12	20.87	32.42	26.25	60.19	134.98	19.62	0.93	58.88	58.88	16.25
2013	1	21.43	30.97	25.90	217.93	127.97	18.64	1.07	66.84	66.84	15.90
2013	2	20.55	31.40	25.51	266.20	259.96	21.14	0.56	68.49	68.49	15.51
2013	3	18.78	30.53	24.28	13.46	113.54	17.75	0.56	64.91	64.91	14.28
2013	4	14.50	27.87	20.41	116.07	203.55	15.71	0.41	71.28	71.28	10.41
2013	5	9.54	27.47	17.57	0.76	84.22	15.19	0.34	67.15	67.15	7.57
2013	6	7.52	28.28	16.80	0.76	160.60	14.03	0.35	62.37	62.37	6.80
2013	7	7.94	26.11	17.02	1.02	71.65	13.12	0.43	59.28	59.28	6.34
2013	8	9.58	27.98	18.78	0.00	111.23	15.41	0.40	53.19	53.19	8.21
2013	9	12.86	31.03	21.95	0.76	105.28	17.69	0.50	51.61	51.61	11.60
2013	10	15.60	29.58	22.59	65.79	117.58	18.40	0.83	55.92	55.92	12.56

### 3.2.2 Vegetation

The vegetation of the study area is characterized by a tropical bush and savannah type land cover. Named after the abundance of Mopani trees, the so called 'Mopani veld' stretches over large areas of the study area (Odhiambo, 2003). With the traditional communal grazing for cattle around the village areas, the veld is mostly over-grazed. The smallholder crop

production farms are usually fenced off so that the grazing animals cannot get to the crops. There are however many accounts of total crop losses due to cattle gaining access to the fields and eating crops such as tomatoes.

### **3.2.3 Geology**

The Great Letaba River starts in the foothills of the mountainous area of Tzaneen and Modjatjieskloof. The geological formation of this catchment is said to have taken place in the Precambrian era. The study area is at the interface between the granitic-greenstone of the Kaapvaal Craton and the metamorphic formations of the southern marginal zone of the Limpopo mobile belt. Grey biotite gneiss and also migmatite of the Goudplaats gneiss is found in the north west of the study area. Whereas in the west, the biotite granite of the Vaalian age period with abundant dykes are found (Sobczyk, et al., 1989).

### **3.2.4 Soils**

The lowveld soils are generally characterized by reddish, brown and gravelly soils that mostly have low fertility for crop production. The best agricultural soils are found on the areas of land adjacent to rivers being formed by alluvial processes (Mchau, 2003).

Very little soil data is available for the study area, but the 1:250 000 land type map gives a good overview of soil forms and families occurring in each of the land types. The study area falls within the Tzaneen 2330 map sheet and each land type has its unique combination of broad soil pattern, terrain type and microclimate (Paterson, 2012). Within each of these individual land types, soil forms are listed according to their dominance, but unfortunately the precise locality or distribution of the different soils within the land type cannot be determined. Several different land types, as seen in Figure 3.3, occur within the study area and these are summarized as follows (Sobczyk, et al., 1989):

i) Land type: Ae 323

The soil series found in the land type are Hutton, Mispah, Oakleaf, Glenrosa, Fernwood, Cartref, Valsrivier and Clovelly forms. With the most dominantly occurring soil form being Clovelly, which covers approximately 50% of the land type.

ii) Land type: Fb 354

The soil series found here are Mispah, Cartref, Glenrosa, Hutton, Shortlands, Oakleaf, Valsrivier, Swartland, Bonheim and Dundee forms. The most dominant soil form, with an occurrence of 35% of the total area of the land type, is the Oakleaf soil form.

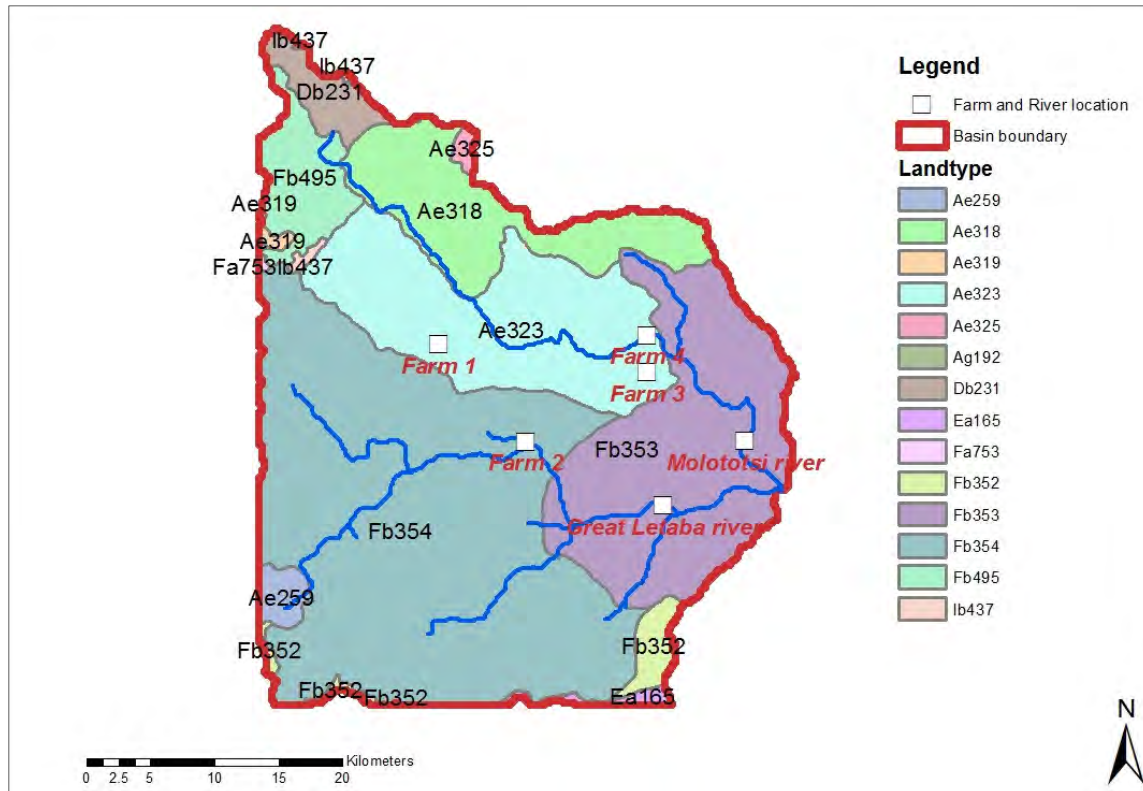


Figure 3.3: Land type map of the study area, including the location of selected farms in the area.

### 3.2.4 Hydrology

The Luvuvhu/Letaba water management area (WMA) is adjacent to Zimbabwe and Mozambique with the major rivers being the Luvuvhu, Shingwedzi, Klein-Letaba, Middle Letaba and the Great Letaba Rivers. All of these rivers flow in an easterly direction. The study area lies within the Letaba river Catchment and measures approximately 13 500 km<sup>2</sup> in size. The area lies on the west-east axis, with the headwaters being formed by the Drakensberg Mountain range. The mountainous zone, starting from Tzaneen, Duiwelskloof and Waterval, is at the highest about 2 000 meters above sea-level and flows north-east to the lower foothills zone and eventually travelling over the large area of the lowveld plains (Department of Water Affairs, 2012).

### 3.3 Site description

Smallholder farms were selected for the EAU4food research project and all of them are located approximately 50 km from Giyani off the R529 road going to Tzaneen. The nearest village to the farms, which is located on the R529 road, is called Ka-Dzumeri. Each farm is then further located close to a smaller village, connected via gravel roads, where these farming households live in their local communities and go out to their farms daily.



The selected farms for this research, Zava and Mzilela, are both Community Cooperative garden projects. These two farms were selected to best accomplish the research goal and to do effective research into the poor farming areas of the Limpopo Province. Female farmers' remain a large portion of the total smallholder farmers in the rural areas of South Africa.

Each farm is quite unique and the farming setup varies considerably. Each farm will be discussed in detail.

### **3.2.1 Farm 1: Zava Garden Cooperative**

Zava is a small farming unit that is situated on the banks of the Great Letaba River. This farm, as a cooperative garden project, consists of 16 elderly female farmers that function as the household head for their respective households. They farm and cultivate the land together. The age of these female farmers range from 60-85 years, and sometimes some of their household-members would help with management practices needed on the farm. The size of the farm covers an area of approximately 12 ha in size. Most of the garden cooperative projects have a head member of the group, the decisions are mostly made by the group through voting and agreement.

The management of the Zava farm is done in such a way that each member of the group receives a small piece of the land, 60 x 40 m in size. Normally the same cropping system is used on all of these smaller portions, except in certain seasons when demands for greater variety of crops are high. The elevation of the farm ranges from about 410 mamsl at the higher slopes of the farms to about 395 mamsl at the banks of the Great Letaba River. The slope average from top to bottom is approximately 3.6%. The great Letaba River is the main source of irrigation water. They pump water from the river into a cement dam, and from there they irrigate their crops.

The small portions of land divided for each member can clearly be seen in Figure 3.4. The river flows all year round and therefore the irrigation water supply is mostly constant. A common challenge occurring on this farm is when the irrigation pump breaks down or gets damaged when the river is in flood. In 2013, the farm could not be used as a 2<sup>nd</sup> and 3<sup>rd</sup> season WP site, because the pump had broken down and it took 4 months for the problem to be fixed. When these breakdowns occur, the crops are left in the field and usually the crop is totally lost. These issues highlight the food security challenges faced by these farming households.



*Figure 3.4: Zava Cooperative Garden farm location and boundary*

### **3.2.2 Farm 2: Mzilela Cooperative Garden**

Mzilela farm is slightly bigger compared to Zava and also consists of about 16 female farmers producing crops together on the land. These farmers are also mainly elderly and are generally in the same age range as the Zava farmers. This cooperative garden farm works slightly different than Zava farm in terms of management and working relation between members. The 16 members use a communal bank account and all operations are run by the whole group. It is a team system and all members work on all the crop activities and therefore they share in all the profit or losses.

Mzilele is one of the more intensively cropped farms in the Giyani area and has recently received many awards and prizes in terms of their production successes. The most recent award was won by this farm for the 'Women in Water' project, which was organized by the Department of Water Affairs. This prize, as seen in Figure 3.5 was a cash amount of R100 000 and some of these finances were used to buy their own tractor. This farm mainly produces vegetable crops and the irrigation water is pumped from two boreholes on the farm.





*Figure 3.5: Some of the recent trophies and prizes won by Mzilela for their crop production performances.*

Mzilela farm was selected as a case study site for the remainder of the research project and also to do most of the trials. It was thus decided to do a soil survey in order to get a better perspective of the production potential of the farm. No previous data or any reports were available for any of the farms that were initially selected for research.

The soil survey was conducted in August of 2013 on Mzilela farm. Soil profile pits were classified according to the soil classification work group (Soil Classification Working Group, 1991). During the soil survey a total of 16 profile pits were made as selected according to variation in elevation, vegetation type, difference in topsoil colour and differences seen on an aerial photo of the farm. Hired labour was used to dig a couple of deep profile pits (1.5 m deep), while shallower pits (0.5 m deep) were made when labour was unavailable. The terrain of Mzilela farm is mostly flat when the elevation was assessed over the farms. A GPS device was used to log the elevation (m) of the surface of the farm on a grid structure, which was walked in order to get the variance in elevation across the farm by taking logging readings every second. The highest areas on the farm area are 433 mamsl, while the lowest

points are at 420 mamsl. The dominant soil forms, as seen in Figure 3.7, were Hutton and Oakleaf soil. The Oakleaf soils were either deep or very shallow, depending on the location on the farm. The other soil form which was encountered was Mispah soils, which has a shallow orthic-A topsoil horizon on rock. The main physical limitations on this farm are the rocky layers encountered at different depths. The effective (useable) depth for crop production in terms of good root development and water and nutrient uptake to ensure healthy plants, varies greatly. The shallow soils are not used for crop production, but natural grasses and trees grow there.





*Figure 3.6: Soil profile pits of the main soil families on Mzilela farm which included i) Hutton, ii) Oakleaf and iii) Mispah soil forms.*

The chemical properties of each profile was analysed to get an overview of the soil potential in terms of crop production. The material and methods for chemical analysis on soil samples are discussed in detail in the next chapter.



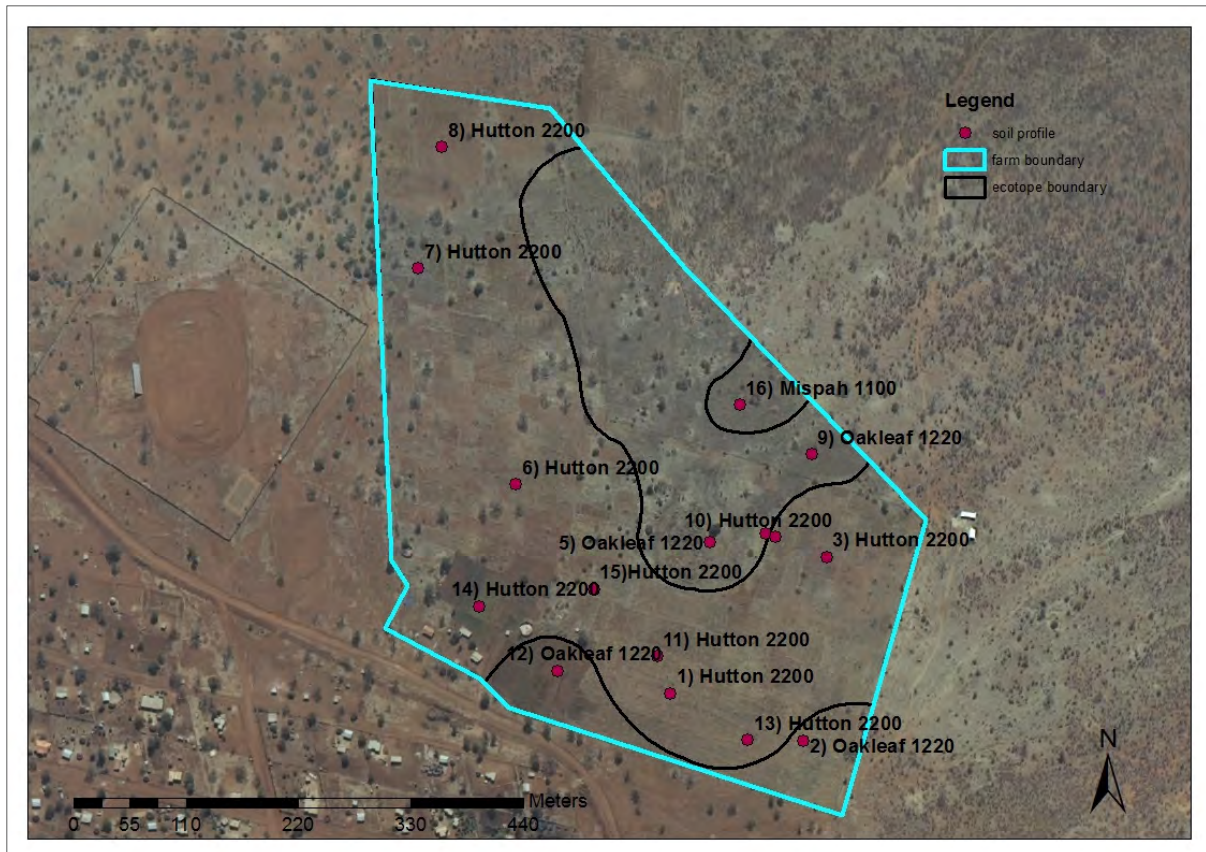


Figure 3.7: Soil form and family map from the soil survey at Mzilela farm

The Hutton soil on Mzilela farm is characterized by structureless, red soil with the amount of coarse fragments differing from site to site. Normally, the soil layer below 40cm showed higher coarse fragment contents as seen in Figure 3.6 (iii). The effective depth of these Hutton soils averaged at 50-60cm and has a high production potential for vegetable production.

The Oakleaf soil located on the southern part of the farm has an effective depth of 50-60cm and differs mostly in soil colour compared to the Hutton soils. These soils had higher P and K values compared to the Oa 2 ecotope as illustrated on the soil map seen in Figure 3.9. Oa 1 and Hu 1 have high production potentials and this is also the area on the farm that is used for crop production. The other areas, including the Ms 1 and Oa 2 ectopes, have very low soil potentials due to the effective depth being below 20cm due to a rocky subsoil layers.

Table 3.2: Summary of soil chemical results for each profile at Mzilela farm.

Profile nr	Map unit	Depth (cm)	Clay (%)	Coarse fragments (%)	pH (KCl)	EC (mS/m)	(mg/kg)		Exchangeable cations (cmol(+)/kg-1)				
							P	K	Ca	Mg	Na	K	CEC
1	Hu 1	10	5	9	6.42	16.97	8.30	194.51	4.15	3.59	0.21	0.50	8.45
		30	20	60	5.61	25.70	3.57	118.70	3.81	5.51	0.19	0.30	9.82
2	Oa 1	10	5	8	7.28	50.20	25.14	415.95	28.56	9.12	0.43	1.07	39.18
		30	10	10	7.36	47.10	14.87	136.66	27.72	9.68	0.49	0.35	38.23
3	Hu 1	10	5	6	5.48	15.53	7.89	293.26	3.94	2.28	0.05	0.75	7.02
		30	20	14	4.76	8.53	3.78	61.84	4.15	3.04	0.08	0.16	7.42
4	Oa 2	10	10	4	6.13	47.50	7.27	488.77	3.98	1.90	0.07	1.25	7.20
		30	25	7	5.21	15.61	0.08	265.33	7.06	2.83	0.12	0.68	10.70
5	Oa 2	10	20	6	4.11	38.00	6.04	494.76	4.31	2.82	0.10	1.27	8.50
		30	30	14	4.38	11.61	3.16	323.19	4.17	3.15	0.17	0.83	8.31
6	Hu 1	10	5	7	4.77	8.54	3.16	298.25	3.28	2.08	0.05	0.76	6.18
		30	20	13	4.08	9.62	1.32	84.79	2.69	2.71	0.06	0.22	5.67
7	Hu 1	10	5	5	5.03	10.65	2.96	468.82	4.48	3.51	0.06	1.20	9.26
		30	15	6	4.35	3.30	1.32	147.63	2.90	3.77	0.07	0.38	7.12
8	Hu 1	10	5	8	4.83	21.40	3.78	291.27	3.40	1.69	0.05	0.75	5.89
		30	15	17	4.83	6.00	0.91	108.73	3.68	2.44	0.06	0.28	6.46
9	Oa 2	10	5	31	4.70	11.73	0.08	212.47	1.11	0.80	0.04	0.54	2.49
		30	10	66	4.35	4.96	0.49	215.46	0.93	0.75	0.05	0.55	2.28
10	Hu 1	10	10	22	5.96	32.30	16.54	180.05	2.82	3.02	0.12	0.56	7.85
		30	25	24	5.60	25.30	16.31	153.61	3.53	2.72	0.16	0.57	6.42
11	Hu 1	10	5	5	6.58	65.00	23.58	260.10	4.21	3.97	0.16	0.71	9.78
		30	25	6	6.41	321.10	17.74	159.85	4.96	4.33	0.26	0.45	11.32
12	Oa 1	10	5	7	7.06	43.40	2.70	116.71	3.99	3.97	0.45	0.39	8.82
		30	10	7	7.02	44.60	2.95	11.97	4.17	4.07	0.33	0.36	8.65
13	Hu 1	10	10	22	7.21	60.01	16.54	223.94	3.96	3.64	0.12	0.57	8.29
		30	20	24	6.65	43.80	16.31	206.73	3.65	2.57	0.13	0.53	6.88
14	Hu 1	10	5	7	6.96	118.10	117.47	361.19	6.61	4.69	0.17	0.93	12.39
		30	25	23	6.84	67.30	10.86	310.72	4.72	4.73	0.34	0.80	10.59
15	Hu 1	10	10	16	6.64	25.10	4.69	88.18	5.76	0.70	0.68	0.23	7.36
		30	25	17	6.47	27.90	0.58	84.09	3.68	0.56	0.70	0.22	5.16
16	Ms 1	-	-	-	-	-	-	-	-	-	-	-	-

The pH (KCl) of the soils at Mzilela farm was in the range of 4.3 and 7.4. pH varied between different sampling sites, while the EC was generally lower than 320 mS/m. Most samples had plant available P values below the optimum of 12-16 mg/kg, which is needed for vegetable production. The plant available K values were generally within the optimum range of 100-250 mg/kg (Sawyer & Mallarino, 1999). The Hu 1 and Oa 1 soils showed CEC values

between 5-15 cmol(+)/kg, while some of the Oa 2 soils showed CEC values lower than 5 cmol(+)/kg).

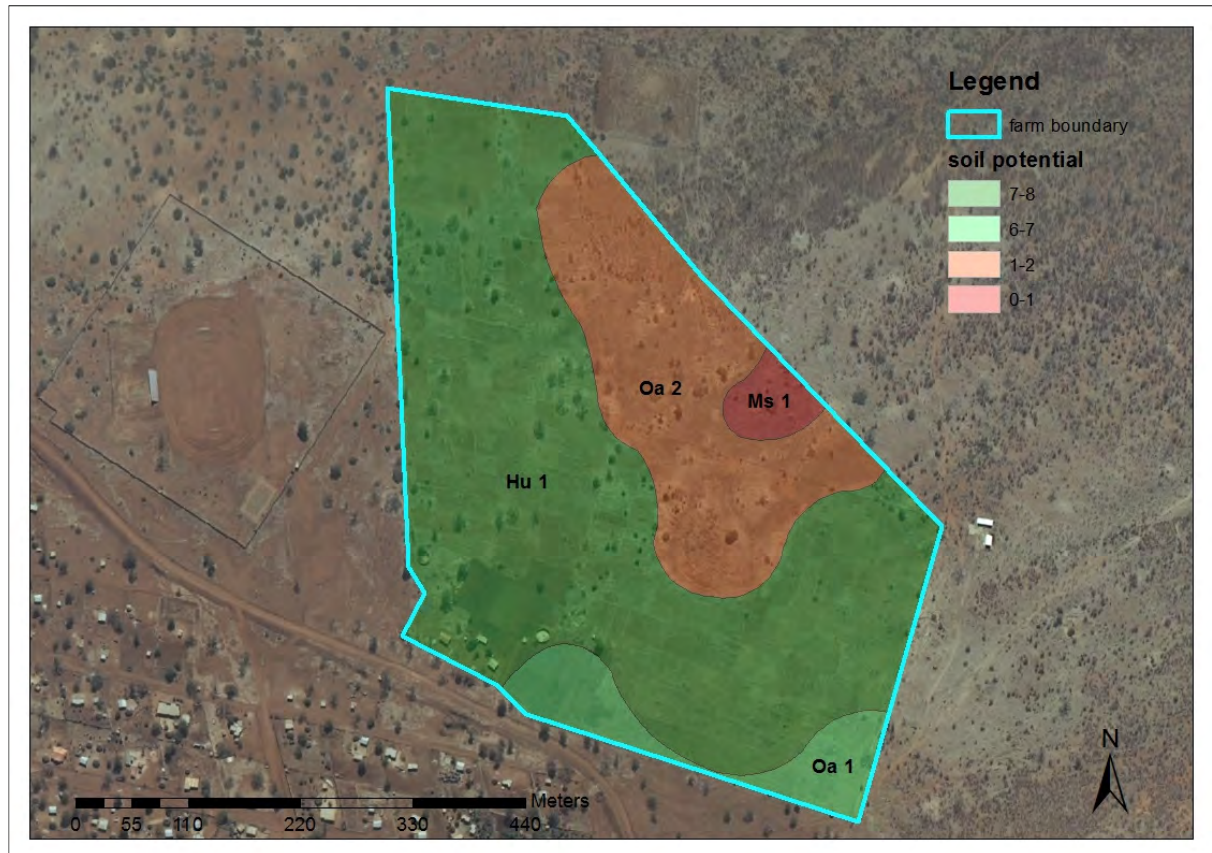


Figure 3.8: Soil potential map of the different Ecotopes on Mzilela farm.

A large portion of the Mzilela farm has a high soil potential for vegetable production (Hu1 & Oa 1). This area is found in the south and western parts of the farm and has an effective depth of 50-60cm. With proper soil fertility management, these soils can maintain high yields.

The north-eastern part of the farm is characterized by very shallow soils and is therefore a major soil limitation for crop production. This limitation cannot be corrected and therefore the smallholder farmers should not plant here.

## CHAPTER 4

### NIR Spectroscopy for Soil Chemical Characterization

#### 4.1 Introduction

Smallholder farmers in the former homeland areas of South Africa face many challenges which inhibit the improvement at farm level in order to increase food production. Some of the main challenges include the access to market, production factors and credit combined with property right constraints. The high transaction costs also make life very difficult for these smallholder producers farming on small pieces of land (Ortmann & King, 2006). These farmers' firstly needs to produce sufficient food for their households' consumptive needs. Secondly, only once production increases to such a level that excess food is produced, can smallholder farmers start to look for opportunities to sell their produce. This is however rarely the case in the former homeland areas with only 5% of these farming households selling their produce for the market (Pienaar, 2013).

The dualistic nature of the agricultural sector in South Africa consists of a highly capitalized commercial sector that is well-integrated and on the other hand the smallholder farming sector is mostly subsistence farming which fluctuates regularly (Vink & Kirsten, 2003; May & Carter, 2009; Aliber & Hart, 2009). These two types are distinctly different from one another and the failure to recognize these have contributed to failed interventions to increase the production capacity of the smallholder production systems. When addressing the needs and challenges to make smallholder farming more successful, there needs to be a farmer-focussed approach which identifies the specific opportunities and constraints for these smallholder producers, which is often not applicable or relevant to the solution proposed to their large-scale, commercial counterparts. The general agronomic principles remain the same for both large and small-scale producers, but the application needs to change. This chapter proposes one such application towards smallholder farming and focusses on the significant improvements in soil nutrient management amongst these smaller farming systems in the rural areas of South Africa.

A new innovation technique for proper soil nutrient management for smallholder farmers is proposed. The predictive ability of NIR technology and chemometrics on soil samples is tested in order establish whether or not the standard soil chemical parameter can be successfully predicted at a relatively high accuracy. This procedure is seen as a possible method to determine fertilizer recommendations and will give smallholder farmers access to site specific, agronomic soil fertility advice to improve production. This process will be discussed in this chapter.



## 4.2 Background

The Mzilela farm in Giyani was selected as the study site for the research of the use of NIR technology for determining soil chemical properties for fertilizer recommendation purposes. A soil survey was conducted on this farm, which included all the different soil forms and families. Soil samples were also taken at this farm and analysed for the WP research (see chapter 5 and Appendix 1) sites and therefore this farm was chosen. Mzilela farm therefore had a large number of samples of which soil chemical characteristics were analysed and could be used for NIR and chemometric analysis.

Throughout the study period, with many conversations with smallholder farmers in the area, it was found that the commercial sector's manner of fertilizer recommendation calculation techniques are not conducive for effective application on smallholder farms in the former homeland areas. Many do not see the need, or have the available finances, to invest in buying fertilizer, and therefore investment to do soil chemical analysis is not even considered as an option. This leads to smallholder farmers having no idea of the soil chemical status of the soils on their farms and continued production without fertilizing occurs commonly among them. Those smallholder farmers that do fertilize, do so without any knowledge of the amount of fertilizer required and therefore the applied amount is based on what they 'feel' is the correct amount to apply. This can often lead to fertilizer being applied at higher levels than what is required, which has dangerous negative effects on the environment. Alternatively, this method can lead to fertilizer application being below the required amount which leads to low crop productivity and low yields. The latter seems to be common among smallholder farmers and subsequently the crop yields gradually decrease (Larson & Frisvold, 1996). Smallholder farming households are becoming increasingly at risk when food production decreases. Soil fertility management is therefore seen as a key area to address in order to improve the production of food crops and also to introduce farmers to selling their excess produce when their crop quality improves.

The standard soil chemical tests, which include the necessary analysis for fertilizer requirement calculation, are very expensive (approximately R300-500 per soil sample) in order to know the fertility status of the soil before planting a crop. These soil chemical results are then used to determine fertilizer amounts needed for optimum crop production. In general, smallholder farmers in Giyani do not have access to soil laboratories and cannot afford to do the soil analysis before planting. These farmers have to rely exclusively on the soil to yield enough food for their household, but the optimal fertilizer amount is very rarely applied. This practice leads to soil nutrient mining from successive crop production cycles without any soil nutrient inputs. This is commonly encountered on smallholder farms in SSA



(Henoa & Baanante, 2006). There is thus a need for a cost effective, speedy agronomic analysis, which gives these farmers guidance towards fertility management in a user-friendly format.

The Limpopo Department of Agriculture (LDA) and the local Municipality in Giyani is currently seeking for ways to overcome the great challenge of soil nutrient management for smallholder farmers in this area. There is therefore a need to develop a soil chemical characterization method that is quick, efficient and less costly. South Africa's smallholder farmers would benefit from the development of such a cost-effective and reliable method for soil chemical monitoring. The conventional wet chemistry method which is used in standard soil testing laboratories, are very expensive, tedious and requires the use of many chemicals.

Near-Infrared Spectroscopy and chemometrics are introduced as a possible innovation to aid in solving the soil fertility issues of the smallholder farmers in Giyani. The initial expenditure on this technology and equipment is relatively expensive, but the equipment is easy to operate and can facilitate the analysis of more samples in a shorter time frame (up to 30 samples per hour). In contrast, standard laboratory results may take up to 7 working days to be completed, which stresses the efficiency of the method as proposed in this study. It is expected that these smallholder farmers do not need to have 100% accurate soil chemical results, but rather a basic overview of the chemical status of their soils and how much fertilizer to apply. To test the validity and suitability of this technology, the subsequent section will give the materials, methods and results for this study.

## **4.3 Materials and Methods**

### **4.3.1 Study site and soil sampling**

A complete soil survey was conducted at Mzilela Cooperative garden farm (23° 35' 32.77" S, 30° 49' 03.71" E, 420 m) and soil samples were taken throughout the research period from 2012 to 2013. All the respective soil forms and families were inspected which included Hutton, Oakleaf and Mispah soils. Soil samples were taken and all chemical analyses were performed at the Department of Soil Science, Stellenbosch University. In total, 217 soil samples were collected which included 72 topsoil samples (0-20 cm) and 145 subsoil (20-40 and 40-60 cm) samples across the farm. Samples were oven-dried at 105 °C for 24 hours and then sieved through a 2 mm sieve, which removed the coarse fragments larger than 2 mm. Each sample was grounded with a mortar to make it even finer for more effective application in the NIR analysis.

#### **4.3.2 Soil chemical analysis**

Standard soil chemical characterization was done for each sample which included pH (KCl), electrical conductivity (EC), total carbon (%C), total nitrogen (%N), plant available phosphorous (P), plant available potassium (K), exchangeable Ca, -Mg, -Na, -K and the Cation Exchange Capacity (CEC). Soil samples were treated normally by oven drying at 100°C for 24 hours and sieved with a 2mm sieve to exclude coarse fragments larger than 2mm in size.

pH determination was done using a 1M KCl solution with a 1:2.5 soil to KCl solution ratio. A standard pH electrode, Eutech pH 700 meter, was used. EC was determined in water with a 1:5 soil to water ratio with the Eutech Con 700 meter. Total C and N determination was done by finely grounding each sample with the use of a ball mill. The fine samples were analysed at the Central Analytical Facility (CAF) at the Department of Soil Science using the EuroVector instrument.

Plant available P was determined with Mehlich no 3 extraction solution. This was done in order to compare samples that varied considerable in pH, and P amounts were calculated with the colorimetric Ammonium Molybdate method. Absorbance was measured with a spectrophotometer at 660 nm.

CEC was analysed using the Ammonium Acetate (pH 7) extraction method. Leachate was analysed with Atomic Absorption Spectrophotometry (AAS) to calculate the basic cations for Ca, Mg, Na and K. From this K value the plant available K is calculated. CEC is then calculated as the sum of the basic cations.

#### **4.3.3 NIR Spectral measurements**

NIR spectra measurement was done using the Bruker multi-purpose analyser (MPA) spectrometer and OPUS 6.5 software (Bruker, 2011). According to Mashimbye (2013), this is a standard method applied for NIR scans on soil samples and was utilized in this study. The spectrometer properties were set at measuring at wavelengths at a range of 800 – 2800 nm. The ground sample was placed into an aluminium cup with the sample covering the whole surface area of the bottom glass (made from high quality quartz glass) of the cup, which has a 51 mm diameter. The rotating sphere application was used and each sample was scanned 120 times during each scan, to gain the average spectra for each sample. All these soil samples were scanned at Stellenbosch Universities' Institute for Wine Biotechnology.

## 4.4 Data Analysis

### 4.4.1 Spectral and reference analysis

One of the most essential steps in the NIR calibration procedure relates to the selection of a proper sample set which is needed to cover the range of spectral variation in the entire population for which the calibration was carried out on (Chodak, 2008). In this study spectral and reference analysis was done using a stand-alone chemometric software package called SIMCA 13.0.2 (1998-2011©) (Umetrics, 2011). SIMCA is a user-friendly tool used to assess the spectral and reference data, and was also used to illustrate the statistics graphically. After the final data set was selected, these spectra were used in OPUS for model development.

Spectral data from NIR scans in OPUS 6.5 © were transferred into an X-variable matrix using The Unscrambler © (Camo, 2013) software package. The spectral data was then transferred into a data table containing the Y- variables (soil chemical results), and the 1154 columns of X-variable spectral data as seen in Table 4.1.

*Table 4.1: X and Y variable (1 to 1154, not displayed) data for data analysis as imported into SIMCA software.*

Plot and depth (cm)	Y-variables (laboratory soil chemical results) (n=10)									X-variables (spectral data) (n=1154)	
	pH (KCl)	EC (mS/m)	P	K	Ca	Mg	Na	K	Σ sum of basic cations	X1	X1154
1A10	6.96	11.81	117.47	361.19	6.61	4.69	0.17	0.93	12.39	0.103	0.02
1A30	6.84	6.73	10.86	310.72	4.72	4.73	0.34	0.8	10.59	0.089	0.017
1A50	6.77	3.52	9.16	343.54	4.31	3.89	0.36	0.88	9.45	0.1	0.02
1B10	7.51	5.94	56.07	372.07	5.42	4.21	0.17	0.95	10.76	0.113	0.022
1B30	7.64	4.63	44.12	287.28	5.14	3.5	0.14	0.74	9.51	0.114	0.02
1B50	7.63	4.96	30.48	198.5	3.61	3.37	0.12	0.51	7.6	0.105	0.021

In order to select the best sample set, outliers and redundant spectra were identified and removed. A spectral outlier was identified as one that differed significantly from the average spectra and these were not included in the calibration or validation data sets. Before the spectral and reference analysis was done, the noise in the spectral data was removed. These were the wavelength numbers at the end of the highest wavelengths in each spectra where no difference between scans could be seen (X1130-1154 removes).

The structure of the initial sample set data was evaluated by looking at the X- and Y-variable matrixes by performing a PCA (X) and a PCA (Y) respectively. This was done in order to select the calibration and validation data sets and to see if data transformation would be necessary.

#### Principal component analysis (PCA)

A PCA analysis was performed as a technique to reduce the spectral information into the most dominant dimensions in terms of variance in the data. The use of a PCA involves the reduction of dimensions contained in a data set, which contains a large number of inter-related variables. Simultaneously, the PCA analysis retains the maximum amount of variance contained in the dataset (Jolliffe, 2005). After the data transformation is accomplished, a new dataset is created that comprises of a new set of variables, the principal components, which are the scores, calculated for the underlying dimensions in the data. By using the new variables from the resulting components, which was synthesized by the original raw data, the need to standardise or transform the variables for the next step in the analysis is avoided (Gaspar et al., 2008). All 217 initial samples were analysed to see the variation in the data and to see the distribution of variance.

##### i) PCA(X) model

The PCA(X) model was performed in order to identify the main dimensions within the spectral data. 4 components were selected which accounted for 99.5 % of the variation in X. Figure 6.2 illustrates the PCA t-scores of component 1 and 2 which explained the largest variation in the x-space with R<sup>2</sup>X values of 0.875 and 0.101 respectively. The data points are coloured according to the sample site at Mzilela farm. Site 1 and 2 had the most data points because this was the two main research sites on the farm (chapter 5), while site 3 to 14 was samples taken in the soil survey (chapter 3). The result shows that the different sampling site had a major effect on the variation in X and therefore careful consideration was needed in the selection of the final calibration and validation sample sets.

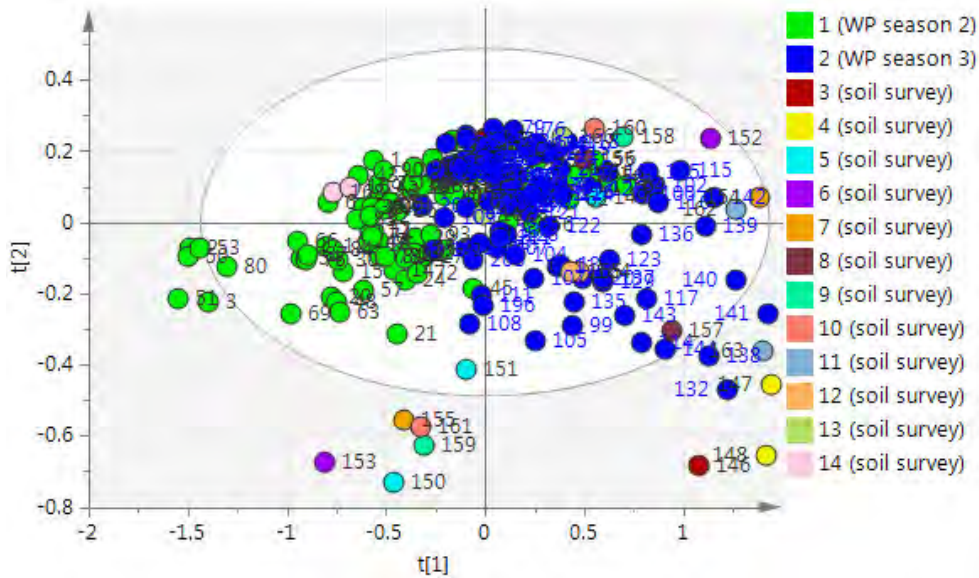


Figure 4.1: PCA(X) analysis showing the scores scatter of the  $t_1$  and  $t_2$  variables summarizing the X-variables. The colours indicate the different sampling sites on the farm.

Another source of variation was identified in the data set, which was the difference in sampling depth (subsoil or topsoil), forming clear a grouping as illustrated in Figure 4.2. The topsoil samples are grouped mainly in the top half of the PCA, while the subsoil samples were grouped mainly in the bottom half of the PCA. Soil sampling depth therefore also had a large effect on the variation in X.

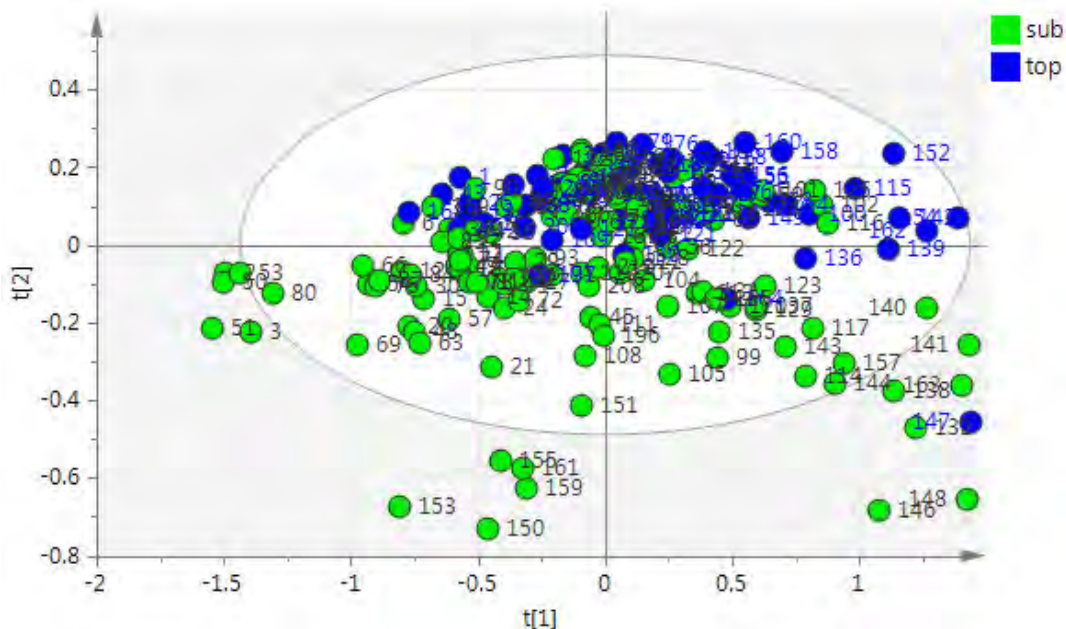


Figure 4.2: PCA(X) analysis showing the scores scatter of the  $t_1$  and  $t_2$  variables summarizing the X-variables. The colours indicate the different sampling sites on the farm.

In order to identify any possible outliers in the X-variables of the PCA, the Hotelling's T2 test were performed. Figure 4.3 shows the Hotelling's T2 values calculated for the selected components (1-4), which indicated the distance from the origin in the model plane (scores space). Here, samples were excluded as outliers when T2 values were larger than the 99% confidence limit. Large T2 range values, which is far above the critical limits, indicates that the corresponding data point is far from the other observation points in the selected range of components. These were excluded as such outliers may pull the model skew if they are included in the final work set.

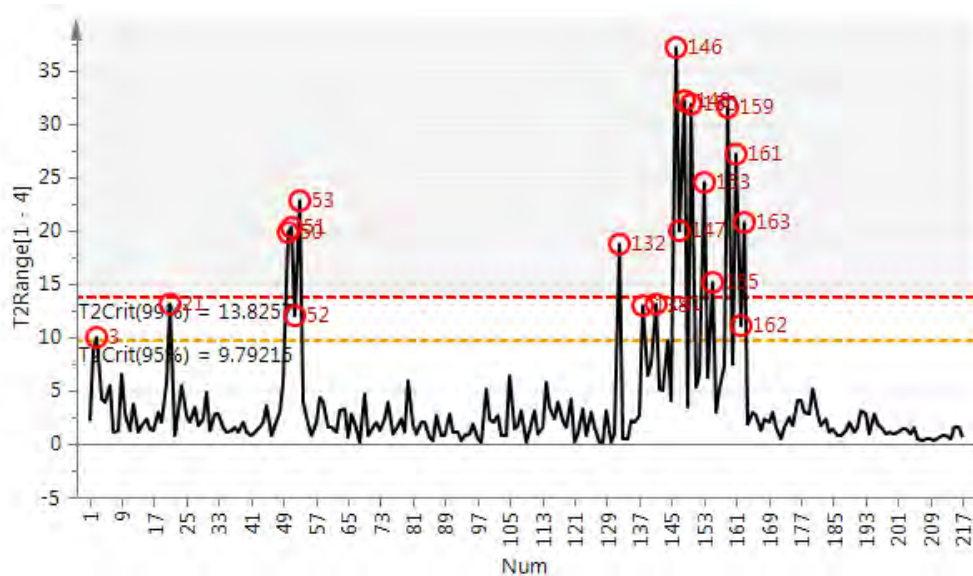


Figure 4.3: Hotelling's T2 plot showing the sample selected as outliers.

### PCA(Y) model

A PCA(Y) analysis was done in order to inspect the variation between the Y variables. After 55 outlier samples were eliminated from the data set as, the PCA(Y) was performed on the remaining 162 sample set. The skewness of the Y-variable data was evaluated, while also considering the PCA fit of the data, and it was decided to perform log-linear transformation of the Y-variable data of for EC, P and Na. Transformation of the data was done according to equation 2 below:

$$Y - var = \log(y + 1) \tag{4.2}$$

Only 2 components were identified and these accounted for 63.2% of the variation, with t1 and t2 showing R2X values of 0.346 and 0.285 respectively.

The PCA(Y), as seen in Figure 4.4, revealed a similar grouping to the PCA(X) results, with the sampling site showing major groupings in the data. This revealed that the variation in Y-



variables were also site-specific. Sampling depth (mm) did not show any groupings and the variation was distributed fairly evenly amongst the different depths.

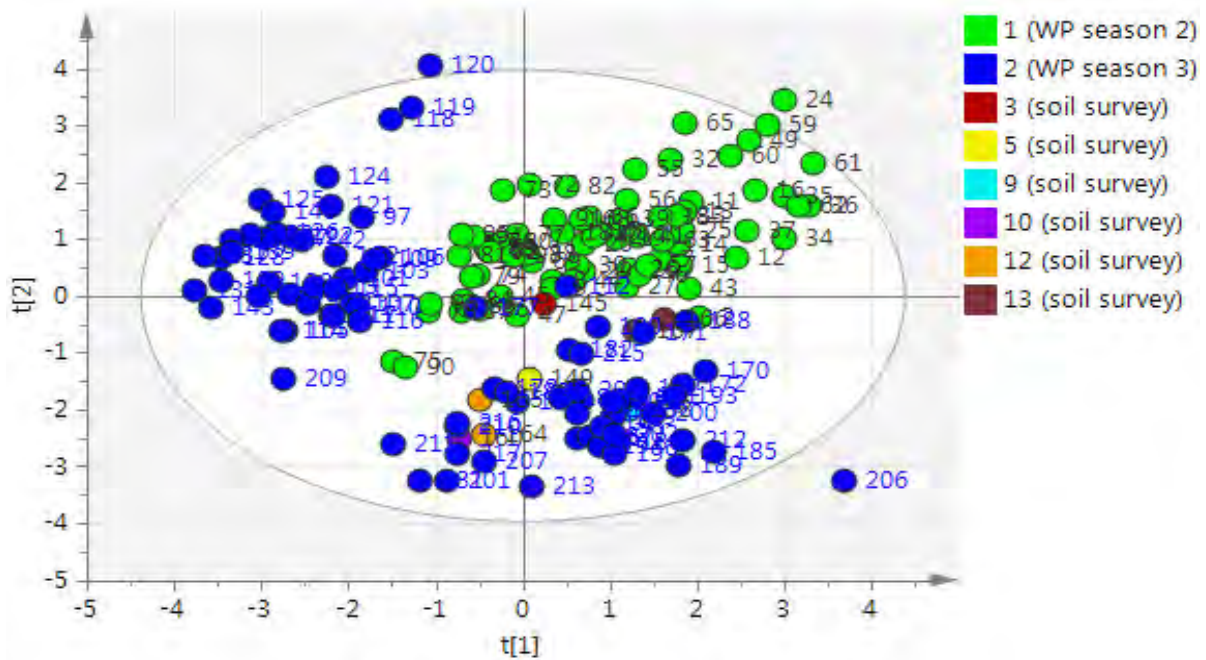


Figure 4.4: PCA(Y) analysis showing the scores scatter of the  $t_1$  and  $t_2$  variables summarizing the X-variables. The colours indicate the different sampling sites on the farm.

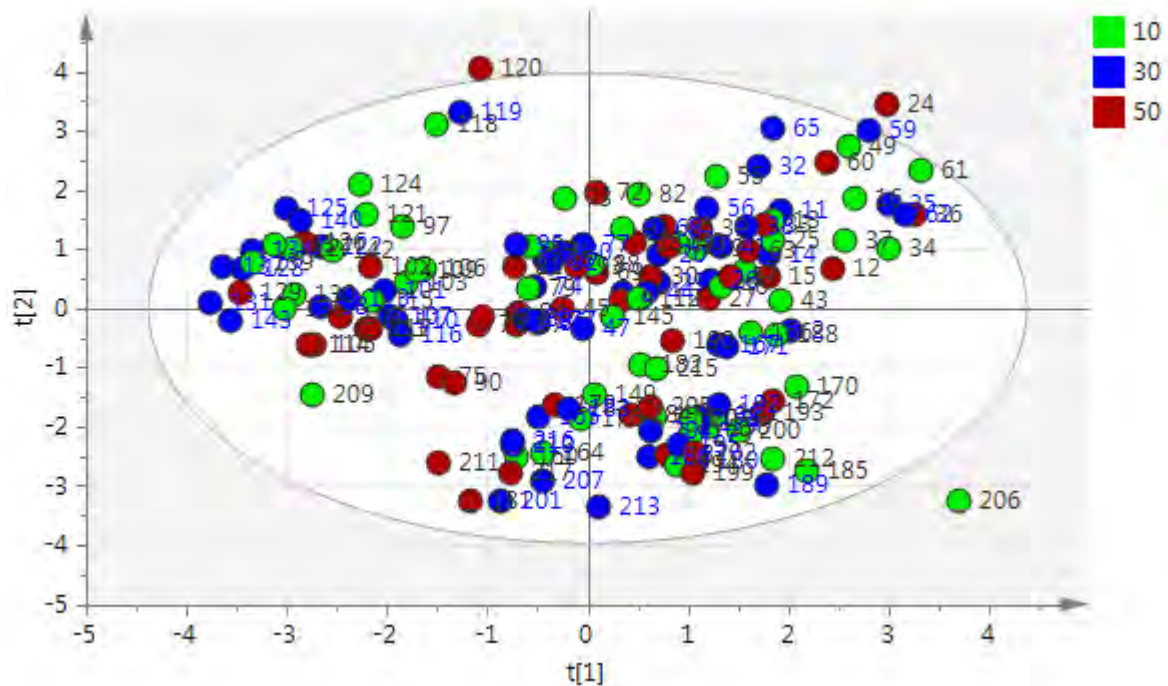


Figure 4.5: PCA(X) analysis showing the scores scatter of the  $t_1$  and  $t_2$  variables summarizing the X-variables. The colours indicate the different sampling depths of 10, 30 and 50 cm on the farm.

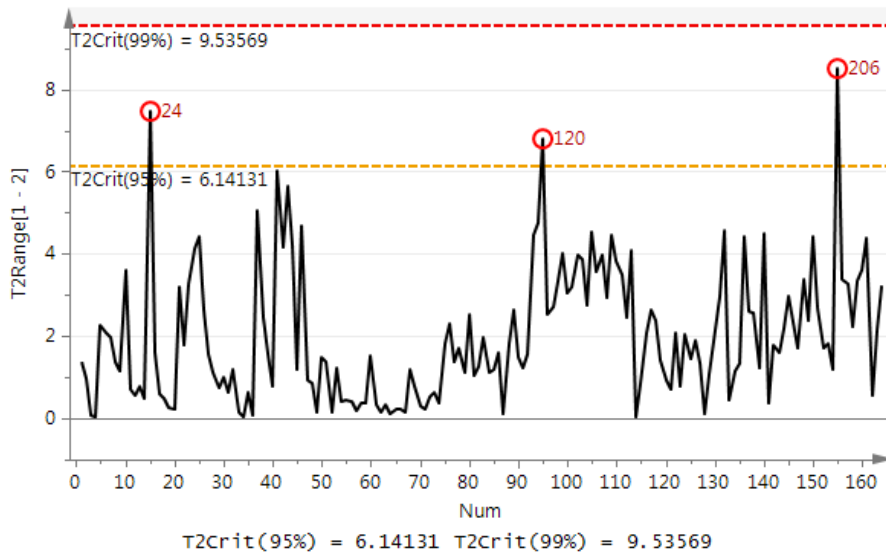


Figure 4.6: Hotelling's  $T^2$  plot for the PCA(Y) showing the sample selected as outliers

After both the X and Y matrixes had been analysed and outliers removed, the final data set consisted of 159 samples. The structure of these matrixes was now appropriate to start with the design of the calibration and validation data sets. A calibration model was independently validated by choosing a separate calibration and validation set using the OPUS software with the corresponding scans. Mathematical treatment of the final sample set ( $n=159$ ) involved no spectral pre-processing, constant offset elimination, straight line subtraction, vector normalization (SNV), min-max normalization, multiplicative scattering correction, first derivative, second derivative, first derivative + straight line subtraction, first derivative + SNV and first derivative + MSC. These pre-processing treatments were selected before the development of the prediction model and the software selected the best techniques for a particular PLSR model. More than 400 models were generated and these were ranked according to the different model evaluation parameters.

#### 4.4.2: PLSR model construction

After the final data set was selected, a PLS regression analysis was performed on the data in order to construct a model to predict the chemical characteristics of the different soil samples according to the spectral data. The prediction equation was constructed and given by equation 1 below.

$$Y = b, X \quad [4.2]$$

The target parameter (Y), relates to a soil property analysed in the laboratory, and is obtained by using the calibration function (b) and the NIR spectral data to create the equation for prediction:



To construct this model for soil property prediction, the NIR-spectra matrix as well as the matrix of the analysed soil chemical properties is used. The NIR-spectra matrix is composed of the 159 (final sample set) rows used for calibration and 1129 columns of absorbance values (from 800-2500nm) and these formed the source of the X-variables in the prediction model (1). The analysed soil chemical results formed the other matrix which was composed of 159 rows and a column for every analysed chemical property (9). This matrix was the source of the Y-variables in the prediction equation (1) (Zornoza et al., 2008). In the prediction of soil chemical constituents, this method has been widely used in literature on chemometrics in NIR analysis (McCarty et al., 2002).

#### 4.4.3 Selection of models

The performance of each model for prediction of the different soil chemical constituents was evaluated using the coefficient of determination ( $R^2$ ), root mean square error of estimation (RMSEE), root mean square error of prediction (RMSEP) and the ratio of performance to deviation (RPD). The RMSEE is a measure that relates to the unit of the observed Y variable and the model fit. RMSEE is computed as:

$$RMSEE = \frac{\sqrt{\sum(Y(obs)-Y(pred))^2}}{n-1} \quad [4.3]$$

RMSEP is an analogous measure to RMSEE, but for the prediction set, which measures the prediction power of the model. RMSEP is computed as:

$$RMSEP = \frac{\sqrt{\sum(Y(obs)-Y(pred))^2}}{n} \quad [4.4]$$

RPD is a measure of the ratio of percentage deviation from the RMSEP. There categories of model reliability, as listed according to Bellon-Maurel, et al (2010), are i)  $RPD > 2$  which are excellent models, ii)  $1.4 > RPD < 2$  which are fair models and iii)  $RPD < 1.4$  which are unreliable models (Chang, et al., 2001).

$$RPD = \frac{StD}{RMSEP} \quad [4.5]$$

## 4.5 Results and discussion

### 4.5.1 Spectral features

The spectral features of the final sample set ( $n=159$ ) can be seen in Figure 4.7 showing the reflectance as is typically observed for soil samples. Bending and stretching of the O-H bonds of the free water can be seen at 7142, 5128 and 4546  $\text{cm}^{-1}$  wavelength and these are the prominent absorption features in the spectra. (Viscarra Rossel et al., 2006).

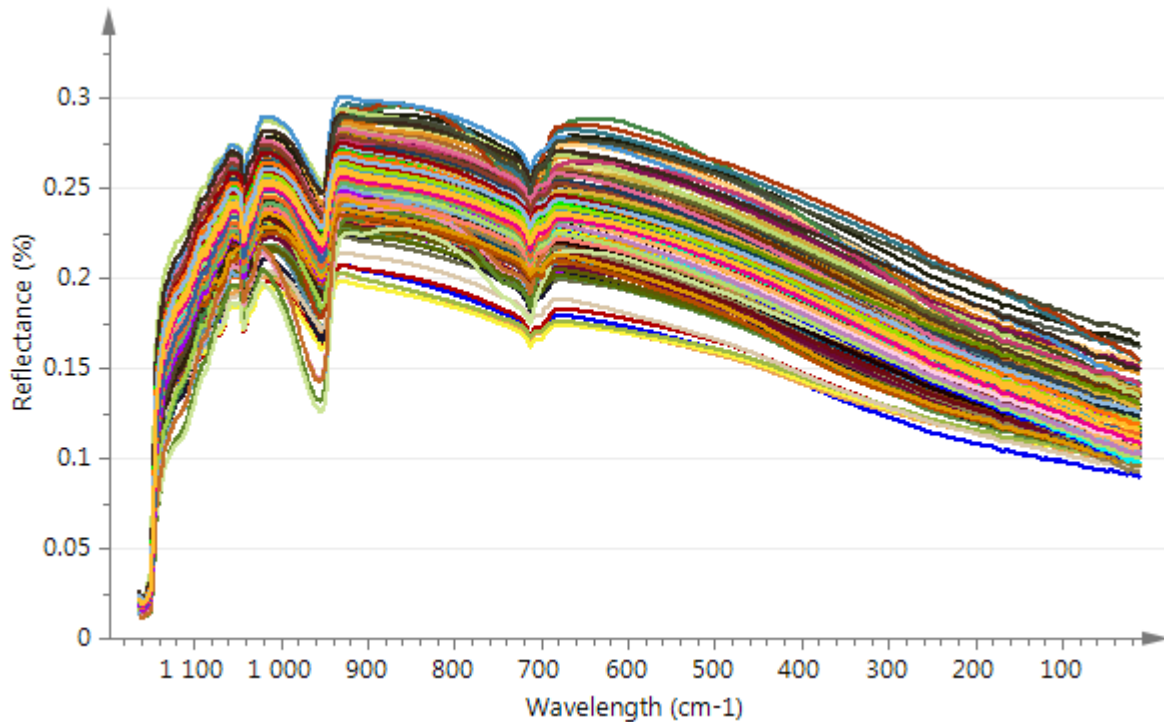


Figure 4.7: Spectral reflectance (untransformed) of the final sample set.

#### 4.5.2 Soil Chemical properties

Soil chemical results, as seen in Table 4.2, shows the main statistics of the chemical properties of the selected 159 samples used in the PLSR model. A large range of variability was covered due to the different sampling sites, which can as seen in the min/max values. pH levels were mostly above 5.5 and showed a low standard deviation (SD). Due to different cropping practices on the different land areas on the farm, large SD was calculated for P and K.

Table 4.2: Summary of soil chemical property statistics for Mzilela farm.

Soil chemical property	n	mean	min	max	standard deviation
pH (KCl)	159	6.28	4.08	7.75	1.05
EC (mS/m)	159	7.80	0.77	51.70	8.40
P (mg/kg)	159	21.21	0.70	231.79	29.99
K (mg/kg)	159	180.36	44.29	387.53	91.30
Ca (cmol(+)/kg)	159	4.39	2.25	8.05	1.38
Mg (cmol(+)/kg)	159	2.98	0.47	7.30	1.85
Na (cmol(+)/kg)	159	0.52	0.05	1.78	0.37
K (cmol(+)/kg)	159	0.46	0.11	0.99	0.23
CEC (cmol(+)/kg)	159	8.32	4.34	16.21	2.77

After the different model results were obtained, those with the best possible fit were identified and the final calibration set, as well as the separate validation set, were selected. Standard statistical evaluations were performed on the observed and predicted data sets. Table 4.3 shows all the different chemical properties, including the three properties that were transformed (EC, P and Na) due to skewness in the Y-variable data set.

*Table 4.3: Summary of soil chemical properties for the observed and predicted data sets.*

Soil chemical property	log transformed	Observed					Predicted				
		n	mean	SD	min	max	n	mean	SD	min	max
pH (KCl)		81	6.28	1.05	4.08	7.75	78	6.37	1.02	4.48	7.91
EC (mS/m)	log(y+1)	81	0.81	0.27	0.29	1.5	78	0.85	0.29	0.27	1.72
P (mg/kg)	log(y+1)	81	1.17	0.34	0.36	2.07	78	1.21	0.33	0.62	2.37
K (mg/kg)		81	180.36	91.30	44.29	387.53	78	187.88	98.22	50.97	413.46
Ca (cmol(+)/kg)		81	4.39	1.38	2.25	8.05	78	4.44	1.49	1.95	8.78
Mg (cmol(+)/kg)		81	2.98	1.85	0.47	7.3	78	2.88	1.79	0.48	8.14
Na (cmol(+)/kg)	log(y+1)	81	0.55	0.21	0.17	0.92	78	0.54	0.21	0.17	0.96
K (cmol(+)/kg)		81	0.46	0.23	0.11	0.99	78	0.48	0.25	0.13	1.06
CEC (cmol(+)/kg)		81	8.32	2.77	4.34	16.21	78	8.33	2.69	4.33	17.57

Model development results, as seen in Figure 4.3, was performed in the OPUS Software. The software determines the best pre-processing technique for each of the soil chemical properties and also the spectral range. The calibration and independent validation results are also given in Figure 4.4. The range of  $R^2$  values for the validation sample set were between 0.44 and 0.95. The highest  $R^2$  values were for pH with 0.95, while Mg and Na also had high coefficient of determination values of 0.72 and 0.76 respectively. EC, P, K (mg/kg), K (cmol(+)/kg) and CEC had  $R^2$  values above 0.60, while Ca had the lowest value with 0.44. The high correlation ( $>0.60$ ) for most of the soil chemical properties showed these models had significant correlations between the measured and predicted values.

*Table 4.4: Calibration and independent validation PLSR statistics, spectral regions and pre-processing methods.*

Soil chemical parameter	Calibration				Validation							
	n	$R^2$	RMSEE	RPD	n	$R^2$	RMSEP	RPD	bias	rank	Spectral range	pre-processing
pH (KCl)	81	0.97	0.19	5.94	78	0.95	0.23	4.45	0.05	10	7506-6796.3	Second derivative

EC (mS/m)	81	0.84	0.11	2.53	78	0.67	0.17	1.74	0.02	10	(7506-6094.3) (5454-4242.8)	Straight line subtraction
P (mg/kg)	81	0.75	0.18	2.01	78	0.65	0.19	1.70	0.01	9	(7506-6094.3) (5454-4242.8)	Straight line subtraction
K (mg/kg)	81	0.72	51.30	1.88	78	0.65	57.40	1.70	1.33	9	(9403.7- 4597.7)	First Derivative + MSC
Ca (cmol(+)/kg)	81	0.63	0.88	1.64	78	0.44	1.10	1.34	0.07	10	(9403.7- 7498.3) (6102- 4242.8)	First Derivative + MSC
Mg (cmol(+)/kg)	81	0.78	0.92	2.14	78	0.72	0.94	1.89	0.05	9	(9403.7- 7498.3) (5454- 4597.7)	First derivative
Na (cmol(+)/kg)	81	0.84	0.09	2.52	78	0.76	0.10	2.06	0.01	9	(9403.7- 7498.3) (5454- 4597.7)	First derivative
K (cmol(+)/kg)	81	0.72	0.13	1.89	78	0.65	0.15	1.70	0.00	9	(9403.7-4597.7)	First Derivative + MSC
CEC (cmol(+)/kg)	81	0.77	1.40	2.10	78	0.62	1.65	1.63	0.14	8	(9403.7- 7498.3) (5454- 4242.8)	First Derivative + straight line subtraction

The predictive power of the model was evaluated with the RMSEP and RPD measure. pH and Na had the lowest RMSEP and accordingly also showed RPD values higher than 2. These chemical prediction models were classified as having high predictive power (Bellon-Maurel et al., 2010). EC, P, Mg, K (cmol(+)/kg) and CEC had low RMSEP values and RPD values larger than 1.5, indicative of the fairly accurate prediction capability of the model (Mashimbye, 2013). Model results for K(mg/kg) and Ca showed less favourable results due to a large RMSEE and large bias values for K and a low RPD (<1.4) value for Ca.

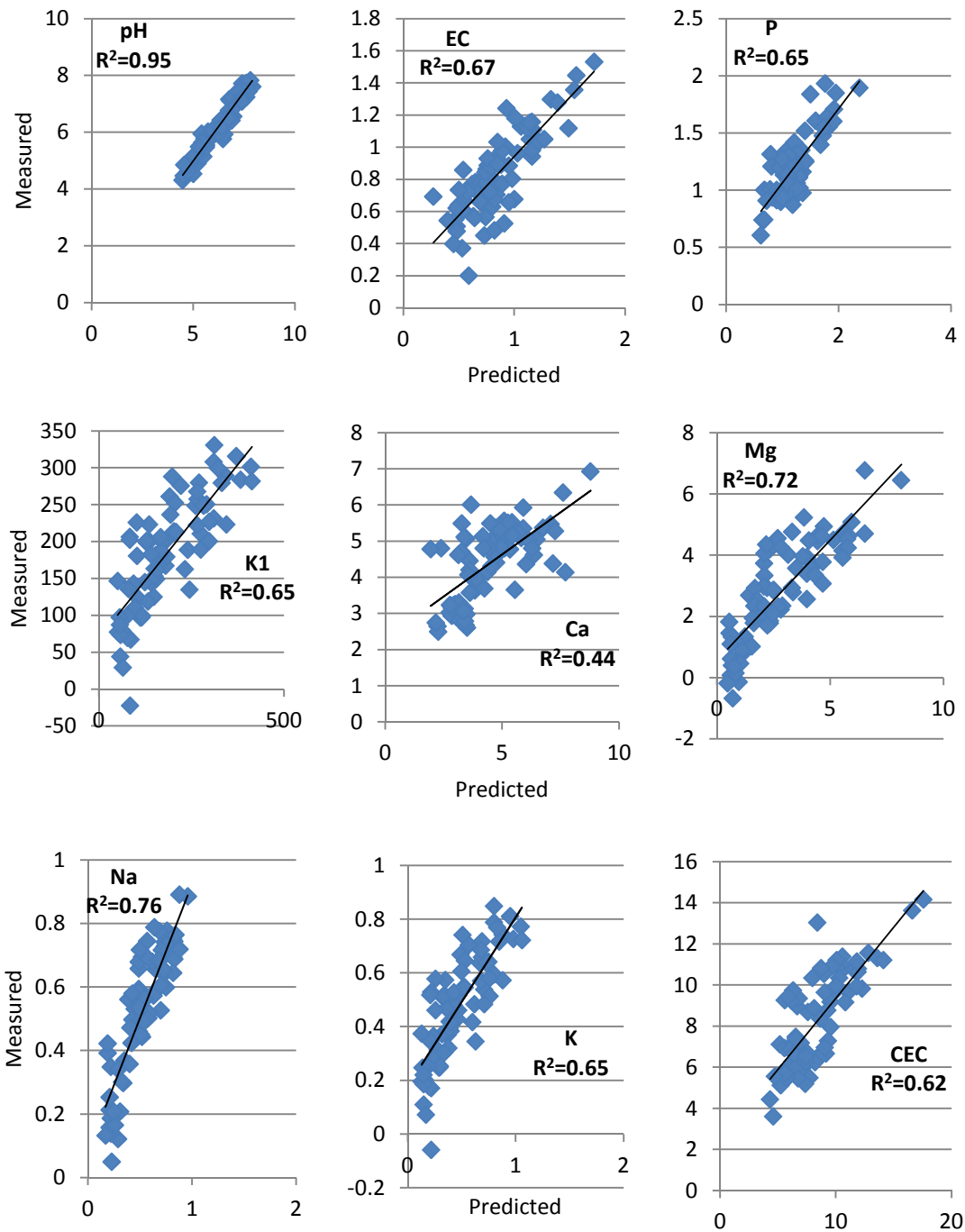


Figure 4.8: Plots of predicted versus measured values for pH, EC, P, K, Ca, Mg, Na, K and CEC.

Scatter plots of the measured versus the predicted soil chemical properties are illustrated in Figure 4.8. These results show that there were high correlations between the measured and predicted soil chemical properties investigated on Mzilela farm.

The study found that reliable predictions can be made for soil chemical properties of pH, EC, P, K, Mg, Na and CEC. The PLS regression  $R^2$  for pH of 0.95 was higher as compared to

the range in other studies of 0.70-0.74 (Reeves et al., 1999; Sheppard & Walsh, 2002; Zornoza et al., 2008). The RPD for pH was also higher than the above mentioned studies, while the range for RPD was similar to Zornoza et al (2008). Thus the predictive power of this model was very strong.

The EC  $R^2$  value of 0.67 was comparable to ranges found by Zornoza et al (2008) and Mashimbye (2013), yet much higher compared to values of 0.10 (Islam et al., 2003). The EC parameter gave a RPD (1.74) value similar as to what was recorded in Zornoza et al., (2008), while a higher RPD value was recorded by Mashimbye, (2013).

The  $R^2$  value of 0.65 for plant available P was lower than the recorded of 0.81 (Daniel et al., 2003), yet it was higher than the ranges of 0.29 - 0.59 for mineral soils. (Ben-Dor & Banin, 1995; Ludwig et al., 2002) The low predictability of P in mineral soils can be attributed to the inability of NIR scans to absorb inorganic P (Chodak, 2008).

The prediction of the metal cation gave  $R^2$  values higher than 0.62 for Mg, Na and K and CEC and showed satisfactory predictability in the same range as recorded by Chodak et al (2002). Ca had a  $R^2$  value lower than 0.40 and was similar to results from Chodak et al (2002) which found poor  $R^2$  values for Ca. The low predictability of these models are much lower compared to a range of 0.94 and 0.91 for Ca and Mg respectively, recorded for African mineral soil in a study by Sheppard & Walsh, (2002). These difference are most likely due to different statistical calibration techniques used and also the chemical composition of the soil samples.

#### **4.6 Conclusions**

NIR technology was used to gain spectral reflectance for dried, crushed and sieved soil samples from various sites at Mzilela farm using a laboratory spectrometer. A final data set was selected and a calibration and separate validation set was selected to develop a PLSR prediction model for pH, EC, P, K, Ca, Mg, Na, K and CEC. The study concludes that pH and Na can excellently be predicted with the model, while EC, P, K, Mg, Na, K and CEC showed good predictability. The Ca model however showed weak predictability and the model was not accurate.

This study concludes that the chemical characterization of soil samples can be accurately predicted using NIR technology in order to aid farmers in fertility management. With a 60-70% average accuracy for the most important soil fertility parameters and the subsequent fertilizer recommendation calculation can have a major impact on smallholder farm productivity. NIR will ensure that smallholder farmers can afford chemical analysis and the

possible increases in crop production and income into the household makes this technology a great possibility for future use.

## **CHAPTER 5**

### **WATER PRODUCTIVITY**

#### **5.1 Introduction**

WP trials were conducted on the selected farms in the Giyani study area, from July 2012 to October 2013. The trials were conducted to test the effects of different irrigation methods, crop management practices, such as soil nutrient management and mulching, on the yield and WP of tomato production. Three seasons' of tomato crop production trials were done in order to evaluate WP for the study area under different treatments. Tomato is a very popular crop choice for smallholder farmers in Giyani because of the high demands for the fresh product, as well as opportunities for industrial processing.

A single season trial was conducted at Zava Cooperative Garden farm next to Zava village, in the Limpopo Province of South Africa (23° 38' 23.61" S, 30° 43' 31.78" E, 410 mamsl). Three seasons' of tomato trials were conducted at Mzilela Cooperative Garden situated in Ka-Mzilela village in the Limpopo Province of South Africa (23° 35' 32.77" S, 30° 49' 03.71" E, 425 mamsl). After the 1<sup>st</sup> season was completed, the latter farm was chosen as the main farm for research, based on the availability of water and homogeneity of soil properties. Other farms had some constraints that would have made research very difficult. These include factors such as lack of infrastructure, uneven soil surfaces and lack of support to run the trials effectively.

#### **5.2 Materials & methods**

A WP methodology was developed with the smallholder farmers in order to gain a convenient planting layout that would easily be managed by the farmers, yet scientific in nature to test various aspects of the tomato production of smallholder farmers. This approach was followed in all tomato trials, while different treatments were tested. Here follows a detailed description of the tomato production trials.

##### **5.2.1 Description of tomato management practices**

Soil preparation was done and managed by the farmers themselves. At Mzilela farm, a male tractor driver was usually hired from the village to plough the soil with the tractor owned by the Cooperation farm. Zava farm does not own their own tractor and therefore a tractor and driver was hired to plough the soil. The farmers usually pay a fee of about R750/ha to R1000/ha for the plough services to be done. This was done because the female farmers could not drive the tractor themselves.

The experimental area was initially ploughed with a normal 3-disc plough to clear the field of annual grasses and weeds and to loosen the topsoil for planting. The outside corners of this



area was measured out with a standard 50 meter measuring tape and marked with steel pegs. The row spacing was selected according to the irrigation system specifications, and each row width was measured precisely and also marked. After the main experimental plots and subplots were laid out, soil samples were taken at these sites on both farms beforehand, in order to calculate the fertilizer requirements before planting (See Appendix 1).

After the main plots were measured out with the correct row spacing, farmers made ridges with hoes from side to side, working in straight lines with the use of a string as guide. After the ridges were correctly made, the drip lines were placed on top of the ridges. The irrigation system was installed together with the farmers and all connections were properly sealed to minimize water losses. For the drip irrigation plots, a local product from Netafim South Africa (Pty) Ltd, called the Family Drip System (FDS), was used. This is a low pressure, relatively low cost system covering an area of 200 m<sup>2</sup>. Each system consists of 8 rows of 25 meters each with rows being spaced 1 m apart. The drip spacing is 30 cm apart providing a plant spacing of 0.3 x 1 m. 12 800 tomato plants were planted per system, with a seedling at each dripper outlet. At the main inlet into each separate FDS, a standard water meter was installed to measure the total amount of water (m<sup>3</sup>) delivered to each plot.

When planting commenced, the farmers planted the cultivar of choice early in the morning, applying fertilizers only to the fertilizer treatments according to the calculated fertilizer recommendation. Locally available fertilizers, NPK 2:3:2 (22%), were applied to the crop at planting, while Limestone Ammonium Nitrate (LAN) and Potassium Nitrate were applied during the season. Fertilizer was applied on the ridge, beneath the planting hole and 5 cm next to each plant with the required amount made known to the farmers. Fertilizer was applied using a Coke bottle cap resulting in an average of 7-8 g of fertilizer per cap.

The row direction was determined based on slope, as the most even soil surface was selected for planting. Row direction was either north-south or east-west, depending on the specific site. The tomato plots were all trellised with a normal 3-wire system, using locally purchased, 3 m poles being installed every two meters apart by hitting them firmly into the ground. This was quite a laborious task and, as most of the female farmers were over 65 years old and could not do this physical task themselves, it was necessary to hire labour from the local village.

All other management tasks were performed by the farmers themselves and included planting, fertilizer application, removal of weeds, spraying, irrigation, tying of plant canopies to the wires and harvesting.



*Figure 5.1: Installation of trellising poles for season 2 at Mzilela farm.*

## **5.2.2 Data collected for research**

### 5.2.2.1 Water balance data collection

Soil water content (SWC) was monitored in each treatment for water balance calculations. A rain gauge was installed on site on each farm and one local farmer was appointed to take the rain gauge reading after every rainfall event. Continuous soil water content monitoring was done using ECH<sub>2</sub>O soil water moisture probes and loggers (Decagon Devices Inc., Pullman, USA), installed at each treatment. SWC was measured at 0-20 cm, 20-40 cm and 40-60 cm depths in order to do irrigation scheduling based on available water in the profile and also for water balance calculations.

### 5.2.2.2 Soil Sampling and analysis

#### *i) Soil Chemical analysis*

Three samples were collected at each subplot soil profile at 0-20, 20-40 and 40-60 cm depths, and were analysed at the Department of Soil Science, Stellenbosch University. Soil chemical analyses were done in order to calculate fertilizer requirements for tomato production. The exact same materials and methods for soil chemical analysis, as described in chapter 4, were used.

#### *ii) Soil Physical analysis*

Two soil physical properties were analysed, which included coarse fragment content and bulk density determination. Both of these were done only for seasons 2 and 3. Coarse fragment percentage (CFP) determination was done by weighing coarse fragments (>2mm) after it was separated in the sieving process. The soil (<2mm) was also weighed and the

CFP was calculated as weight percentage. Bulk density was done using the core method for 0-20 cm and 20-40 cm depth.

#### 5.2.2.3 Weather data

Meteorological data was received from the Agricultural Research Council (ARC), from the nearest weather station at the Masalale Packhouse (23° 41' 59.24" S, 30° 47' 22.03 E), which is located approximately 10 km from both farms. On-site rain gauge rainfall volumes were used in the WP calculation because of the great variation of rainfall distribution between the two farms.

#### 5.2.2.4 Canopy growth using the Leaf area index

Canopy growth was monitored through the course of the season using measurements of leaf area. Leaf area index (LAI) was measured throughout the growing period using the Li-Cor LAI-2000 instrument. Readings were taken at 20 sites within each treatment. At each of these sites, readings were taken above the canopy and at ground level, across the row and beneath the plant on the other side of the row in order to get an average LAI value for that site. Readings were taken on cloudless, sunshine days at 11:00 PM and again at 15:00 PM. LAI measurements were done based on the availability of the equipment, but as frequently as possible. The maximum LAI was calculated for season 2 and 3 only, in order to see the effect of different treatments on the growth of the canopy.

#### 5.2.2.5 Yield and Quality

At harvest time, the farmers harvested each sub-plot and treatment separately and then brought the fruits to the sorting area. The farmers sorted the tomatoes according to size and quality into two classes namely A-grade and B-grade tomatoes. A-grade tomatoes were medium to large in size and had a presentable appearance having no pest affected marks or being deformed. A-grade tomatoes were sold to the Spar Supermarket in Giyani. B-grade tomatoes were characterized by small fruits and pest affected areas on the fruit. These fruits did not meet market requirements of Spar and were sold locally in the village. After harvesting started, farmers harvested the fruits twice weekly until the end of harvest. The harvesting period ended when most of plants died naturally and most tomatoes were harvested.

Yield was measured by weighing the marketable yield (A-grade tomatoes), as well as the non-marketable yield (B-grade tomatoes) with a standard scale. Tomato quality was assessed for the 2<sup>nd</sup> and 3<sup>rd</sup> season trials at Mzilela. Representative samples (15-20 tomato samples per sub-plot) were harvested and tested for quality parameters at the Department of

Soil Science and the Department of Horticulture at the University of Stellenbosch. Basic quality assessment was done, such as average fruit size, sugar content (% Brix), pH and titratable acidity (TA).

For quality assessment of tomatoes, representative fruit samples of each treatment were harvested. In order to compare the fruit quality between treatments, the fruits were carefully selected being medium in size, at the same stage of fruit maturity chosen based on fruit colour (Fig 5.2). The tomatoes were washed with water and then dried with cloth paper. Each tomato was weighed and then a picture was taken with a measuring ruler in order to calculate the dimensions of each tomato. The tomato sample was then cut in half and put into a standard liquidizer appliance. The fluid was sieved and collected in 50 ml plastic bottles and kept cool for analysis. Sugar content was measured using a digital hand-held pocket Refractometer (PAL 1), by pouring 5 ml of juice onto the meter and taking the reading. The pH of the juice was measured with a standard pH electrode. TA was calculated by a titration of 20 ml of juice sample with 0.1N NaOH to a pH of 8.1, continuously stirring. These values were converted into titratable acidity per 100 ml of sample.



Figure 5.2: i) Representative tomatoes selected from plot 1B for quality analysis, ii) sugar content analysis (brix %) using the PAL Refractometer and iii) Titratable acidity using the titrino automatic titrator.

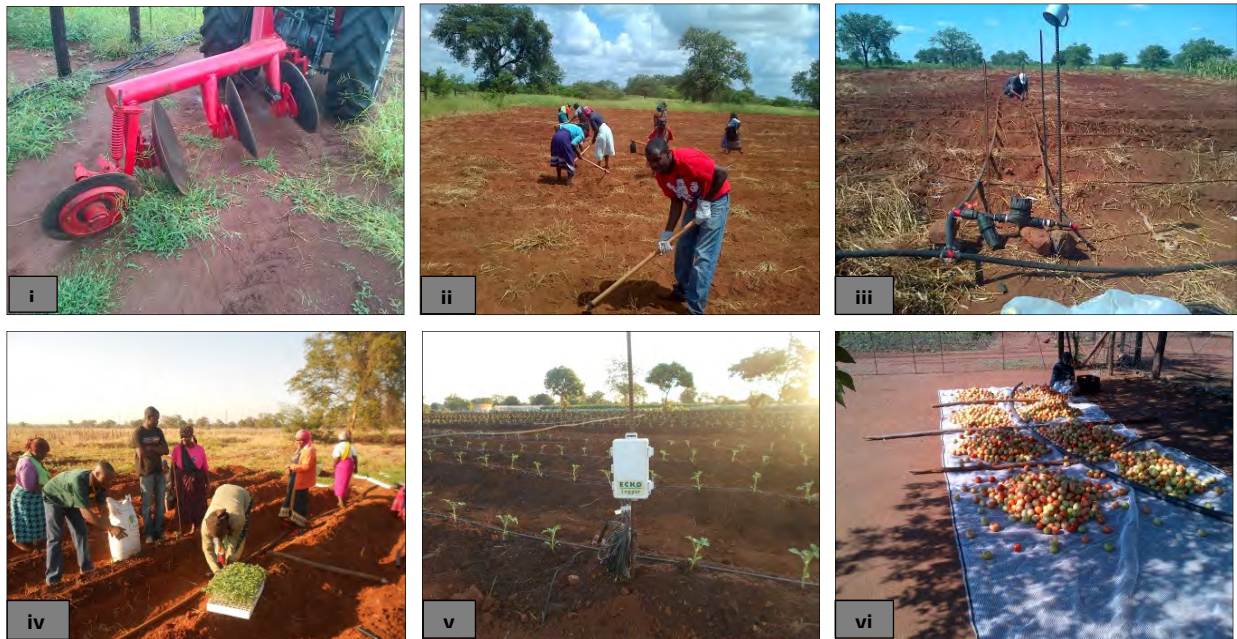


*Figure 5.3: Location of the Water Productivity trials for seasons 1, 2 and 3 at Mzilela farm.*

The three consecutive tomato trial locations can be seen in Figure 5.3. These locations were chosen based on the most even soil surface area, being fairly close to the small shed-house and close to the cement dam and boreholes. The WP trial sites 1 and 3 were areas on the farm which have been intensively used for crop production for many consecutive seasons, while WP trial site 2 was not used for crop production for the last 6 years (Fig 5.3).

Figure 5.4 shows some of the different management practices applied during the tomato production cycle starting with the soil preparation, making the planting ridges, installing the irrigations systems, planting of the seedlings, monitoring the SWC during the season and eventually harvesting the fruits.





*Figure 5.4: i) 3-disc plough used for soil preparation, ii) farmers making ridges before planting, iii) FDS and water meter installation, iv) planting and fertilizer application, v) Echo data logger installed before planting and vi) harvesting and sorting at Mzilela.*

### **5.2.3 Season 1 (July-October 2012): Winter planting**

The first season trial was carried out on both farms (Zava and Mzilela) in order to see if a full-scale trial would be viable under the prevailing management of the farms. The main aim of the trial was to get general WP values for the conventional farming practice that was being applied by the smallholder farmers in the Giyani area. The secondary aim was to evaluate the external factors affecting the results of the trial. These include the management of irrigation application and taking data readings throughout the growth period. These factors were therefore evaluated to see if credible trial results would be obtained.



*Figure 5.5: Conventional tomato plantings in the Giyani area, characterized by small plants, low yielding cultivars that are either un-trellised (left) or trellised with a small 1 wire trellising system (right).*

### **Zava Cooperative Garden**

#### Treatment and design

The smallholder farmers of Zava only made use of conventional furrow irrigation in all their crop production sites, and thus a furrow versus drip irrigation trial was conducted to compare WP values using these two irrigation methods. Two drip system plots were installed and one furrow irrigation plot. All plots received the same management practices in terms of soil preparation, planting, trellising and harvesting. Pest management was done by using regular products such as Biomectin, Makhro Cyper and Copper-count-N, locally purchased in Giyani. When spraying, all three products were mixed together into an 80 litre solution and applied 3 times during the season with a hand sprayer. The farmers did weed-control using a hoe to remove weeds in the furrow and using their hands to remove weeds on the ridges. This was done whenever weeds started growing higher than 5 cm. The drip and furrow treatment plots were irrigated as decided by the specific farm. This decision was mainly based on how dry the soil looked and how hot it has been the preceding days. This approach was followed to ascertain the effectiveness of their irrigation practice in relation to the SWC measurements as well as the amount of water drained out of the root zone. A local, cheap tomato variety, Rodate, was planted, because it is a common cultivar choice for smallholder farmers in the area. The furrow plot (3/4) was double the size of the drip irrigation plots (Figure 5.6).

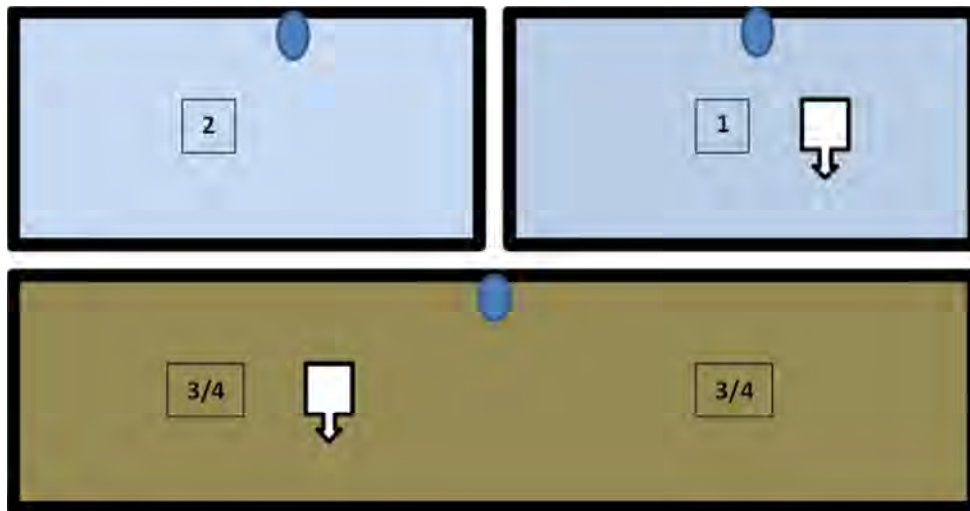


Figure 5.6: Plot layout of the 1st trial planting at Zava farm. Plot 1 & 2 is drip irrigation versus plot 3/4 which is conventional furrow irrigation. The blue circle indicates the installed water meters and the white boxes indicate the soil water content sensors installed at 0-20, 20-40 and 40-60 cm depths.

The total area of the experiment on Zava farm, as seen in Figure 5.6, was 800 m<sup>2</sup> with each irrigation system being 400 m<sup>2</sup> in size. For the first season, only three SWC loggers were available and therefore these were distributed in order to measure at least one site for each of the different treatments.

### Mzilela Cooperative Garden

The farmers at Mzilela farm only used drip irrigation and therefore only two drip irrigation plots were installed to get initial WP values for their current farming practices. Rodate was also planted at Mzilela and both plots received the same farm management practices. The difference between the two treatments of this trial was that plot 1 was irrigated based on the farmers scheduling on their own by their normal way of doing irrigation, while plot 2 was irrigated based on SWC readings. These plots therefore received different amounts of water. Unfortunately there was only one SWC logger available and therefore the SWC was only logged in plot 2 (Figure 5.7). This meant that a drainage volume used in plot 1 was calculated with the SWC data from plot 2. This should therefore be considered when evaluating the results later on in the chapter. Each plot was a separate FDS and therefore 200 m<sup>2</sup> in size with a total experimental area of 400 m<sup>2</sup>.



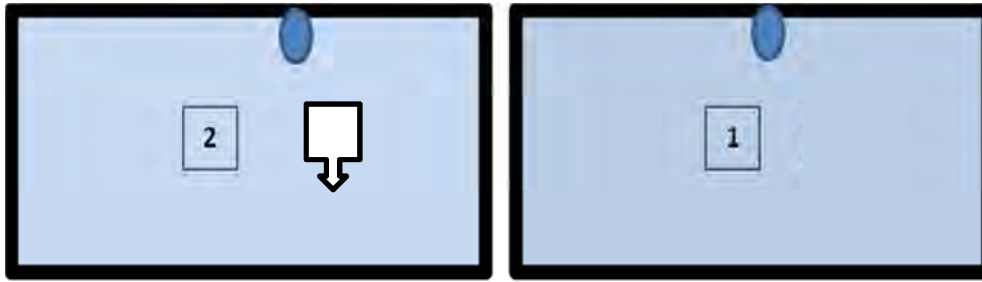


Figure 5.7: Plot layout of the 1st season planting at Mzilela farm, plots 1 and 2 are both irrigation system plots. The blue circle indicates the installed water meters and the white boxes indicate the soil water content sensors installed at 0-20, 20-40 and 40-60 cm depths.

Water meter readings were taken before and after irrigation water was applied. Rain gauge readings were taken by the local farmer named Elias, who would later play an important part in managing the sites at Mzilela farm.

Figure 5.1: A summary of the soil chemical results before planting of season 1 at Zava and Mzilela.

farm	depth (mm)	Clay (%)	% Rock (>2mm)	pH (KCl)	EC mS/m	mg/kg		Exchangeable cations (cmolc/kg-1)						
						P	K	Ca	Mg	Na	K	H	CEC	ECEC
mzi	100	14	10	6.97	5.70	20.54	231.72	4.67	3.92	0.24	0.59	0.20	9.42	9.62
mzi	200	18	11	6.73	4.90	16.54	267.43	3.48	2.22	0.15	0.69	0.20	6.53	6.73
mzi	300	23	34	6.45	5.00	16.25	228.83	8.32	3.74	0.37	0.59	0.20	13.02	13.22
zava	100	15	10	7.23	3.10	26.10	145.53	5.03	2.36	0.20	0.37	0.15	7.97	8.12
zava	200	13	6	6.39	4.10	19.91	138.45	4.71	2.39	0.20	0.36	0.30	7.66	7.96
zava	300	12	28	5.80	2.90	16.08	128.58	4.96	2.68	0.21	0.33	0.25	8.18	8.43

Table 5.1 shows that the pH for both farms was in the optimum range of between 5.5 and 7.5 for tomato production and no lime was needed for pH adjustment. Plant available K for season 1 was above the optimum of 100 mg/kg and therefore, as seen on Table 5.2, no K nutrients application was needed. The plant available P (bray 2) was below the optimum of 30 mg/kg and therefore no P nutrient application was needed. N requirement is based on the target yield and therefore a standard of 180 kg/ha was needed for a normal yield and good canopy growth (FFSA, 2007).

Table 5.2: Fertilizer recommendation of the required macro-nutrients for the trial sites of season 1 at Zava and Mzilela.

farm	depth (mm)	ratio's			R-value	lime required	kg/ha required		
		Ca	Mg	K			N	P	K
mzi	100	50.86	42.67	6.47	42.95	0.00	60.00	52.40	0.00
mzi	200	54.55	34.71	10.74	28.49	0.00	60.00	53.47	0.00
mzi	300	65.78	29.58	4.64	60.32	0.00	60.00	53.33	0.00
zava	100	64.78	30.41	4.81	49.28	0.00	60.00	55.87	5.95
zava	200	63.15	32.09	4.76	23.67	0.00	60.00	54.53	15.40
zava	300	62.25	33.61	4.13	30.58	0.00	60.00	56.13	28.56

The same fertilizer recommendation approach was followed for all three seasons of tomato production. Plant available N was not analysed and N-requirements was based on crop specific N needs during the season according to FFSA (2007).

#### 5.2.4 Seasons 2 & 3: Mzilela Cooperative Garden

##### Season 2 (February – July 2013): Summer Planting

The local farmers successfully managed the first season trial and therefore statistical trials were conducted for seasons 2 and 3. Mzilela farm was selected for the main WP trials because of the more homogenous soils on the farm and also because the farm has a very flat surface area with little slope changes. The FDS does not have pressure compensated drippers (PCD), and therefore the best option was to conduct the trial at the farm with the most even surface area available.

##### Treatment and design

With the first season's WP values gained, the aim of the next two seasons of trials was to increase WP at field scale on the farm through various innovations. Two basic management practices were selected in order to study the effect on WP and tomato production yields in Giyani. Three areas of interest and possible improvement were noted from the knowledge gained in season 1. These main areas include better soil nutrient management, improved water storage in the soil profile because of possible water scarcity (ground water levels dropping, less available borehole water) and improved cultivar selection in terms of plant size and pest resistance. Based on these areas of interest the following treatments were selected for the study:

Treatment 1: Recommended fertilizer application; No Mulch

(F; -M)

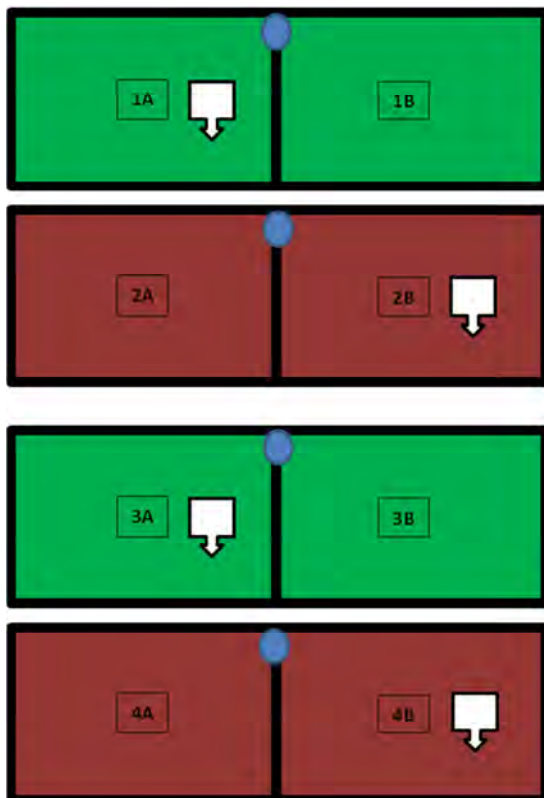
Treatment 2: No Fertilizer; No Mulch (conventional practice, control) (- F; -M)

Treatment 3: Recommended fertilizer application; Straw Mulch (F; M)

Treatment 4: No Fertilizer; Straw Mulch (- F; M)

Eight FDS plots were installed and a standard water meter was fitted at each of the main water inlets. As seen in Figure 5.8, each FDS plot was further divided in two to form a split plot layout to increase the replicates per treatment to 4. The main reasons for the chosen layout of the plots were based on the challenge of managing the plots, done by the uneducated farmers themselves, correctly and without errors. To minimize confusion among the farmers in terms of application of fertilizers and mulch to certain blocks in a random order and also to serve as a visual representation (very important for farmers to observe the effects visually in order to accept new innovations), the block design was not fully randomized. With the chosen design, there was less chance for error because the layout was easy and the farmers knew the differences between treatments.

Plot 1-4, No Mulch



Plot 5-8, Straw Mulch

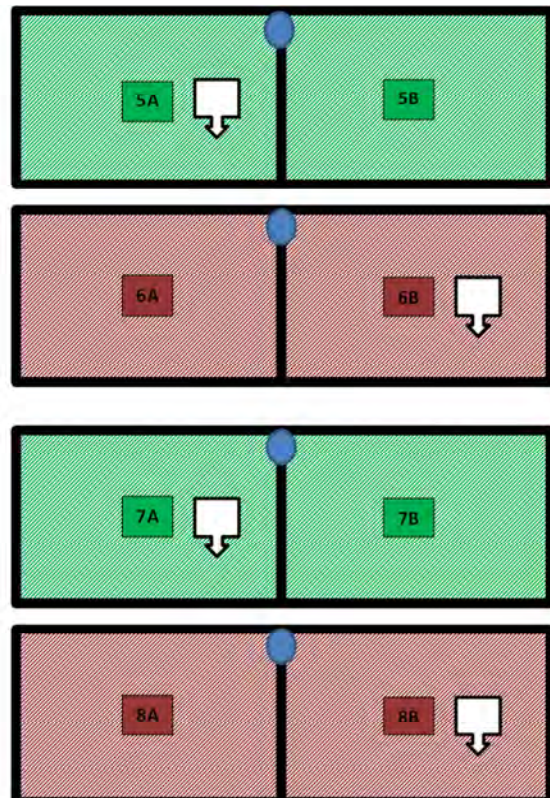


Figure 5.8: Treatment layout for Mzilela farm for seasons 2 and 3 at Mzilela farm. The blue circle indicates the installed water meters and the white boxes indicate the soil water content sensor installation.

Plots were clearly marked (Fig 5.9) and each treatment described in the local Tsonga language for farmers and visitors to learn from the trial when observing the differences between plots and to understand the treatments.



Figure 5.9: Plot labels marked in English for season 2 (left) and plot labels for season 3 marked in Tsonga and English (right) at Mzilela farm.

All plots received the same management practices such as soil preparation, planting, trellising, pest control, weeding and harvesting. The mulch cover was applied to the mulch treatment plots at planting so that the soil surface was covered, as well as most of the plant ridge. All plots were managed to receive more or less the same amount of water as far as possible, but at stages this was challenged due to drippers not being PCD and some uneven surface areas. The decision was made to give all plots the same amount of water, because the separate scheduling of 8 different blocks would need different amounts and would be impossible to be managed by these farmers and could interfere with the irrigation of their other crops. Considering that the crop yield provides food for 16 households, one must be respectful and consider this reality in research decisions. The aim was thus to demonstrate to farmers, which treatments performed best with the same amount of water used. The effects of the different treatments would possibly have been much larger if the trial was managed so that each plot received water as indicated by site specific irrigation volume need, but by doing smallholder farming research we had to be adaptable to field challenges.

#### Selected innovations introduced for improving WP and yield:

##### *Cultivar choice*

A different cultivar was selected for the 2<sup>nd</sup> and 3<sup>rd</sup> seasons, which is better suited for the area and performs better under the environmental conditions. Rodate cultivar gave many management challenges, and subsequently it produced low yields because of its small plant canopy. The low pest and disease resistance of this cultivar had a major impact on yield and

due to the conventional spraying program that the farmers used, the yield was very low. The plant canopies were very small and the average plant height at full growth was less than 50cm at both Zava and Mzilela. This meant that less fruit could be produced per plant and subsequently less fruit yield per hectare.

Topacio tomato cultivar was selected for planting in the trials of seasons 2 and 3. These seedlings were bought from a local nursery called Histill South Africa, which is located in the nearby town of Mooketsi. Topacio is an indeterminate variety that has a good pest resistance, a medium sized fruit and a good firmness, which considerably increases the shelf-life.

#### *Fertilizer application based on soil analysis*

Soil sampling procedure was followed and the soils were analysed for chemical characteristics. The macro-nutrient requirements were determined for the planting area. During season 1, it was discovered that the farmers at Mzilela have not been using any fertilizers or organic inputs into their crop production systems for the previous 6 years. With continued cropping without fallow periods, some areas on the farm have been mined of soil nutrients and accordingly the yields decreased over time.

*Table 5.3: Fertilizer recommendation calculation before planting of seasons 2 and 3 at Mzilela farm.*

farm	season	depth (mm)	% Rock (>2mm)	pH (KCl)	EC (mS/m)	mg/kg		Exchangeable cations (cmol(+)/kg <sup>-1</sup> )						
						P	K	Ca	Mg	Na	K	H	CEC	ECEC
mzi	2	100	8	7.24	6.49	63.74	257.65	4.16	4.82	0.17	0.66	0.006	9.81	9.82
mzi	2	300	18	6.92	6.49	33.41	186.35	5.68	4.76	0.27	0.48	0.013	11.19	11.21
mzi	2	500	36	6.76	7.51	29.80	189.51	5.49	4.53	0.33	0.49	0.012	10.85	10.86
mzi	3	100	19	5.55	4.30	19.31	104.98	6.04	0.70	0.80	0.27	0.012	7.80	7.81
mzi	3	300	27	5.58	3.39	15.43	79.46	4.86	0.78	0.82	0.20	0.011	6.66	6.67
mzi	3	500	49	5.22	2.92	16.50	77.31	4.31	1.06	0.67	0.20	0.006	6.23	6.24

Table 5.3 show the recommendations as calculated based on the main fertility parameters of the soil such as pH, EC, CEC, P and K levels. The required amounts of macro-nutrients needed for the 2<sup>nd</sup> season was 180kg/ha N, 0 kg/ha P and 0 kg/ha K. The location changed from season to season (Figure 5.3), and accordingly the 3<sup>rd</sup> season's soil results showed the area to be less fertile and thus the required nutrients needed were 180 kg/ha N, 52kg/ha P and 250 kg/ha K (Table 5.4). No lime was needed in terms of pH improvement because the



pH range for the 2<sup>nd</sup> and 3<sup>rd</sup> seasons were within the required range of 5.5 - 7.5 for optimum tomato production.

*Table 5.4: Nutrient requirements for season 2 and 3 at Mzilela farm.*

farm	season	depth (mm)	ratio's			R-value	lime required	kg/ha required		
			Ca	Mg	K			N	P	K
mzi	2	100	43.14	50.01	6.85	1437.21	0.00	60.00	0.00	0.00
mzi	2	300	52.00	43.62	4.38	835.35	0.00	60.00	0.00	0.00
mzi	2	500	52.25	43.13	4.62	872.07	0.00	60.00	0.00	0.00
mzi	3	100	86.19	9.97	3.84	579.34	0.00	60.00	14.25	60.03
mzi	3	300	83.12	13.39	3.49	512.85	0.00	60.00	19.43	94.05
mzi	3	500	77.44	18.99	3.57	893.61	0.00	60.00	18.01	96.93

### *Mulching*

Mulching was introduced to the farmers as a means of lowering non-beneficial ET from the soil surface. It was also seen as a long term strategy to improve soil organic carbon, and to improve rain water infiltration over time. This innovation entailed the use of locally available natural resources, such as natural veld grasses, to mulch the planting rows. After ploughing, natural grasses were left in the field to dry out in the sun, after which the farmers collected them and applied them to the plots. Mulch cover, as illustrated by Figure 5.10 (right), was placed between rows and also on the ridge, as close to the plants as possible, in order to limit evaporation from the soil surface. The mulching as a natural resource was free to the farmers and tested to see if this could be a useful innovation for the resource poor farmers.



*Figure 5.10: No mulch (left) versus straw mulch cover (right) treatments before planting at Mzilela.*

### *Pest Management*

The conventional pest spraying program of season 1 was adapted according to a basic tomato spraying program that was received from Ostrichem (trading as Ostrispex South Africa, Pty Ltd), a local chemical supplier in Tzaneen. Spraying was done on time using a variety of products to be more effective to protect the tomato yield especially against white fly (*Trialeurodes vaporariorum*), red spider (*Tetranychus urticae*) and other fungal diseases. When the mulched plots were sprayed for pesticides, the mulch layer was also sprayed to kill pest that may be hiding there. Products from Ostrichem, such as Alpha-thrin, Parsec, Seizer, Mancozeb and Supergel (organic product), were added to the normally sprayed products at Mzilela.

### Season 3 (May-October 2013): Winter planting

The 3<sup>rd</sup> season's planting layout was exactly the same as the previous season. The location of the trial was moved to fit in with the current rotation of plantings on the farm. The planting direction was north-south due to slope difference not allowing enough space for an east-west planting.

Trellising for season 3 was improved by installing stronger anchor poles at the start and end of each row. This was done because of problems encountered with the larger canopies of the fertilized plots in season 2. The trellising system used in season 2 became unstable in the latter part of the growing period, especially when most of the fruits were ripening, which caused some rows to collapse. This trellising method in season 3 may be more expensive, but in the long term it is more beneficial and the trellising system will last longer.

### **5.2.5 Water Productivity calculation**

WP was calculated for all three seasons throughout the study period. For this research, WP was defined as:

$$WP = \frac{\text{Yield (marketable)}}{ET(\text{actual})} \quad (\text{kg/m}^{-3}) \quad [5.1]$$

The WP numerator, marketable tomato yield, was determined by weighing the A-grade tomato fruits (kg) for each plot. The WP denominator, ET (actual), was calculated by using the water balance approach. All inflow and outflow was calculated or assumed according to:

$$ET_{act} = (I + P + C) - R - D - \Delta S \quad [5.2]$$

$$\Delta S = \text{profile SWC (at planting)} - \text{profile SWC (at harvest)} \quad [5.3]$$



The inflows of irrigation (I) and precipitation (P) were measured using the water meters at every plot inlet and a rain gauge respectively. Drainage out of the root zone was calculated from SWC measurements at 40-60 cm depth as excess water above field capacity, and converted to cubic meters that drained. This is done by selecting the SWC peaks (irrigation and rainfall) from the SWC graphs, taking the highest peak value and subtracting the SWC value when drainage due to gravitation has ended (usually 24h after peak occurred). The drainage volumes, as illustrated in Figure 5.11, were calculated by subtracting the maximum SWC value (upper black line) with the SWC when drainage ended (lower black line) for every drainage events throughout the season. This SWC value, in  $\text{mm}^3/\text{mm}^3$ , was then converted to volume (mm) of water drained per area and then converted to cubic meters drained for a specific drainage event as follow:

$$0.105 \text{ mm}^3/\text{mm}^3 \times 200\text{mm}^2 \text{ (depth represented)} = 10.5 \text{ mm drained}$$

$$10.5 \text{ mm}/1000 = 0.0105 \text{ m water drained}$$

$$0.0105 \text{ m} \times 100 \text{ m}^2 \text{ (surface area represented)} = 1.05 \text{ m}^3 \text{ drained for that peak.}$$

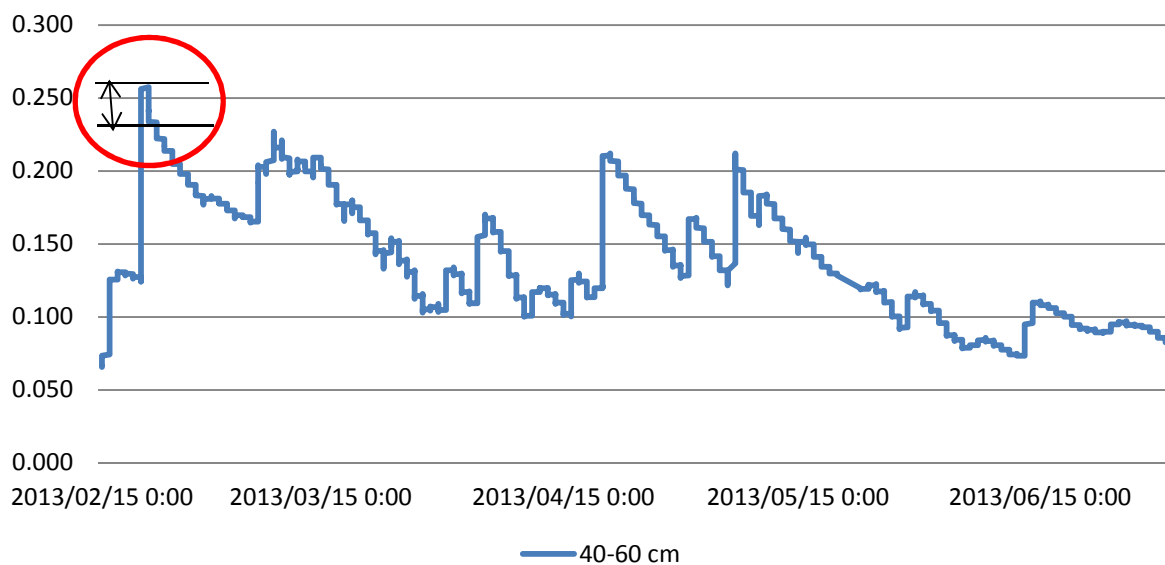


Figure 5.11: Drainage volume calculation illustration for SWC graph for the 40-60 cm probe in one of the WP trial plots.

Runoff was assumed to be zero for all rainfall events, given the soil preparation in ridges and furrows. There was no shallow water table that would contribute water to the soil profile by capillary rise (C). The change in water storage ( $\Delta S$ ) was calculated by subtracting the measured total SWC of the profile at planting with the total SWC of the profile at the last day of harvest.

### 5.2.6 Statistical analyses

All statistical analysis of results obtained from this study was done using the SAS Enterprise Guide 5.1 statistical package (copyright © 2012 by SAS Institute Inc.). All of the data that was statistically analysed were assumed to be distributed normally, homoscedastic and independent of observations. When different treatments were compared, the Tukey's studentized range comparison method was used at a 0.05 significance level. Treatment difference was analysed with a standard single factor ANOVA test with the p-values indicated in text if significant difference occurred or not. All comparison bar and line graphs displayed the main effect p-values for each ANOVA table test. Bar graphs were assigned with different letters such as a, b or ab, that indicates significant differences between those groups. In some instances, linear regressions were performed in order to show correlations between certain parameters in this study. Only data from seasons 2 and 3 was statistically analysed. Both seasons had a 4 treatment with 4 replicates trial layout, while the data analysed together for both seasons had 4 treatments with 8 replicates.

## 5.3 Results and discussion

### 5.3.1 Season 1

#### i) Yield and Water Productivity

Tomatoes were planted on the 23<sup>rd</sup> of July 2012 and the harvesting period lasted about a month and a half and was completed on the 13<sup>th</sup> of October 2012. Figure 5.11 (left) shows that the total yields for all drip and furrow plots were very low, consistent with those reported in literature for smallholder farmers in the area (NDA, 2000; Chikazunga, 2013).

The drip treatment at Zava farm yielded much higher yields than the conventional furrow irrigation with an average total yield of 24.33 t/ha and 15.20 t/ha respectively. Yield differences between treatments at Zava can be attributed to better irrigation management during the season, especially under very hot weather conditions when ET demand was the highest. The plants in the drip irrigation plots received water from the dripper directly above the main root area of the plant and therefore performed better when water was limited. The furrow irrigation plot had long furrows and consequently it took longer for water to reach some plants during every irrigation event. The top 10cm of soil on the ridge received very little water and this is where the finer root hairs of the root structure, assisting the plants with water uptake, are found.

The drip plots at Mzilela yielded the highest between the two farms for season 1 with 30.13 t/ha for plot 1 and 32.59 t/ha for plot 2.

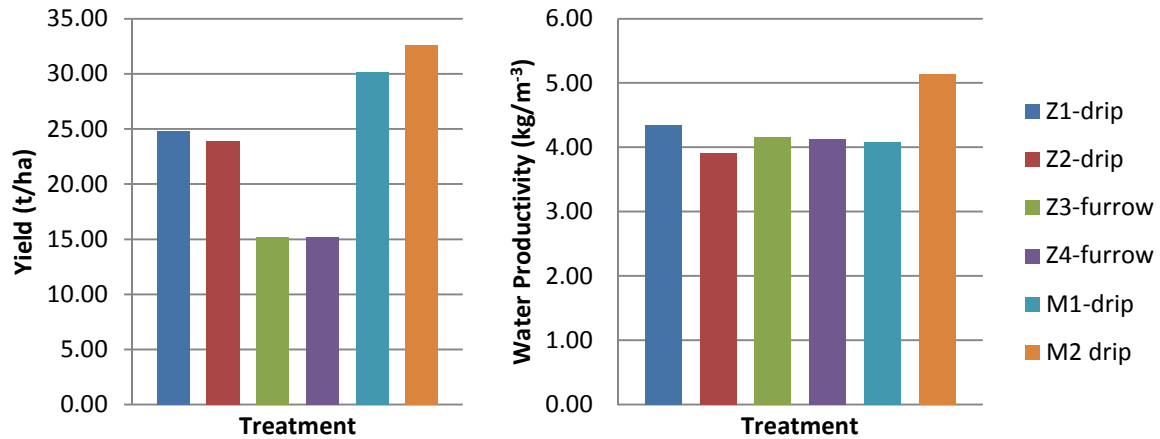


Figure 5.11: Total yield per plot harvested (left) and WP per plot (right) for season 1 at Zava (Z) and Mzilela (M) farms.

Figure 5.11 (right) shows that all the WP values for season 1 were in the range of between 3.92 and 5.13 kg/m<sup>3</sup> and difference in treatments were quite small. The average for the drip irrigation plots calculated on both farms was 4.37 kg/m<sup>3</sup>, while the WP of the furrow irrigation plot was 4.17 kg/m<sup>3</sup>. The SWC based scheduled treatment (plot 2) at Mzilela performed best in terms of WP and this was due to the higher yield and less irrigation water used as seen in Table 5.5.

Table 5.5: Yield and water balance accounting for WP values calculation for season 1 at Zava and Mzilela farm.

Farm & treatment	A-grade	t/ha	Volume water (m <sup>3</sup> )							ET (act)	WP (kg/m <sup>3</sup> )
			I	P	D	R	profile water (planting)	profile water (harvest)	ΔS		
Z1-drip	380.62	24.78	92.00	10.40	16.31	0.00	10.44	12.06	-1.61	87.71	4.34
Z2-drip	351.60	23.88	94.00	10.40	16.31	0.00	10.44	12.06	-1.61	89.71	3.92
Z3-furrow	208.00	15.20	77.50	10.40	48.32	0.00	4.06	14.44	-10.38	49.96	4.16
Z4-furrow	208.00	15.20	78.00	10.40	48.32	0.00	4.06	14.44	-10.38	50.46	4.12
M1-drip	446.16	30.18	110.00	10.00	20.80	0.00	18.70	28.90	-10.20	109.40	4.08
M2 drip	494.78	32.59	97.00	10.00	20.80	0.00	18.70	28.90	-10.20	96.40	5.13

### ii) Profile water content

All of the plots were over-irrigated when looking at the drainage volumes as seen in Table 6.5. There was less deep drainage out of the rootzone for the drip plots at Zava and Mzilela farm with an average of 18.55 m<sup>3</sup>. The drainage for the furrow plot was more than double

amounting to 48.32m<sup>3</sup>, which shows that the management of furrow irrigation scheduling was not done properly. A substantial amount of the irrigation water was lost due to deep drainage. This means that less of the total applied irrigation water was actually used to produce the crop. When calculating (equation 1) the amount of water used by the crop (ET actual) to produce the yield, the drainage volume is subtracted and therefore gives smaller ET actual values. This explains why the plots with large amounts of drainage (Fig 5.12, right) still showed high WP values because the high total drainage volume substantially decreased ET actual.

The volume amounts in Figure 5.12 (right) highlight some of the benefits of drip irrigation, not only in terms of higher yields but also in terms of water storage within the rootzone during the season. More of the water that was added to the plot, either through irrigation or rainfall, was effectively stored in the rootzone for drip as compared to the furrow plots.

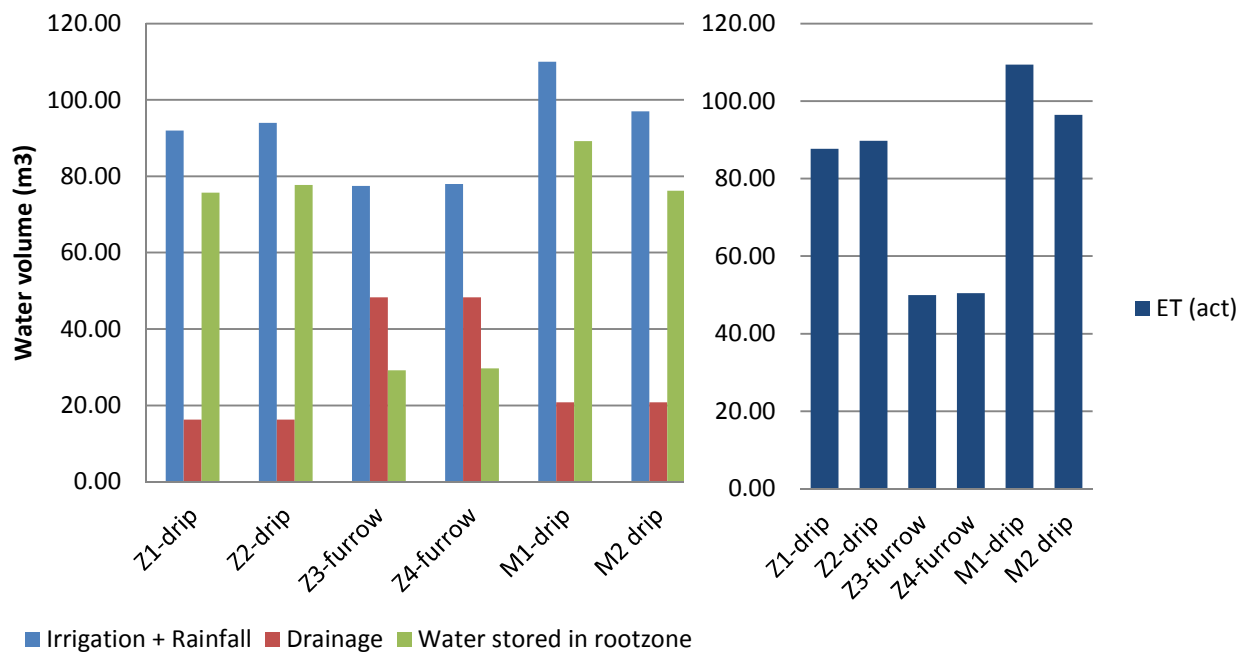


Figure 5.12: Volume of water inputs (irrigated + rainfall) volume drained and volume of water stored (available to the plant during the season) in the rootzone (left) at Zava and Mzilela farm. Volume of water used to produce the crop (right) calculated as ET (actual).

The difference in yield between the SWC based scheduling (plot 2) and the farmers managed scheduling (plot 1) was relatively small. This can be attributed to the fact that plot 2 receive the correct amount (97m<sup>3</sup>) of irrigation water according to SWC measurements, while the farmers' scheduled drip plot received much more water (107m<sup>2</sup>) than was needed.



Consequently, the SWC based irrigation management plot performed the best in terms of WP. Figure 5.13 illustrates the extent of over-irrigation encountered at plot 1 at Mzilela farm on a field visits.



*Figure 5.13: Example of an over-irrigated plot at Mzilela. The wetted area extends almost 2 meters outside the last row of plants. Weeds growth also increased due to this practice.*

Other benefits of drip irrigation were also noted at Zava farm. It resulted in a lot less weed control needed compared to the furrow plots, and in the fact that furrow irrigation needed more time and energy. In furrow irrigation the water delivery pipe had to be moved from furrow to furrow, while the drip plots simply needed opening and closing of taps. It was noted on Zava, and also from other farmers in the area, that the moving of the delivery pipe for furrow irrigation is a challenge for farmers. The challenge of irrigating, while spending a lot of time out in the sun, is a possible reason for crop losses during heat-waves in the summer. The farmers would many times prefer not to irrigate in these conditions, especially when irrigation is most necessary, and this is where changing to drip irrigation will be even more beneficial.

### iii) Fruit quality

The tomato fruit quality was not analysed for the 1<sup>st</sup> season, but the feedback from the Spar supermarket was that the tomatoes had a very short shelf-life and the fruits were generally of poor quality in terms of colour and also marks on the fruits. This is one of the major challenges with smallholder production, because the quality of production is mostly at a much lower level than the commercial producers, which forces the supermarkets to rather buy from quality-assured producers in the area. Figure 5.14 shows some of the low quality produce at Zava farm. These fruits are not fit for the supermarket in Giyani.



Figure 5.14: 1<sup>st</sup> season planting at Zava farm. i) Li-Cor 2000 measurements during the season, ii) badly damaged tomatoes because of pest infection, iii) farmers harvesting the first harvest. 1<sup>st</sup> season planting at Mzilela farm iv) Tomato rows being examined by Bilankulu for pests and fruit quality, v) sun damaged tomatoes and vi) poor quality tomato not fit for the market in Giyani.

### 5.3.2 Season 2

According to standard statistical analysis using Tukey's LSD with a 0.05 significance level, there were no significant differences between the treatments prior to planting for pH (KCl) ( $p = 0.2993$ ), EC ( $p = 0.0459$ ), P ( $p = 0.2872$ ), K ( $p = 0.3302$ ) and CEC ( $p = 0.8705$ ). Results from Table 5.6 show that there were no significant differences in the main soil fertility parameters before planting when different treatments were compared. Soil chemical characteristics were therefore eliminated as a possible factor influencing the effect of differences treatments on crop yield and WP.



The average course fragments percentage per soil profile did not show any significant differences between treatments ( $p = 0.4653$ ) with the average course fragments percentage in the whole planted area being 17.13%.

*Table 5.6: Initial soil physical and chemical property averages per treatment before planting of season 2 at Mzilela. The data labels are defined as follow: (1) F, -M: treatment 1, fertilizer added and not mulched; (2) -F, -M: treatment 2, no fertilizer added, not mulched. (3) F, M: treatment 3, fertilizer added and mulched. (4) -F, M: treatment 4, no fertilizer and mulched.*

Treatment	Physical		Chemical				
	Course Fragments (%)	BD ( $\text{g}/\text{cm}^{-3}$ )	pH (KCl)	Total N (%)	P-Mehlich 3 ( $\text{mg}/\text{kg}$ )	K ( $\text{mg}/\text{kg}$ )	CEC ( $\text{cmolc}/\text{kg}^{-1}$ )
1) F, - M	19.62	1.35	7.09	0.12	34.55	250.70	10.88
2) -F, - M (control)	25.41	1.40	7.02	0.09	57.99	190.91	12.02
3) F, M	15.32	1.44	7.16	0.10	17.42	177.61	10.78
4) -F, M	19.74	1.40	6.63	0.11	38.57	225.46	11.41
p (95%)	0.465	0.120	0.299	0.004	0.287	0.330	0.871

#### i) Yield and water productivity

Figure 5.15 (left) shows a general trend in terms of total yield of tomatoes per plot with treatment 1 yielding highest with an average total yield of 122.36 t/ha. The lowest yield was harvested in treatment 4 with an average yield of 103.28 t/ha. There were no significant differences between treatments for total yield ( $p = 0.291$ ). Figure 5.15 (right) shows the calculated WP values between treatments and again no significant differences ( $p = 0.895$ ) were encountered between treatments. The highest WP value was for treatment 4 with an average WP of  $18.56 \text{ kg}/\text{m}^{-3}$ , while the lowest WP averages were found in treatments 1 and 3 with averages of  $17.16 \text{ kg}/\text{m}^{-3}$  and  $17.16 \text{ kg}/\text{m}^{-3}$  respectively. These results also showed that the highest WP does not necessarily mean the highest yield (Zwart & Bastiaanssen, 2004).



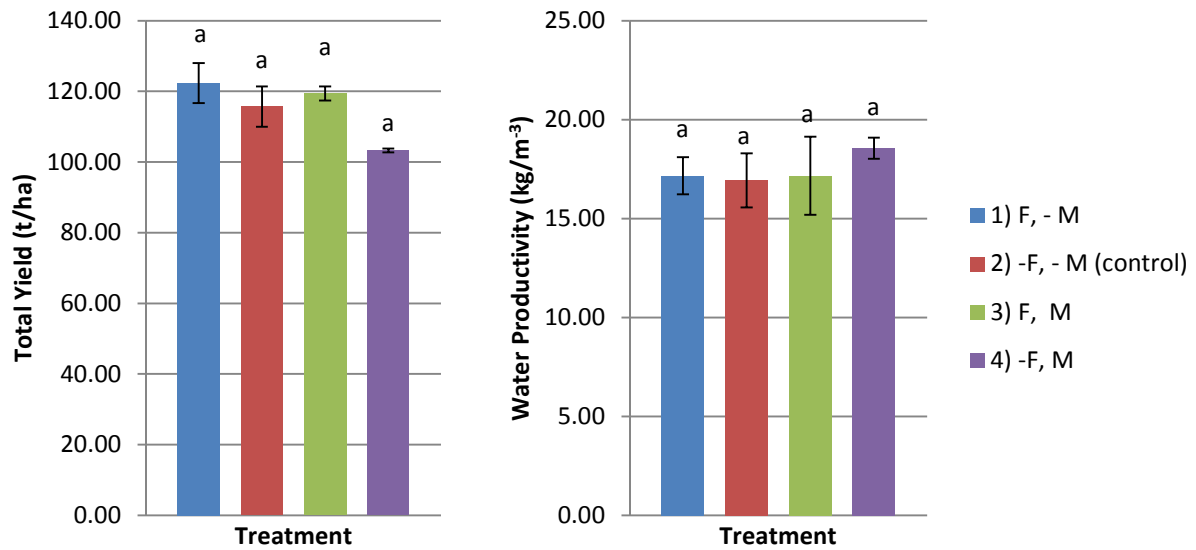


Figure 5.15: Average total yield for harvested tomatoes (left) and WP values (right) for each treatment for season 2 at Mzilela. The data labels are defined as follow: (1) F, -M: treatment 1, fertilizer added and not mulched; (2) -F, -M: treatment 2, no fertilizer added, not mulched. (3) F, M: treatment 3, fertilizer added and mulched. (4) -F, M: treatment 4, no fertilizer and mulched.

The different treatments had little effect on both yield and WP due to the fact that the planting area used was left fallow for almost 6 years before planting and thus the soil was very fertile and pest build-up was minimal. Table 5.6 shows that from soil analysis averages, the macro-nutrients were available at above optimum levels (FFSA, 2007) and thus the fertilizer treatments did not show significant effects on either yield or WP. Plant available P (Mehlich 3) was mostly above the optimum level of 16 mg/kg soil, while K levels were all higher than the optimum of 100 mg/kg soil for all treatments (Sawyer & Mallarino, 1999; FFSA, 2007).

Tomato production increased greatly during season 2 compared to season 1, and the harvesting period continued for 3 months. The total yield increased from an average of 26.34 t/ha in season 1 to 115.18 t/ha in season 2. This amounts to a 437.3% yield increase. The marketable yield (A-grade tomatoes) increased from 17.41 t/ha in season 1 to 75.47 t/ha in season 2, which is an increase of 433.5%. The increases in WP from season 1 to season 2 were also remarkable, increasing from 4.37 kg/m<sup>3</sup> for drip irrigation to 17.62 kg/m<sup>3</sup>. This amounts to a 403.2 % increase in WP. The new variety performed very well as seen in the harvested amounts for each plot. This is arguably the main reason for the impressive yields, but irrigation management and overall improvement in production practices also made a difference.

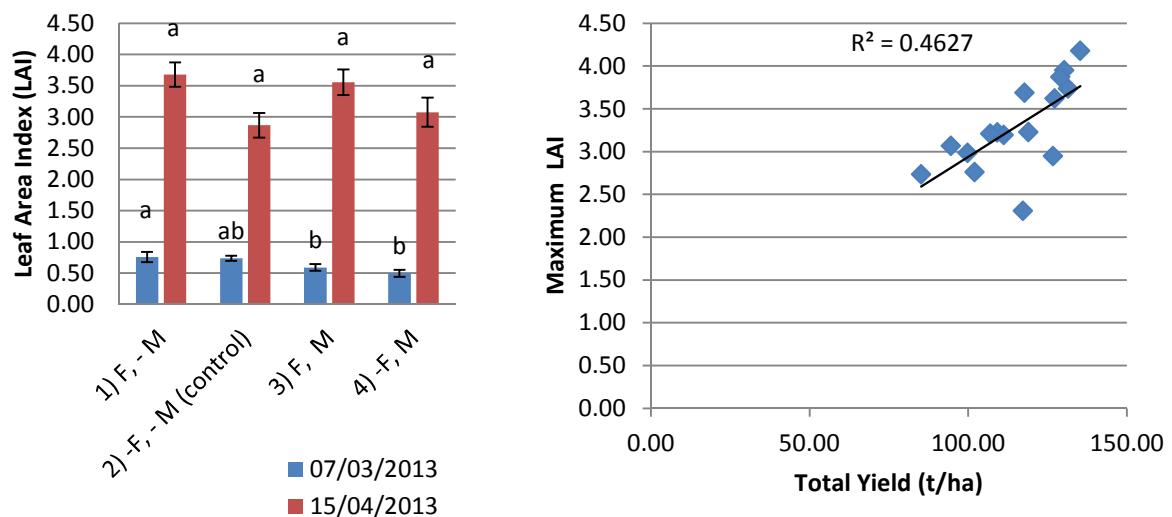
*ii) Canopy growth*

LAI results in Figure 5.16 show that there was quite a difference in canopy growth during the growing period. The LAI was taken one month after planting and also at harvest when canopy was at full growth. One month after planting, the canopy of treatment 1 and 2 was significantly larger ( $p = 0.0028$ ) than for treatment 3 and treatment 4. Table 5.7 shows a possible explanation for the differences in growth. Treatments 1 and 2 received slightly more water in the initial growth period than treatments 3 and 4.

*Table 5.7: LAI averages and average irrigation water applied for the different treatments, one month after planting at Mzilela.*

Treatment	LAI average (07/03/2013)	Average irrigation water applied (m <sup>3</sup> ) (08/03/2013)
1) F, - M	0.760	9.50
2) -F, - M (control)	0.738	6.50
3) F, M	0.592	7.75
4) -F, M	0.498	6.50

The LAI values at harvest also reflected on yield as the two fertilizer treatments had higher LAI values than the non-fertilized treatments. These were however not statistically different ( $p = 0.00523$ ), but in terms of a visual indication, growth differences could be noted. The maximum canopy size at harvest may have had an effect on the crop yield as seen in Figure 5.16 (right) with a moderate correlation ( $R^2=0.487$ ) between these two factors.



*Figure 5.16: LAI average values measured during the season for different treatments (left) and a correlation between maximum LAI and total harvested yield (right) for season 2 at Mzilela.*

Mzilela farm. The data labels are defined as follow: (1) F, -M: treatment 1, fertilizer added and not mulched; (2) -F, -M: treatment 2, no fertilizer added, not mulched. (3) F, M: treatment 3, fertilizer added and mulched. (4) -F, M: treatment 4, no fertilizer and mulched.

The differences in canopy growth could be seen visually from the early growing stages. Figure 5.17 shows the larger canopies of plot 2 (treatment 2) compared to the adjacent plots 1 and 3 (treatment 1).



Figure 5.17: Differences in plant growth one month after planting of fertilized (2A) plots and unfertilized (3A) plots at Mzilela farm.

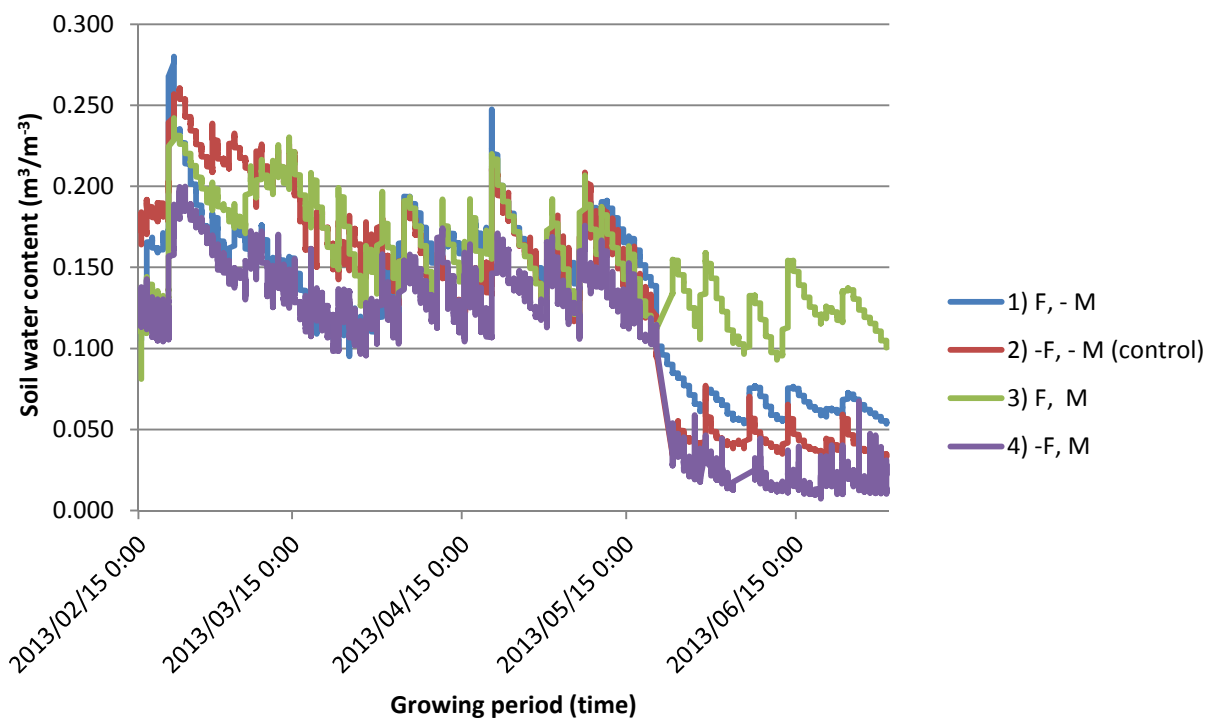
### iii) Profile water content

Figure 5.18 shows the SWC fluctuation as an average for each treatment calculated from the continuous logging of SWC every 30 minutes during the growing period. The averages were calculated for each depth (0-20, 20-40 and 40-60 cm) and given as the average for each treatment.

There were three distinct stages of SWC during the season when the treatments were differentiated. In the first 3<sup>rd</sup> of the season, the SWC averages for treatment 2 and 3 were higher than treatment 1 and 4. It is assumed that treatment 1 had higher surface evaporation because this plot received more water (Table 5.7) and had larger canopies than the other treatments, which meant more transpiration when compared to treatments 2 and 3. Treatment 4 received less water because of its position, being on a relatively higher slope than the other treatments. Treatment 2 had larger canopies and therefore had less surface

evaporation compared to treatment 1, while treatment 3 was mulched and also ensured higher SWC averages.

In the second 3<sup>rd</sup> of the growing season, all treatments showed similar SWC averages. This was due to the fact that the canopies were mature and had similar canopy sizes for treatments 1, 3 and 4 (Fig 5.16, left), while treatment 2 had a mulch cover, which limited evaporation. For this reason the mulched and non-mulched treatments showed similar SWC averages.



*Figure 5.18: Average relative SWC per treatment for season 2 at Mzilela. The data labels are defined as follow: (1) F, -M: treatment 1, fertilizer added and not mulched; (2) -F, -M: treatment 2, no fertilizer added, not mulched. (3) F, M: treatment 3, fertilizer added and mulched. (4) -F, M: treatment 4, no fertilizer and mulched.*

In the last 3<sup>rd</sup> of the growing season, Treatments 1, 3 and 4 had much lower SWC averages compared to treatment 2. It is important to note that during this stage, one of the irrigation pumps broke down on the farm. The problem was solved but a different pump was used (lower pumping capacity) during this stage, which delivered water to the plots at a lower pressure. This change in pressure affected the water distribution to some of the plots with some plots receiving less water. This is the explanation for a sudden drop in water content for all treatments as seen in Fig 5.18. It is also interesting to see the effect of the mulch treatments when water became limited during this stage, with treatment 3 maintaining the

highest SWC averages. The reason that treatment 4 (also mulched) had the lowest SWC averages is because this treatment was located at a slightly higher position in the field and due to the lower pressure of the new pump, this treatment received less water later during the season.

The effect of the mulch treatment can be seen when comparing the SWC at different depths. Figure 5.19 shows the effect of the mulch (treatment 3) versus the non-mulched (treatment 1) plots which were both fertilized and both had similar maximum canopy sizes (LAI of 3.56 and 3.68 respectively on 15/04/2013). The SWC for the mulch treatment at 20-40 cm depth was higher than the 0-20 cm depth throughout the season. With the non-mulched treatment, the opposite was observed with the topsoil layer being mostly higher than the 20-40 cm depth. This can be ascribed to the evaporation effect which means that top soil water is lost into the atmosphere and continues to draw water from the subsoil layer to the surface as the process continues. Where evaporation is inhibited by the mulch layer, the subsoil layers remain at a high SWC and the top soil SWC decreases as water is taken up mainly by the plants and not lost to the atmosphere through evaporation. It also means that the soil water was better conserved in the mulched treatment than in the non-mulched treatment. As a result of soil evaporation, the non-mulched treatment may have been under-irrigated.

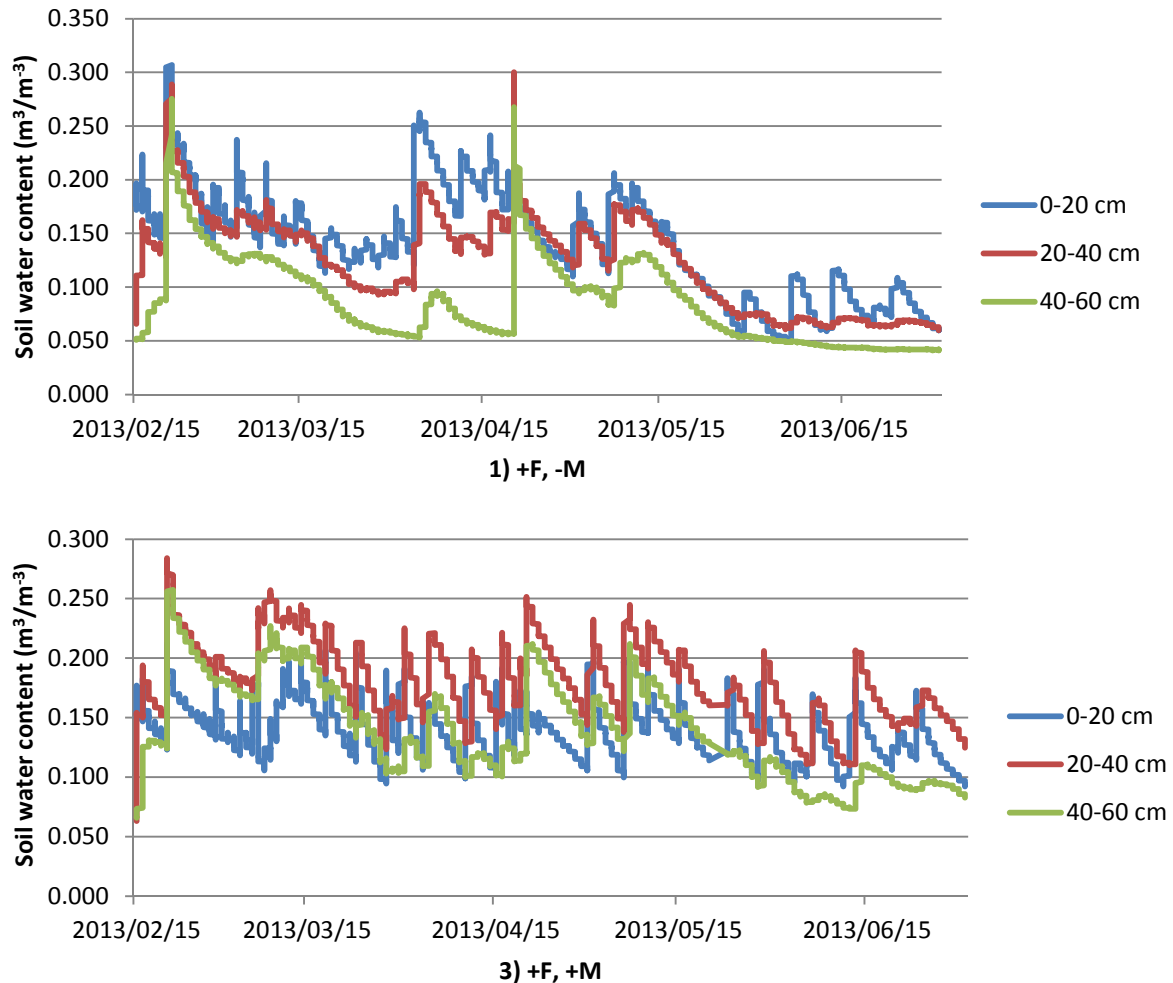


Figure 5.19: SWC for the three depth for treatments 1 (above) and 3 (below) for season 2 at Mzilela. The data labels are defined as follow: (1) F, -M: treatment 1, fertilizer added and not mulched; (3) F, M: treatment 3, fertilizer added and mulched.

#### iv) Fruit quality

Basic fruit quality parameters were assessed for each treatment as a relative overview of the effect of different treatments on fruit weight, sugar content (% Brix), pH and titratable acidity (TA) of the fruits. Figures 5.20 and 5.21 show that there were no significant differences between treatments on average fruit weight ( $p = 0.0653$ ), % Brix ( $p = 0.1469$ ) and TA ( $p = 0.3617$ ). There were however positive trends, where the two mulched treatments gave better results for average fruit weight, % Brix and TA. According to Yara (2007), the best quality in terms of market requirements for tomatoes is high sugar content and a high acidity content, which gives a good flavour for table tomatoes.



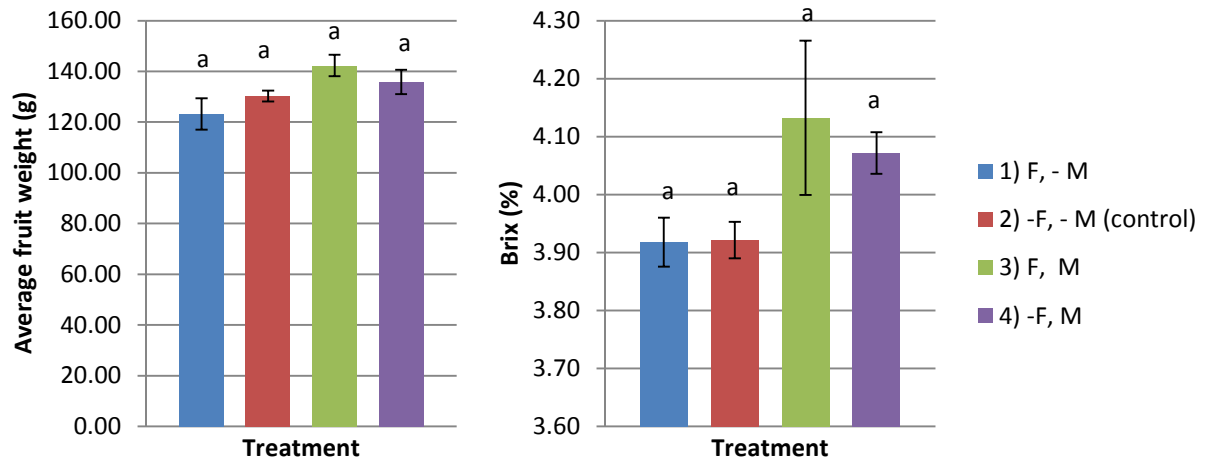


Figure 5.20: Average fruit weight (left) and sugar content (right) averages of the fruits for different treatments of season 2 at Mzilela farm. The data labels are defined as follow: (1) F, -M: treatment 1, fertilizer added and not mulched; (2) -F, -M: treatment 2, no fertilizer added, not mulched. (3) F, M: treatment 3, fertilizer added and mulched. (4) -F, M: treatment 4, no fertilizer and mulched.

In this trial, treatments 3 and 4 had the highest sugar contents, while the TA was generally in the same range for all treatments. The pH values for the different treatments were in the range between 4 and 4.5. There were significant ( $p = 0.017$ ) differences between treatments with treatment 4 having the highest average pH, and treatments 2 and 3 being higher than treatment 1.

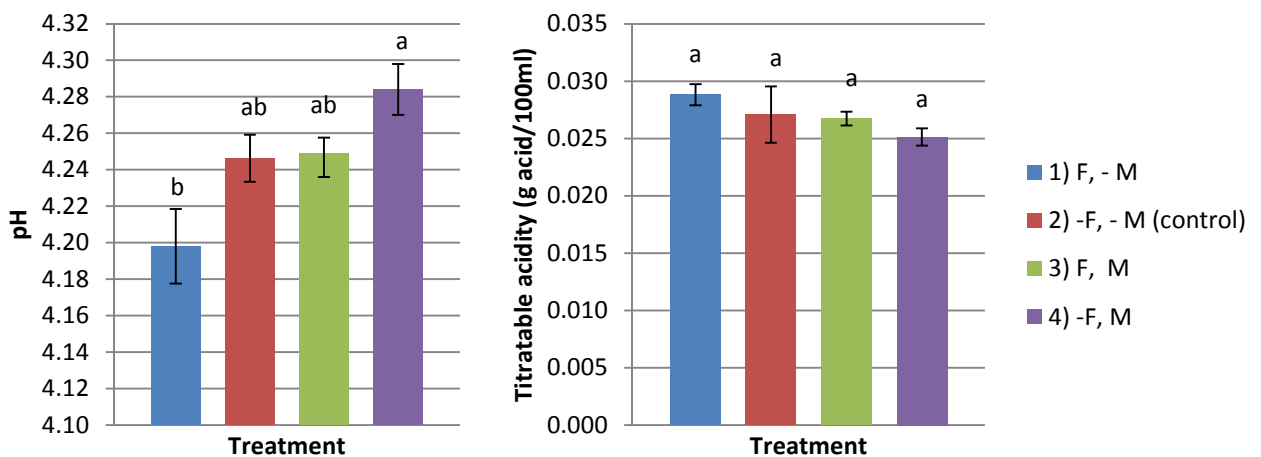


Figure 5.21: pH (right) and TA (left) averages of the fruits for different treatments for season 2 at Mziela farm. The data labels are defined as follow: (1) F, -M: treatment 1, fertilizer added and not mulched; (2) -F, -M: treatment 2, no fertilizer added, not mulched. (3) F, M: treatment 3, fertilizer added and mulched. (4) -F, M: treatment 4, no fertilizer and mulched.

The Brix percentages encountered were also in the normal range between 3.5 to 5.5 % Brix according to Yara (2007). When assessing all the fruit quality parameters tested, treatment 3 and 4 performed the best.

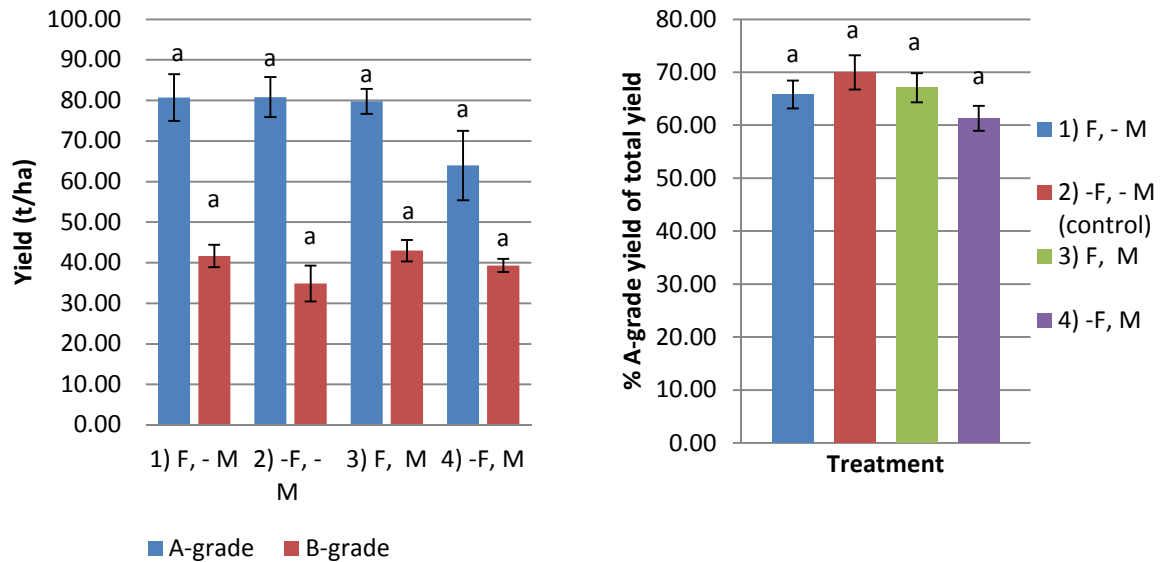


Figure 5.22: Average harvested amounts for A-grade and B-grade tomatoes (left) and percentage of A-grade tomatoes of the total harvest from each plot (right) of season 2 at Mzilela. The data labels are defined as follow: (1) F, -M: treatment 1, fertilizer added and not mulched; (2) -F, -M: treatment 2, no fertilizer added, not mulched. (3) F, M: treatment 3, fertilizer added and mulched. (4) -F, M: treatment 4, no fertilizer and mulched.

Figure 5.22 shows the results of an important quality parameter that has an indefinite link to the economic return for the smallholder farmers. A-grade tomatoes are sold at about R70-80 per crate, while the B-grade tomatoes were sold locally in the village for between R30-50 per crate. The harvested A-grade ( $p = 0.2083$ ) and B-grade tomato yield ( $p = 0.2955$ ) between the different treatments showed that there were no significant differences. When comparing average percentages of A-grade of the total yield, treatment 2 performed best with a percentage of 69.97 and treatment 4 was the worst with an average of 61.29%.



*Figure 5.23: Fruit development (left) and neatly trellised tomatoes (right) for season 2*

### **5.3.3 Season 3**

Results from the initial soil sample analyses taken before planting showed that there were no significant differences in the main fertility parameters between treatment plots. Table 5.8 shows that there were no significant differences between treatment plots before planting for pH (KCl) ( $p = 0.047$ ), EC ( $p = 0.224$ ), P ( $p = 0.276$ ), K ( $p = 0.042$ ) and CEC ( $P=0.721$ ). The soil fertility status for this trial was below optimum levels for some parameters due to the selected site being intensively cropped every 6 months over the last decade. The site was located on an area of the farm which is close to the irrigation pump and thus because of practical reason, cultivated year after year without fertilizing. This site is about 50 m from the 2<sup>nd</sup> season planting area, but the pH average of season 2 were 7.15 as compared to 5.44 for season 3. The plant available P (Mehlich 3) was low and the average was 17.19 mg P/kg soil, which higher than the optimum 16 mg/kg needed for tomato crop production (Sawyer & Mallarino, 1999). Some of the soils in treatments 3 and 4 had plant available K levels which were below the optimum of 100-250 mg/kg soil (FFSA, 2007)

The average CFP per profile before planting showed a significant difference ( $p = 0.037$ ) between treatments. Treatments 4 and 1 were significantly higher than treatments 2 and 3. The average percentage coarse fragment content throughout the planting area was 32.3%.

*Table 5.8: Initial soil physical and chemical property averages per treatment before planting of season 3 at Mzilela. The data labels are defined as follow: (1) F, -M: treatment 1, fertilizer added and not mulched; (2) -F, -M: treatment 2, no fertilizer added, not mulched. (3) F, M: treatment 3, fertilizer added and mulched. (4) -F, M: treatment 4, no fertilizer and mulched.*

Treatment	Physical		Chemical				
	Course Fragments (%)	BD (g/cm <sup>3</sup> )	pH (KCl)	Total N (%)	P-Mehlich 3 (mg/kg)	K (mg/kg)	CEC (cmolc/kg <sup>-1</sup> )
1) F, - M	31.68	1.47	5.72	0.05	4.10	130.01	7.21
2) -F, - M (control)	25.55	1.52	5.82	0.07	6.01	94.75	7.75
3) F, M	23.97	1.44	5.34	0.16	3.54	63.42	6.67
4) -F, M	31.33	1.46	4.89	0.16	2.72	61.81	6.17
p (95%)	0.037	0.616	0.0467	0.6161	0.276	0.042	0.721

#### *j) Yield and water productivity*

Tomato production of season 3 at Mzilela was higher than compared to season 1, but performed slightly poorer than season 2. The harvesting period lasted only 2 months, due to a fungal infection and various pest activities in the trial site. This was the result of pesticide spraying being delayed for 3 consecutive weeks during the crucial stage of flowering and early fruit development. This was caused by the farmers being busy with other activities on the farms needing attention and also due to poor management. This production system changed the way in which the farmers previously operated and therefore tested their ability to adapt. Consequently, corrective measures had to be implemented but mostly too late. This indicated gaps in their understanding of the required operations and refocused the need for training.

The yield results between treatments as shown by Figure 5.24 (right), was more substantial compared to season 2. Due to the more nutrient deficient soils of season 3, the fertilized plots had much higher averages for total yield of tomatoes. Treatment 3 gave the highest average of total yield with 111.14 t/ha and treatment 1 yielded slightly less with 103.76 t/ha. The unfertilized treatments 2 and 4 yielded significantly less ( $p = 0.0001$ ) than treatments 1 and 3 with averages of 69.82 ton/ha and 66.04 ton/ha respectively.

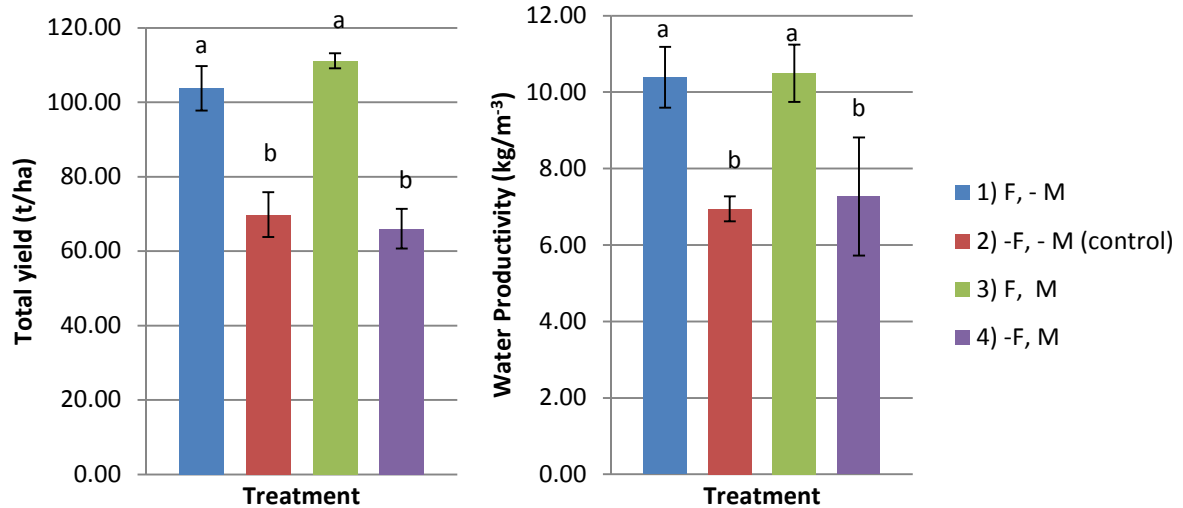


Figure 5.24: Average total yield (left) and WP (right) for different treatments for season 3 at Mzilela. The data labels are defined as follow: (1) F, -M: treatment 1, fertilizer added and not mulched; (2) -F, -M: treatment 2, no fertilizer added, not mulched. (3) F, M: treatment 3, fertilizer added and mulched. (4) -F, M: treatment 4, no fertilizer and mulched.

Figure 5.24 (right), shows the WP values between treatments with significant differences ( $p = 0.0008$ ). Treatment 3 had the highest WP, with an average of  $10.49 \text{ kg/m}^3$ , while the lowest was recorded for treatment 2 with an average of  $6.95 \text{ kg/m}^3$ . WP for the fertilized treatments was significantly higher compared to the unfertilized treatments. The mulch versus non-mulched treatments showed no significant yield differences, but the mulch treatments in both cases gave higher WP values than the non-mulched treatments.

Yield and WP was greatly affected by fertilizer treatments due to the low initial fertility levels of the soil for season 3. The combination of fertilizer and mulch performed the best in terms of the total yield and WP.

### ii) Canopy growth

Figure 5.25 shows that the LAI averages per treatment were remarkably different in terms of canopy growth and size. The LAI measurements were only taken at harvest because the LAI-2000 instrument was malfunctioning in the first part of the growing season. Although LAI was not measured in the early stages of the season, differences in growth is illustrated in Figure 5.26, showing differences in growth between the fertilized plot (7) and the un-fertilized plot (8). The fertilized treatments had a great effect on LAI and these had much denser canopies. The LAI for treatments 1 and 3 were significantly higher ( $p = 0.0001$ ) than for treatments 2 and 4, with average values of 4.27 and 3.51 respectively. The soil macro-

nutrients levels showed low levels before planting and thus the addition of N had a significant impact on vegetative growth and subsequently also on yield.

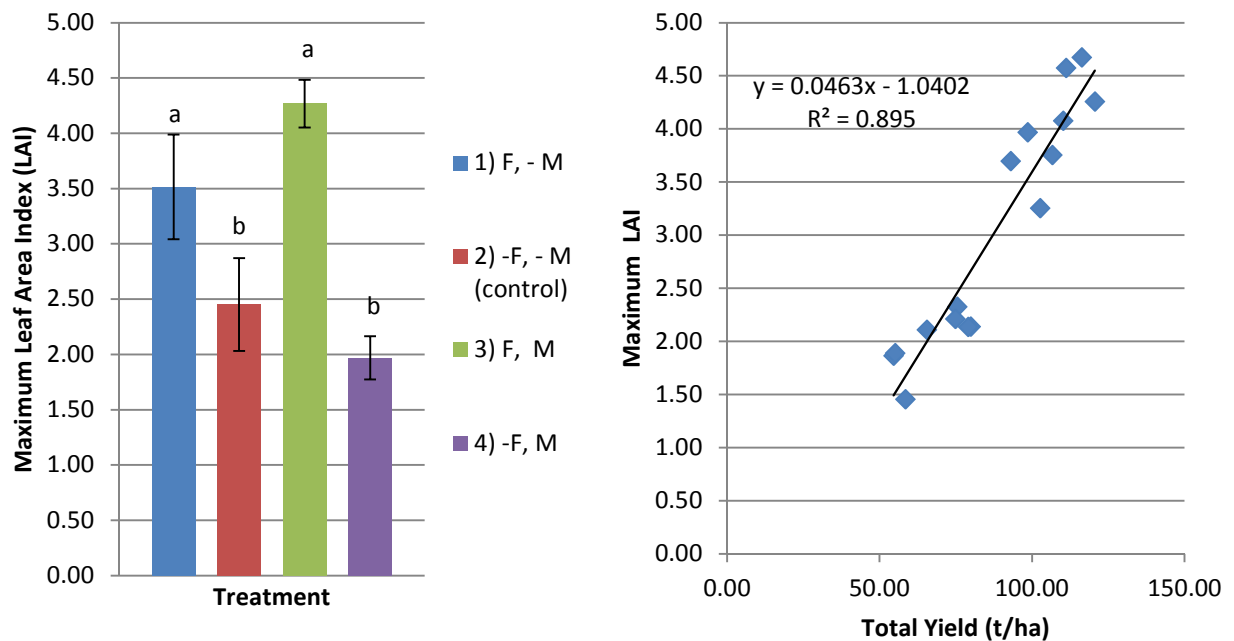
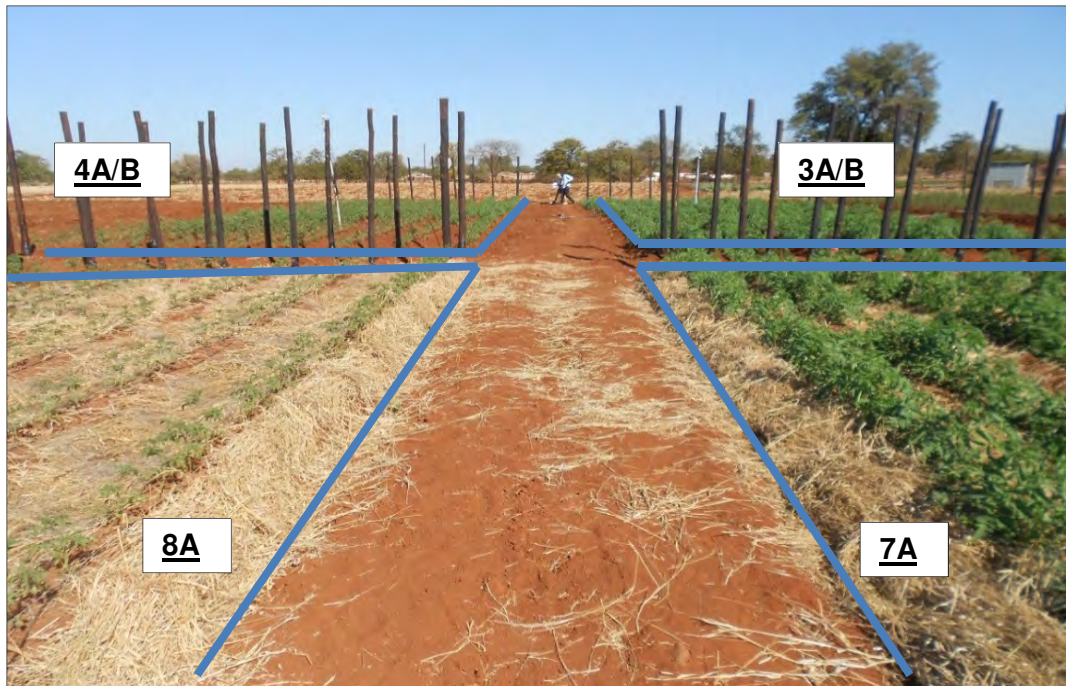


Figure 5.25: LAI averages at full growth per treatment for season 3 (left) and correlation between LAI and total harvested yield (right) at Mzilela farm. The data labels are defined as follow: (1) F, -M: treatment 1, fertilizer added and not mulched; (2) -F, -M: treatment 2, no fertilizer added, not mulched. (3) F, M: treatment 3, fertilizer added and mulched. (4) -F, M: treatment 4, no fertilizer and mulched.

Figure 5.25 (right) shows a very strong correlation between maximum LAI and total yield harvested ( $R^2 = 0.895$ ). This is due to the fact that a larger canopy with healthier leaves facilitated higher transpiration levels, which enabled more fruit to ripen. The leaves are the 'factory' of the crop and when water supply is optimal, the plant can transport water and nutrients to the fruit and therefore the direct link shown between LAI and yield in Figure 5.25 (right). The decrease in yield when compared to season 2 was due to a leaf fungal infection that senesced leaves and therefore the harvesting were stopped prematurely. The results also serve as an indicator that yield and WP are affected by routine management practices such as pest management (Kijne et al., 2002).





*Figure 5.26: Mulching (plot 7 & 8) versus non-mulched (plot 3 & 4) treatments for season 3 at Mzilela farm. Also note the canopy growth difference between the unfertilized (8A) and fertilized (7A) plots in the early stages of growth. Big anchor poles are installed at the start and end of each row.*

*iii) Profile water content*

Figure 5.27 shows the general average trends in SWC per profile during the season. The same general trend was observed during season 2. The differences in canopy size had an effect on the SWC during the season. Larger canopies generally transpired more, and at full growth, evaporation is minimized from the soil surface due to less surface area being exposed to the sun. The smaller canopies of the un-fertilized treatments (2 and 4) had lower average SWC values during the season. This resulted from evaporation losses during the season with most of the soil being exposed to direct sunlight. The bigger canopies of treatments 1 and 3 showed higher SWC averages in the beginning of the season, with lesser surface exposure to the sun.

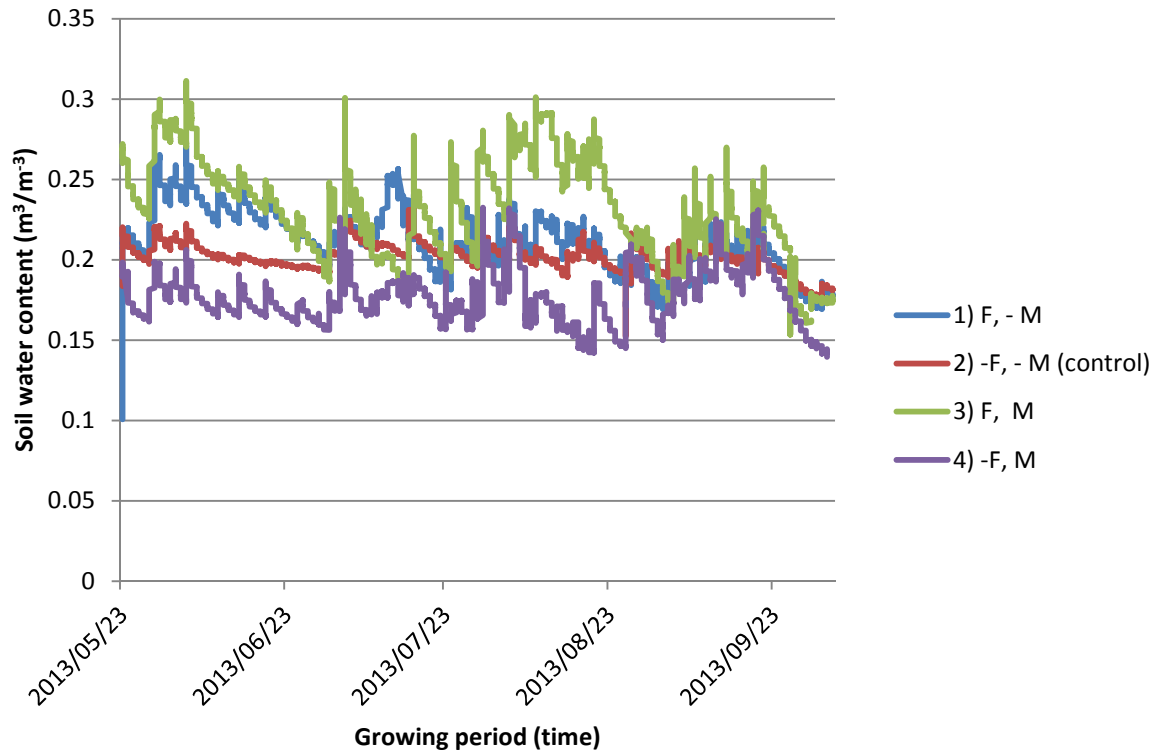


Figure 5.27: Average relative soil water content per treatment for season 3 at Mzilela. The data labels are defined as follow: (1) F, -M: treatment 1, fertilizer added and not mulched; (2) -F, -M: treatment 2, no fertilizer added, not mulched. (3) F, M: treatment 3, fertilizer added and mulched. (4) -F, M: treatment 4, no fertilizer and mulched.

The highest plant available water in terms of water storage in the profile was recorded in treatment 3. Although this treatment had the highest LAI, the mulch cover limited evaporation and minimized losses from the profile during the whole season. Again treatment 4 had the lowest average SWC over the growing period and this can once again be ascribed to high surface evaporation.

#### iv) Fruit quality

The fruit quality of the tomatoes for season 3 was much poorer when compared to season 2. This difference was already noted during harvest when complaints were received from the supermarket in Giyani of fruit having a short shelf-life. Soil fertility and specifically the plant available P and K played a role in the poor performance in fruit quality for season 3. The effects were so severe that towards the end of the season, only tomatoes harvested from treatments 1 and 3 (fertilized treatments) were fit to be delivered to the main market in Giyani.

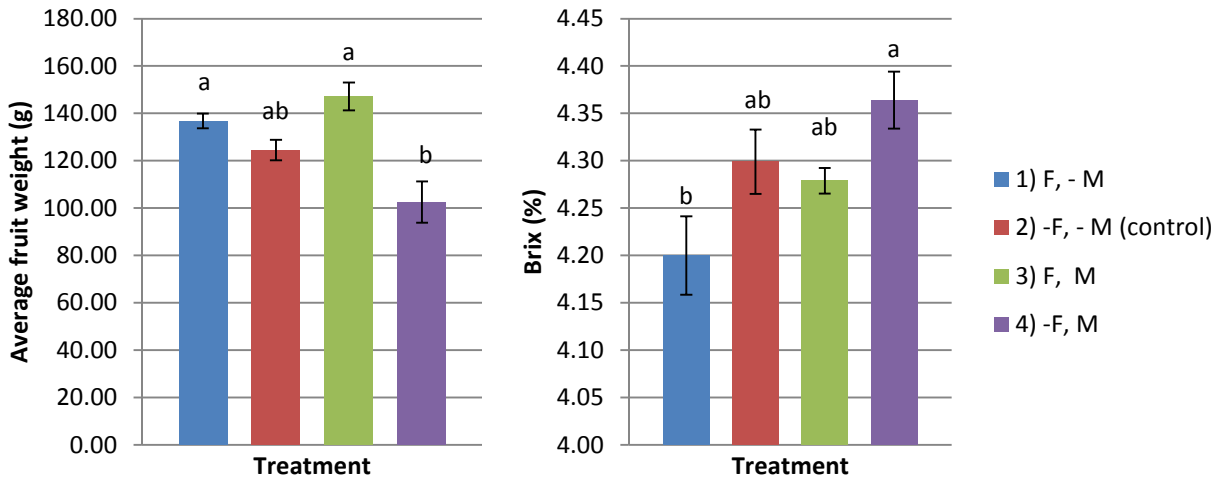


Figure 5.28: Average fruit weight and percentage Brix for the different treatments of season 3 at Mzilela. The data labels are defined as follow: (1) F, -M: treatment 1, fertilizer added and not mulched; (2) -F, -M: treatment 2, no fertilizer added, not mulched. (3) F, M: treatment 3, fertilizer added and mulched. (4) -F, M: treatment 4, no fertilizer and mulched.

As indicated by Figures 5.28 and 5.29, significant differences were found between the fertilized treatments (1 and 3) and the un-fertilized treatments (2, 4) for average fruit weight ( $p = 0.0011$ ), pH ( $p = 0.0239$ ) and % Brix ( $p = 0.0228$ ). No significant differences were found in TA ( $p = 0.2782$ ) amongst all treatments but the values were generally much lower than for season 2. With the best quality indicators in terms of market requirements for tomatoes being fruit with high sugar content and high TA, treatments 3 and 4 performed best in this regard. The acidity levels were in the same range. The pH range for the treatments were in the normal range of 4 - 4.5 (Yara, 2007). Treatment 4 had significantly higher average pH values, than treatments 2 and 3, while treatment 1 had the lowest pH. The brix values were also in the normal range of between 3.5 to 5.5 % Brix (Yara, 2007).

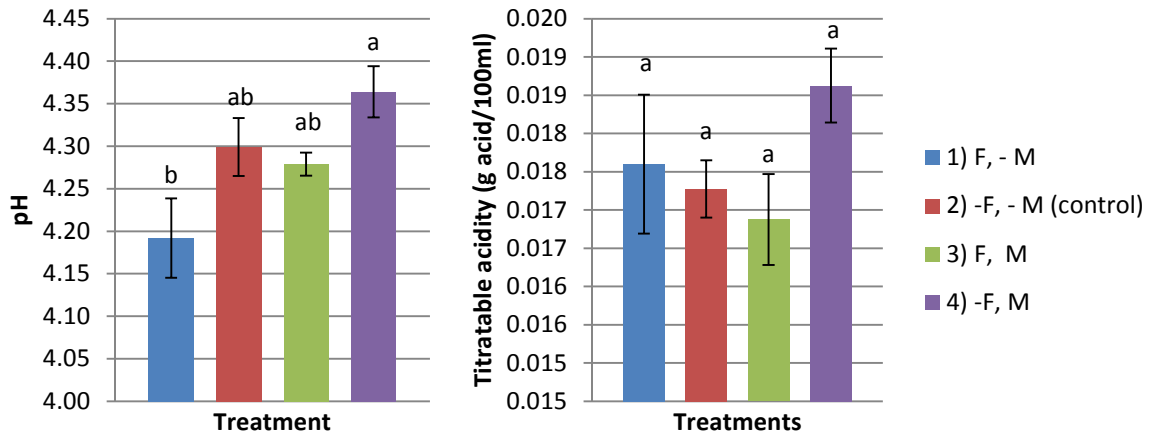


Figure 5.29: pH and Titratable acidity of the fruits for different treatments of season 3 at Mziela. The data labels are defined as follow: (1) F, -M: treatment 1, fertilizer added and not mulched; (2) -F, -M: treatment 2, no fertilizer added, not mulched. (3) F, M: treatment 3, fertilizer added and mulched. (4) -F, M: treatment 4, no fertilizer and mulched.

When assessing all the fruit quality parameters tested, treatments 1 and 3 seemingly performed the best. There were quality differences, as measured in terms of amount of A and B grade tomatoes (Figure 5.30), with A-grade tomatoes being 49 - 55 % of the total yield. This was lower compared to season 2, which had averages of between 61 and 69 %. This had a big impact on the economic returns.

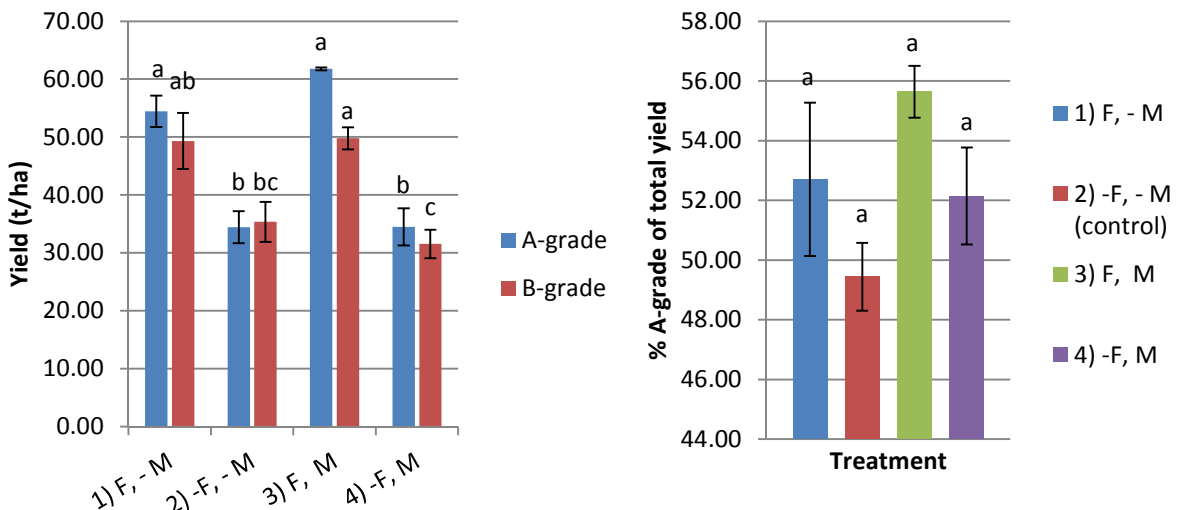


Figure 5.30: Average harvested amounts for A-grade and B-grade tomatoes (left) and percentage of A-grade tomatoes of the total harvested from each plot (right) for season 3 at Mziela. The data labels are defined as follow: (1) F, -M: treatment 1, fertilizer added and not

mulched; (2) -F, -M: treatment 2, no fertilizer added, not mulched. (3) F, M: treatment 3, fertilizer added and mulched. (4) -F, M: treatment 4, no fertilizer and mulched.

### 5.3.4 Combined results for Seasons 2 and 3

The trial layouts for seasons 2 and 3 were exactly the same and to get an overall idea of the effects of the fertilizer and mulch treatment combinations over two seasons, the data were statistically analysed for both seasons together. The four treatments were analysed, with 8 replicates each, in order to investigate the overall effects of the treatments across seasons.

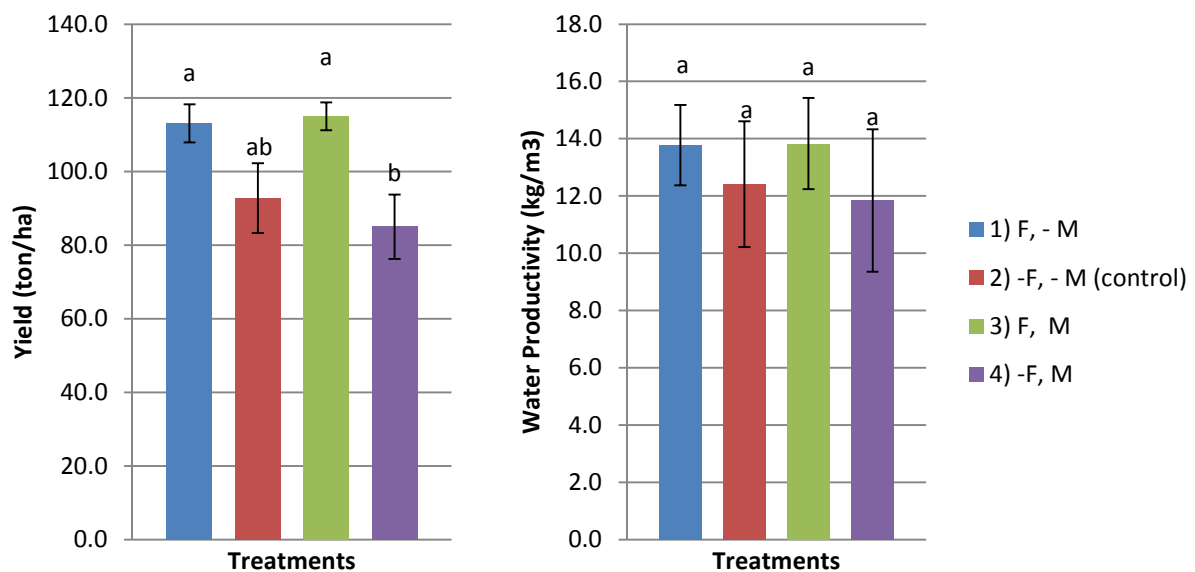


Figure 5.31: Overall total yield (left) and WP (right) for the four treatments of season 2 and 3 at Mzilela farm. The data labels are defined as follow: (1) F, -M: treatment 1, fertilizer added and not mulched; (2) -F, -M: treatment 2, no fertilizer added, not mulched. (3) F, M: treatment 3, fertilizer added and mulched. (4) -F, M: treatment 4, no fertilizer and mulched.

Table 5.9 summarizes the results from seasons 2 and 3 in terms of yield and WP. Drainage amount out of the rootzone was low for both seasons and compared to season 1, improved considerably. This means that the available water was used more efficiently, through the applied water being used by the plant for fruit production. With the plants being much bigger than compared to season 1, water was taken up much quicker, which also ensured that the field was not easily over-irrigated.

Figure 5.31 shows the results of the overall trends in total yield and WP for the study. Treatment 3 had the highest yield with an average of 114.9 t/ha. Treatment 1 yielded slightly less with an average of 113.1 t/ha. Yields in these two treatments, which are the fertilizer treatments, were significantly ( $p = 0.0113$ ) higher than in treatments 2 and 4. Treatment 4

had the lowest total yield average. These results show that over two seasons, the highest yield was obtained with treatments of recommended fertilizer application and a straw mulch cover. The mulching did not show a significant effect on yield.

Figure 5.34 (left) shows the overall WP trend. Again it was treatment 3 that had the highest WP average of  $13.83 \text{ kg/m}^{-3}$ , while treatment 1 had a slightly lesser average of  $13.78 \text{ kg/m}^{-3}$ . Treatments 2 and 4 had lower averages, with  $12.41 \text{ kg/m}^{-3}$  and  $11.85 \text{ kg/ha}^{-3}$  respectively. There were no significant differences between treatments for WP ( $p = 0.7748$ ).



Table 5.9: Summary of Yield and WP results for season 2 and 3 combined at Mzilela farm.

season	treatment	replicate	Yield (kg)			t/ha	Volume water (m <sup>3</sup> )								WP (kg/m <sup>3</sup> )
			A-grade	B-grade	Total		I	P	D	R	profile water (planting)	profile water (harvest)	ΔS	ET (act)	
2	1	1	875.50	477.60	1353.10	135.31	48.04	6.65	2.22	0.00	5.77	3.25	2.52	49.95	17.53
2	1	2	815.30	362.20	1177.50	117.75	39.96	6.65	2.22	0.00	5.77	3.25	2.52	41.87	19.47
2	1	3	895.30	376.80	1272.10	127.21	51.29	6.65	0.76	0.00	6.87	3.25	3.62	53.56	16.72
2	1	4	642.00	449.70	1091.70	109.17	40.71	6.65	0.76	0.00	6.87	3.25	3.62	42.98	14.94
2	2	1	870.80	318.80	1189.60	118.96	42.34	6.65	0.30	0.00	7.33	2.09	5.25	43.44	20.05
2	2	2	911.60	356.20	1267.80	126.78	47.66	6.65	0.30	0.00	7.33	2.09	5.25	48.77	18.69
2	2	3	743.00	254.90	997.90	99.79	60.13	6.65	0.14	0.00	12.37	2.09	10.28	56.36	13.18
2	2	4	707.40	465.10	1172.50	117.25	39.87	6.65	0.14	0.00	12.37	2.09	10.28	36.09	19.60
2	3	1	835.10	468.00	1303.10	130.31	51.70	6.65	0.30	0.00	5.57	6.03	-0.46	58.51	14.27
2	3	2	699.60	412.00	1111.60	111.16	43.30	6.65	0.30	0.00	5.57	6.03	-0.46	50.11	13.96
2	3	3	814.50	476.20	1290.70	129.07	36.87	6.65	0.14	0.00	4.17	6.03	-1.86	45.23	18.01
2	3	4	706.10	363.40	1069.50	106.95	23.13	6.65	0.14	0.00	4.17	6.03	-1.86	31.50	22.42
2	4	1	874.30	440.30	1314.60	131.46	46.57	6.65	0.04	0.00	3.98	2.77	1.20	51.98	16.82
2	4	2	648.80	371.50	1020.30	102.03	27.43	6.65	0.04	0.00	3.98	2.77	1.20	32.83	19.76
2	4	3	558.80	386.30	945.10	94.51	26.46	6.65	0.00	0.00	6.58	2.77	3.81	29.30	19.07
2	4	4	476.30	375.01	851.31	85.13	24.54	6.65	0.00	0.00	6.58	2.77	3.81	27.38	17.39
3	1	5	599.00	607.70	1206.70	120.67	72.52	1.50	1.18	0.00	10.26	10.72	-0.46	73.30	8.26
3	1	6	580.90	405.10	986.00	98.60	57.48	1.50	1.18	0.00	10.26	10.72	-0.46	58.26	10.11
3	1	7	487.90	539.00	1026.90	102.69	42.88	1.50	1.72	0.00	12.45	10.24	2.21	40.45	11.38
3	1	8	509.40	421.20	930.60	93.06	43.12	1.50	1.72	0.00	12.45	10.24	2.21	40.70	11.81
3	2	5	346.50	309.50	656.00	65.60	43.81	1.50	0.70	0.00	11.96	10.89	1.07	43.54	7.91
3	2	6	266.20	280.10	546.30	54.63	39.19	1.50	0.70	0.00	11.96	10.89	1.07	38.92	6.79
3	2	7	384.50	414.70	799.20	79.92	57.99	1.50	3.18	0.00	13.25	10.10	3.15	53.16	6.63
3	2	8	380.50	410.60	791.10	79.11	59.01	1.50	3.18	0.00	13.25	10.10	3.15	54.18	6.45
3	3	5	619.30	544.80	1164.10	116.41	73.79	1.50	0.26	0.00	14.06	10.37	3.68	71.35	8.39
3	3	6	602.50	509.90	1112.40	111.24	57.21	1.50	0.26	0.00	14.06	10.37	3.68	54.76	10.53
3	3	7	610.64	456.20	1066.84	106.68	54.49	1.50	0.88	0.00	12.45	8.99	3.46	51.65	11.21
3	3	8	622.00	480.30	1102.30	110.23	52.51	1.50	0.88	0.00	12.45	8.99	3.46	49.68	11.84
3	4	5	302.60	249.20	551.80	55.18	78.58	1.50	0.62	0.00	11.65	9.62	2.03	77.43	3.85
3	4	6	406.70	348.90	755.60	75.56	61.42	1.50	0.62	0.00	11.65	9.62	2.03	60.28	6.62
3	4	7	278.10	307.30	585.40	58.54	75.03	1.50	1.24	0.00	12.85	11.17	1.68	73.60	3.71
3	4	8	392.30	356.40	748.70	74.87	51.97	1.50	1.24	0.00	12.85	11.17	1.68	50.55	7.55

## 5.4 Conclusion

Results showed significant increases in yield and WP from season 1 to seasons 2 and 3. The conventional smallholder production system was low-yielding, while drip irrigation performed better than furrow irrigation for cropping of tomatoes. The 1<sup>st</sup> season results highlighted some of the key aspects why smallholder farmers in Giyani have low yields and low quality tomatoes. These aspects include i) cultivar selection, ii) soil fertility management, iii) irrigation management (scheduling) and system type (furrow systems) and iv) pest management and control.

With improvements in the above mentioned aspects, large yields and WP increases were obtained. Total yields increased from 26.34 t/ha (season 1) average to between 107.45 t/ha (season 3) and 120.87 t/ha (season 2) on average for the best performing treatments which were the fertilized plots. This marked an increase in total yield of between 407.93 - 458.88 % with the introduced innovations on the same farm.

WP also increased with the introduced innovations from 4.61 kg/m<sup>-3</sup> on average in season 1 to between 10.44 kg/m<sup>-3</sup> (season 3) and 17.69 kg/m<sup>-3</sup> (season 2) for the same farm. This marked a total average WP increase of between 226.46 and 383.73%. This result implied that the improvement in yield and fruit quality ensured the continued interest of the supermarket. This resulted in a positive economic result, impacting on all the households. The innovations also ensured much better use of the fresh water resources with less water loss through deep drainage, the result of better irrigation management and less surface evaporation from the soil when mulch treatments were used. Tomato production with Topacio cultivar, with the recommended fertilizer application based on soil analysis, is therefore recommended for smallholder farmers in Giyani to obtain high yields, and high WP. Mulching had an effect in water shortage conditions in terms of SWC storage and is therefore also recommended although it did not have a significant effect of yield or WP.

## **CHAPTER 6**

### **FARM-SCALE MONITORING USING MONQI**

#### **6.1 Introduction**

Smallholder agriculture in the Giyani area is mainly characterized by low yield and low crop productivity, especially for tomato production (Chikazunga, 2013). There are however little or no crop data available for the area with regards to crop yield, fertilizer usage, pesticide amounts and other inputs and outputs into their cropping systems. The majority of these farmers are not schooled and therefore record keeping of the inputs and outputs is one of the challenges this project faces. The result is that they have no success indicators in order to assess their production performance. Year after year they continue with conventional production practices and do not see improvements in yield or even notice changes in production. The result is a farming system that declines over time due to nutrient mining and ineffective management practices (Keating et al., 2010).

A methodology has been developed in order to assist with the monitoring of smallholder farms. This method is used to record all inputs and outputs of the farming system for smallholder farms and have been successfully implemented on smallholder farms across the world. The MonQI methodology was used to monitor farms in the Giyani area, aiming eventually to train the Department of Agriculture, Forestry and Fisheries' (DAFF) Extension Services Officers in the use of this technology to improve production in the region. The MonQI analysis was performed over 4 half year planting seasons on Mzilela farm. MonQI has a wide range of farm analysis calculations, but for this research the focus area was on farm productivity (crop yields) and macro-nutrient (N, P and K) balances. Nutrient balances were calculated in the MonQi software (van Beek et al., 2009), while P and K balances were also calculated from soil data in the last season's tomato production. This was done in order to compare the accuracy of the software calculations.

#### **6.2 Methodology and research design**

For the farm-scale assessment, the MonQI methodology was used to evaluate the farming practices on Mzilela farm. MonQI can be seen as a simple accounting system that accounts for every input and output into each one of the land activities (crop production sites) on the farm. Farmer involvement is the key to successful evaluation of the farming systems in order to identify problem areas in their production systems which will have a major impact on productivity and could lead to great yield improvements if they are properly solved.

The farm monitoring was done over a 2 and a half year period from 2011-2013. Table 6.1 shows the different seasonal monitoring periods on Mzilela farm. Yield, nutrients balances and net farm income (NFI) was calculated for every season.

*Figure 6.1: The periods, evaluations and parameters tested for MonQi monitoring on Mzilela farm from 2011 to 2013.*

Season (period)	MonQi monitoring	Parameters
1) Oct 2011 - March 2012	Evaluation of existing farm management practices	Yield, nutrient balances, net farm income
2) April 2012 - Sept 2012	Evaluation of continuing crop production, tomato trial and innovations evaluation	Yield, nutrient balances, net farm income
3) Oct 2012 - March 2013	Evaluation of continuing crop production,	Yield, nutrient balances, net farm income
4) April 2013 – Sep 2013	Evaluation of continuing crop production, tomato trial and innovations evaluation	Yield, nutrient balances, net farm income

In the first season of MonQi application, a comprehensive data collection was done which includes household data of every household member. This was done only in the first season, unless a household member was a born or passed away in the preceding years. The MonQi working approach, as summarized in a five step procedure, was conducted on Mzilela farm:

### **6.2.1 Data collection**

Information was collected using the MonQi questionnaires, seen in Appendix 1, during on-farm interviews after the harvest for each season was completed. The 16 farmers at Mzilela were interviewed in a group context in order to give each member a chance to speak and take part in the monitoring process. With the help of a Tsonga interpreter, the data was gathered. The aim of the data capturing is to gather all the input/output information for each land-use (cropping) area of the farm. This was done as accurately as possible and was sometimes a challenging task, especially considering that the farmers are uneducated. It was therefore very important to monitor what was happening on the farm during these production cycles, and to instruct the farmers how to record data effectively.

### **6.2.2 Background data**

Data obtained from the farm was then used in the MonQi 0.92 software package (copyright © 2012, Envista Consultancy). The background database (BGDB) is built into and maintained using the background data software in MonQi. The database contains all the

relevant items and products, as well as the characteristics (prices, calibrations, energies and nutrient contents) of each.

The BGDB stores farm specific data such as geographic area, soil types, meteorological stations data and land types. Also the data that was created stored in this database contains all farming input/output information such as household categories, crops and land uses, animal types, product types, crop products, animal products, fertiliser and manures, labour and services, animal inputs and other products. The site specific data that was needed for Mzilela farm in the BGDB was collected as follows.

- i) Meteorological data was received for the Masalale Packhouse (-23.70053 ° S, 30.78879 ° E, 420 mamsl) weather station, which is the closest weather station to the farm. This data was supplied by the Agricultural Research Council (ARC). The BGDB uses the monthly averages of rainfall (mm) and evapotranspiration (total relative ET in mm, calculated with Penmon-Monteith). These amounts were imported into the BGDB using the input software.
- ii) Land type data is described as the estimated value of that land in terms of production potential.
- iii) Soil type data was gained from various chemical and physical soil analyses, which was done at the Department of Soil Science, Stellenbosch University. An average for a planted area, for each of the parameters needed in MonQi, is illustrated in Table 6.2.

#### Soil physical parameters

Soil bulk density (BD) was determined using the core method in the first and the last season of monitoring. An average BD value was used when necessary for the other seasons'. A core of known volume were hit into the soil with a small hammer at 10 and 30 cm depths and carefully removed and sampled in order to calculate the mass of soil. The soil was then oven-dried at 105 °C for 24 hours after which it was weighed with a two decimal scale. The oven-dried mass were used to calculate the weight of soil per volume ( $\text{g/cm}^3$ ) and then converted to  $\text{kg/m}^3$  which was then used in the BGDB.

Soil particle size analysis was done using the standard pipette method (Gee & Bauder, 1986). Other clay content determinations were done using the 'feel method' during the soil classification process. Rooting depth, calculated as the average for vegetable crop depth, was taken as 50 cm.

#### Soil chemical characteristics

Total C and N percentages were determined by dry combustion method using the EuroVector instrument. Secondly, the basic cations such as Ca, Mg, Na and K as well as the Cation Exchange Capacity (CEC) was determined using the Ammonium Acetate (pH 7) extraction method with a 1:10 soil to extraction solution ratio.

Because of a wide range of pH values for different areas on the farm, the Mehlich no 3 extraction method was used to determine plant available P in mg/kg (Mehlich, 1984). This was done because of application of this extraction method for a wide pH range that includes acidic and alkaline soils. The ammonium-molybdate colorimetric method was used, with the Ultrospec III Spectrophotometer, to measure the absorbance at 660 nm wavelength. The USLE K factor was calculated as a factor of soil texture (Kassam et al., 1991).

*Table 6.2: Soil type input data required in the MonQI data entry software.*

Soil types inputs	Units
Bulk density	kg/m <sup>3</sup>
Rooting depth	M
Mineralization rate	ratio
Clay content	%
Soil organic carbon	%
Nitrogen total (N)	%
Phosphorous total (P)	%
Potassium total (K)	%
Cation Exchange Capacity (CEC)	cmol <sub>c</sub> /kg
USLE K factor	0.11-0.28 (sandy clay loam)
Enrichment factor	1

### 6.2.3 Data-entry

The information obtained from the questionnaires was entered into the farm database using the data entry module of the software. Automated consistency checking was performed on the datasets to make sure the inputs and outputs were correct. All input and output data was entered and checked.

### 6.2.4 Data processing and reporting

The Data Processing software is used to read the databases for a given number of farms, period and settings. Results are calculated, checked again and presented for export in structured output tables for further analysis and the drawing of result graphs.



## 6.2.5 Calculations

### i) MonQI software calculations

Nutrient balance, for each production unit, was modelled with the use of the MonQI software. N, P and K balances is calculated as the balance of the all inputs into and all outputs from every land activity. Some of these flow components are easy to quantify as it can be calculated from the farm and background data, while other flows are much harder to quantify. For the latter, the software uses transfer function. Figure 6.3 show the components of all the nutrient inflows and outflows. To study the nutrient balance transfer function calculations were outside the scope of this research project and therefore the different components and equation (as used in MonQI) is listed. These will only be mentioned and discussed briefly. Most of the transfer functions are built into the software package and the constant's that is used cannot be modified.

*Table 6.3: Nutrient balance calculation components of the different in- and outflow of N, P and K.*

NPK balance	nutrient inflows		nutrient outflows	
easy to quantify	IN 1	Mineral inputs	OUT 1	Harvested products
	IN 2	Organic inputs	OUT 2	Harvested crop residues
hard to quantify	IN 3	Atmospheric deposition	OUT 3	Leaching
	IN 4	Biological N fixation	OUT 4	Gaseous losses
	IN 5	Sedimentation	OUT 5	Erosion
	IN 6	Grazing	OUT 6	Grazing

IN 1 and 2, as well as OUT 1 and 2 from Table 6.3 is calculated from the weight amounts recorded for each season. The hard to quantify flows are calculated in the software program with the following equations:

$$(\text{Atmospheric deposition}) IN 3 = a \times \sqrt{\text{rainfall}} \quad (\text{Lesschen, et al., 2007}) \quad [4.1]$$

Where a, is the N content of precipitation constant (kg/mm) and for this study defined as 4.9 mm/kg.

$$(\text{Symbiotic biological deposition}) IN 4 = a \times \frac{\text{nutrients (harvestable crop parts)}}{\text{Harvest Index}} \quad [4.2]$$

$$(\text{Non – symbiotic biological deposition}) IN 4 = C1 + (C2 \times \sqrt{\text{rainfall}}) \quad [4.3]$$

Where C1 and C2 are equal to 0.5 and 0.1 respectively and cannot be changed in the software program (Lesschen, et al., 2007). OUT 3, which is the leaching out of the soil profile, is calculated for N and K since these nutrients don't have a high absorptive capacity,

as is the case for P. Leaching for N and K is estimated with the use of a transfer function (Lesschen, et al., 2007):

$$OUT\ 3\ (N) = 0.0463 + (0.0037 \times (\frac{rainfall}{clay\ (\%)/rootdepth})) \times (IN1(N) + IN2(N) + C:N \times N(org) - N(uptake)) \quad [4.4]$$

$$OUT\ 3\ (K) = -6.87 + 0.0117 \times rainfall + 0.173 \times (IN\ 1(K) + IN2(K)) - 0.265 \times CEC \quad [4.5]$$

Denitrification and volatilization are the main processes for gaseous N emissions. Gaseous losses using transfer functions on clay fraction, fertilizer inputs, mineralization and precipitation:

$$OUT\ 4 = 0.025 + 0.000855 \times rainfall + 0.117 \times IN1\ (Nut) + IN2\ (Nut) + e * CEC \quad [4.6]$$

Erosion is extremely difficult to estimate and MonQI uses the generally accepted universal soil loss equation (USLE). This approach provides reasonable estimates.

$$OUT\ 5\ (NPK) = NPK(soil) \times R \times K \times S \times L \times C \times P \times enrichment\ factor \quad [4.7]$$

Where R=rainfall erosivity, K=soil erodibility, S=slope gradient (%), slope length (m), C=crop factor and P= soil conservation measures.

### NPK field calculations

In the final season of MonQI monitoring, the P and K balances of the 2<sup>nd</sup> season WP trial were calculated (chapter 5). Soil samples were taken before planting and after harvest, in order to calculate the P and K balances for each of the different treatment plots. Unfortunately, the plant available N was not analysed, but rather total N (%) and this measure could not be compared to the N-balance of the MonQI data. The plant available P and K was analysed and subsequently the P and K balance were calculated from the soil chemical analysis data. Plant available P and K were analysed and given in mg/kg soil for a given sample. Soil sampling was done at 0-20, 20-40 and 40-60 cm depths and these represented the total volume of soil used for the tomato production. The P and K mg/kg soil values were converted to kg/ha for the total area. Each soil sample represented a relative value for the planted treatment of 100 m<sup>2</sup>. The layer depth then represented a total volume of 20 m<sup>3</sup> for each soil sample. The sum of these represented the total volume of 60m<sup>3</sup> for a specific treatment area. The MonQI estimation, as well as the calculated P and K balances, was converted to t/ha in order to effectively compare these values.

$$Balance, mg/kg\ (P, K) = soil\ P, K\ (after\ harvest) - soil\ P, K\ (before\ planting) \quad [4.8]$$

After the P and K balance (mg/kg) was calculated, the values were converted by the use of the site specific bulk density as seen in equation 4.9:

$$\text{Soil weight (kg/layer)} = \text{BD (kg/m}^3\text{)} * 20 \text{ m}^3 \text{ (area represented)} \quad [4.9]$$

$$P, K \text{ (kg/layer)} = (P, K \text{ (mg/kg)} / 1 \times 10^{-6}) \times \text{soil weight (kg/layer)} \quad [4.10]$$

$$P, K \text{ Balance (kg/area)} = P, K (0 - 20\text{cm}) + P, K (20 - 40\text{cm}) + P, K (40 - 60\text{cm}) \quad [4.11]$$

$$P, K \text{ Balance (kg/ha)} = P, K \text{ (kg/area)} / 0.01 \text{ ha}$$

## 6.3 Results

### 6.3.1 BGDB Results

The specific soil parameters, as needed in the BGDB, were used in the software as seen in Table 6.4. The monthly weather data was also inserted into the software as the monthly rainfall and ET amounts. This is summarized in Chapter 3, Table 3.3.

*Table 6.4: Summary of the BGDB soil analysis results as used in MonQI for Mzilela farm.*

MonQI season	bulk density (kg/m <sup>3</sup> )	rooting depth (m)	Clay (%)	C (%)	N (%)	C:N	P (%)	K (%)	CEC (cmol(+)/kg)
1	1420.54	0.5	17	0.17	0.04	4.25	0.0034	5.30	9.18
2/3	1420.54	0.5	18	0.92	0.07	13.74	0.0011	3.96	9.66
4	1345.32	0.5	17	1.02	0.12	8.54	0.0014	5.91	10.87
4	1398.74	0.5	17	1.06	0.10	10.12	0.0028	4.08	12.01
4	1443.37	0.5	17	0.95	0.05	18.89	0.0009	4.22	10.78
4	1395.62	0.5	17	1.18	0.05	24.01	0.0016	5.07	11.39
4	1472.78	0.5	15	0.70	0.05	14.79	0.0005	4.68	7.04
4	1519.80	0.5	15	0.69	0.07	9.68	0.0006	3.14	7.75
4	1438.86	0.5	15	0.93	0.08	11.63	0.0005	2.44	6.67
4	1455.75	0.5	15	0.84	0.07	12.28	0.0005	2.60	6.14

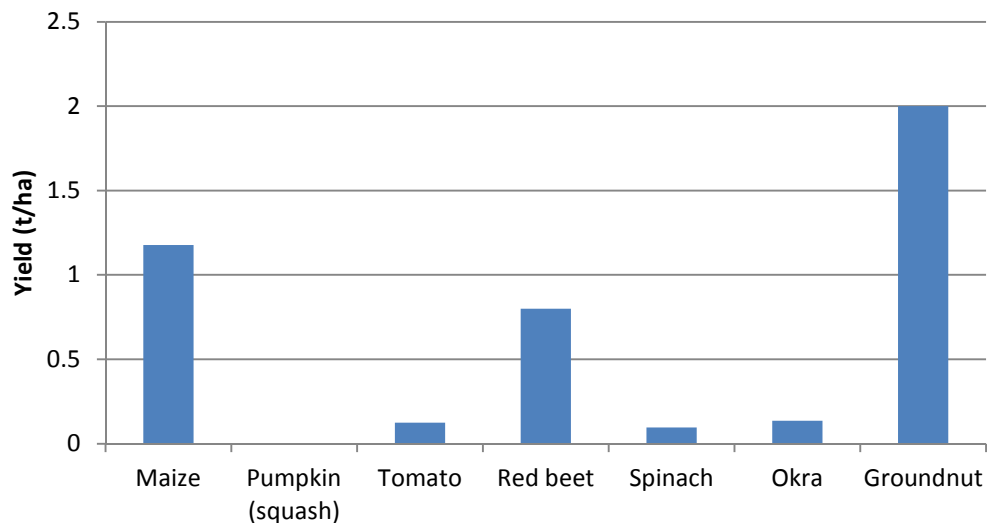
Farm productivity and yield results were gathered and analysed over 4 seasons at Mzilela. Most of the values given by farmers were given in terms of money made from the sales of crop products. The produce which was consumed by the farmers and their household members were not included in the analysis in terms of cost, but was accounted for in terms of yield amounts. All yield amounts that was reported were converted to t/ha by doing a simple conversion in order to see basic productivity of that crop. All plots were irrigated with

a standard drip system, except for some of the maize production sites, which was done by dry land production.

### 6.3.2 Season 1 (Oct 2011 - March 2012)

#### Crop Productivity

Yield data for season 1, as shown by Figure 6.1, gives the average yield for each of the planted crops. In the first season, a wide variety of crops were planted at Mzilela which included a new citrus planting of about 0.1 ha. The yield values show very low yields for most of the crops planted. The low yield for pumpkin squash and tomatoes were caused by a very rarely occurring hail-storm on the farm, which meant that both crops were almost entirely lost.



*Figure 6.1: All crops and harvested yields for season 1 at Mzilela farm.*

Red beetroot, spinach and okra yielded very low and all were below 1 ton/ha. These yields are very low especially considering that all of these crops were irrigated with drip irrigation. The main reason for low productivity was found when the soil nutrient input history was made known by the farmers. The Mzilela farmers said that they have not used any soil nutrient inputs, not fertilizer or organic inputs, since 2009. These crops were all planted in the area located close to the small farm house and the two boreholes, which is cropped intensively every year. The soils are mostly mined from macro nutrients with soil N, P and K below optimum levels for standard crop production (see Appendix 1). Subsequently, the crop growth is very poor and the yield, as well as the produced product quality, remains very low. The maize and groundnut production yield was slightly higher with 1.17 t/ha and 2 t/ha respectively. The maize was also irrigated with drip irrigation.



Figure 6.2: Maize production field (left) and remaining harvested maize cobs (right) at Mzilela farm.

### Nutrient Balances

Results for nutrient balances for the different cropping systems showed some reasons for concerns because of high negative balances, which showed soil nutrient mining, especially because no fertilizer or any soil nutrient inputs was made since 2009. Figure 6.3 show that all crops, except tomatoes, had negative NPK balances. Pumpkin squash was not harvested and thus displays a zero balance and very little tomatoes were harvested because of many fruits being damaged by the heat-wave. Red beetroot had the highest negative N balance, while all the remaining crops had negative balances of between -40 to 0 kg/ha. These values are on par for the nutrient removal for the planted crops.

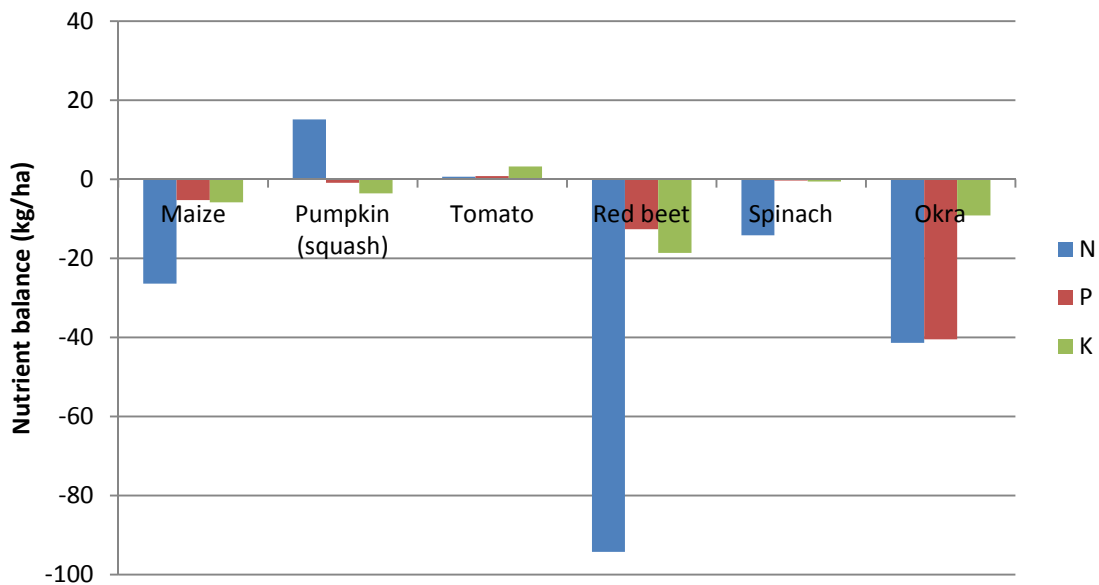


Figure 6.3: NPK Balances for all crops produced during season 1 on Mzilela farm.

### 6.3.3 Season 2 (April 2012 - Sept 2012)

#### Crop Productivity

In the 2<sup>nd</sup> season, the first WP tomato experiment was conducted at Mzilela and was included in the MonQI monitoring of season 2. The winter planting season was very dry and received almost no rain. The farmers only planted 3 crops during this period and used borehole irrigation water. Figure 6.4 (left) shows the yields for season 2 and it is important to note that both the maize and okra crops were lost due to drought and improper irrigation management. The only other crop planted was the tomato trial which was managed well. The harvested tomato yield increased greatly compared to season 2. The recorded tomato yield average was 30.8 t/ha and these fruits were sold to the Spar in Giyani.

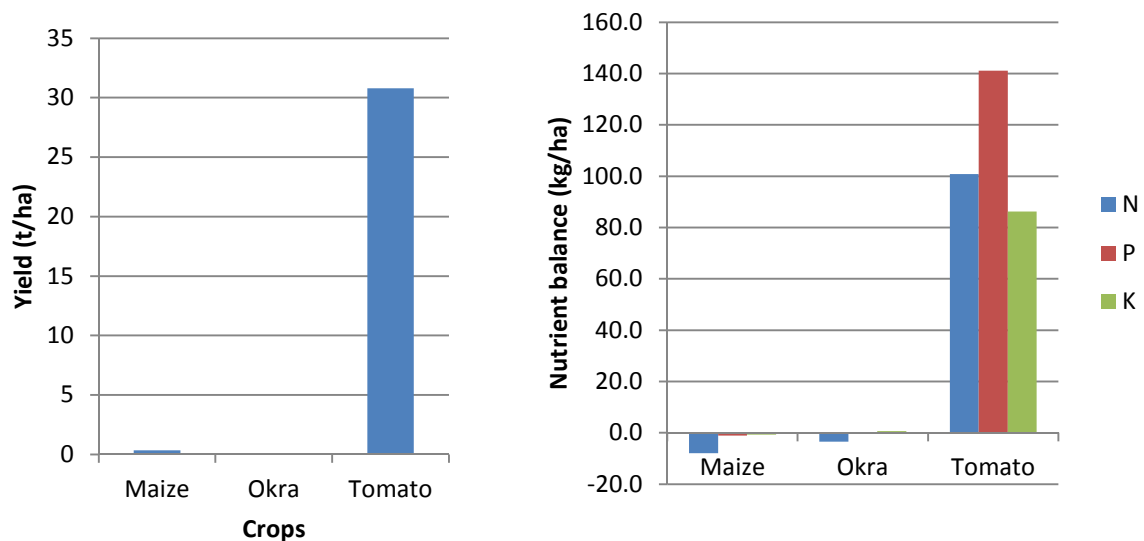


Figure 6.4: Yield (left) and NPK Balances for season 2 on Mzilela farm.

#### Nutrient Balances

The NPK-balances, as seen in Figure 6.4, illustrates the negative balances for maize and okra. No soil nutrients were added to these crops and therefore very little crop was harvested and subsequently nutrient were still removed from the system. It was confirmed that the produce was fed to their cattle. The nutrient balances for the tomato trial had positive values for N, P and K. The tomato trial received a basic soil nutrient application and thus the increases in the macro nutrient balances. These positive balances can be ascribed to the fact that the plot was fertilized, and also because the crop did not yield very high and therefore relatively small amounts of N, P and K was removed through the harvesting of the fruits.





Figure 6.5: Smallholder farmer, Lizzy Matsimbye (right), standing with a bag of harvested tomatoes and the tomato trial field (left) of season 2 at Mzilela.

### 6.3.4 Season 3 (Oct 2012 - March 2013)

#### Crop productivity

Five crops were planted in season 3 which included maize, cabbage, sweet potato, spinach and red beetroot. Yields (Fig 6.5) were very low and for maize and red beetroot no crop were harvested. A heat-wave, coupled with insufficient irrigation, was the contributing factors resulting in crop losses and low yields. No fertilizer application also resulted in small plants which subsequently yielded very low. Spinach and cabbage had low yields, while the sweet potato performed best with a yield of 3.7 t/ha.

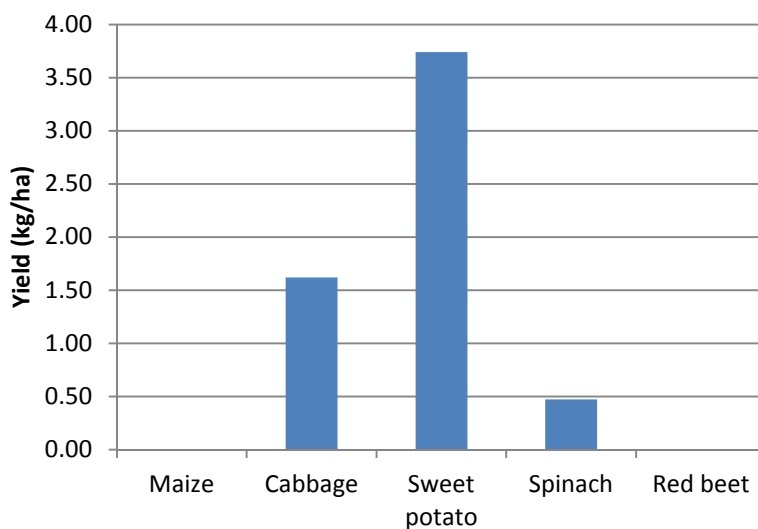


Figure 6.6: Yield (left) and NPK Balances for season 3 on Mzilela farm.

#### Nutrient Balance

With the recorded yields for season 3 being low, the subsequent N and P balances displayed fairly low negative values. The K balance for all crops showed large negative balances. The negative K-balances for spinach was quite large, while all other balances showed smaller negative balances between -11 to 2 kg/ha.

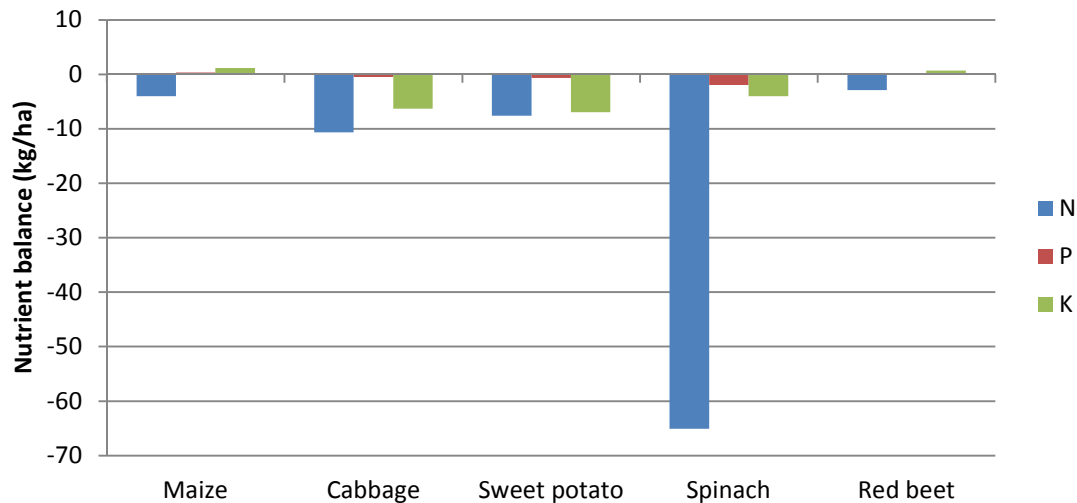


Figure 6.7: NPK Balances for the 3rd season crops at Mzilela farm.

The maize production, without any fertilization, were characterised by very small maize plants (at harvest) as seen in Figure 6.8. At full growth, these plants were approximately 50 cm in length with most plants having none, or very small cobs to harvest. These cobs were fed to the cattle. Although the maize was irrigated with drip irrigation, the farmers did not harvest any maize cobs for food or to sell. Some of the plant stems were very weak and was bent over due to insufficient strength to carry the upper parts of the plant. Considering that the maize cobs and maize-meal are the staple food for these households, this shows the challenges with regards to food security that they face.



Figure 6.8: 3rd seasons maize plants at harvest on Mzilela farm.

### 6.3.5 Season 4 (April 2013 – September 2013)

#### Crop Productivity

The 4<sup>th</sup> and final MonQI monitoring season included the two main tomato production trials for the WP research study. Chapter 5 describes the tomato production trials in detail. The MonQI planted areas for tomatoes were separated according to the different treatments of the WP trial. The farmers also planted another piece of land with a different tomato cultivar compared to the trial tomatoes, while spring onions were also cropped. The yields, as shown in Figure 6.9, were substantially higher than any of the previous season's tomato yields.

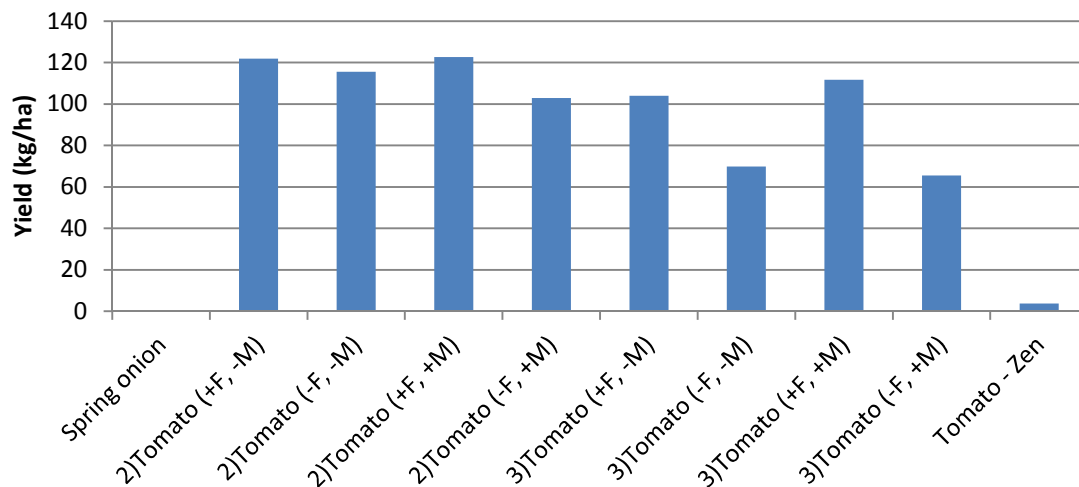


Figure 6.9: Yield results for season 4 at Mzilela farm. 2 and 3 represents the season number according to the tomato WP trial (see chapter 5), where (F, -M): treatment 1, fertilizer added and not mulched; (-F, -M): treatment 2, no fertilizer added, not mulched. (F, M): treatment 3, fertilizer added and mulched. (-F, M): treatment 4, no fertilizer and mulched.

Spring onions yielded no harvest, while the tomato (Zen variety) plot, planted by the farmers, yielded very low with 3.74 t/ha. The WP trials tomatoes yielded substantially higher, with the fertilized treatments yielding over 100 t/ha. This marked a large yield increase and was achieved through better cultivar selection and improved irrigation management (see chapter 5). It was interesting to see the difference between the trial tomatoes and the farmers' planted tomatoes. The same management practices were done on both, but the crop growth and subsequent yield was very different. This shows what a great effect the cultivar selection can have on crop yield. The Topacio cultivar seedlings (WP 2 and 3) were almost double the price of the other cultivars that the smallholder farmers normally purchase, costing approximately R1.20 and R0.40 respectively. The larger input cost for a better performing cultivar is the main reason that smallholder farmers continues to plant the low yielding cultivars.

## Nutrient balances

Nutrient balances for season 4 showed negative balances for the crops planted by farmers. The WP trial treatments of added fertilizers, as seen in Figure 6.10, showed positive P and K balances of between 0-120 kg/ha. The non-fertilized WP trial plots showed negative balances for N and K, while all the WP trial sites showed large negative N balances. This is mainly because the tomato plants were removed after harvest so that pest and diseases did not spread. The two unfertilized treatments of WP season 2 had the highest negative N balances and this can be ascribed to the fact that no N were added, yet fairly large yields were harvested and subsequently large N nutrient removal.

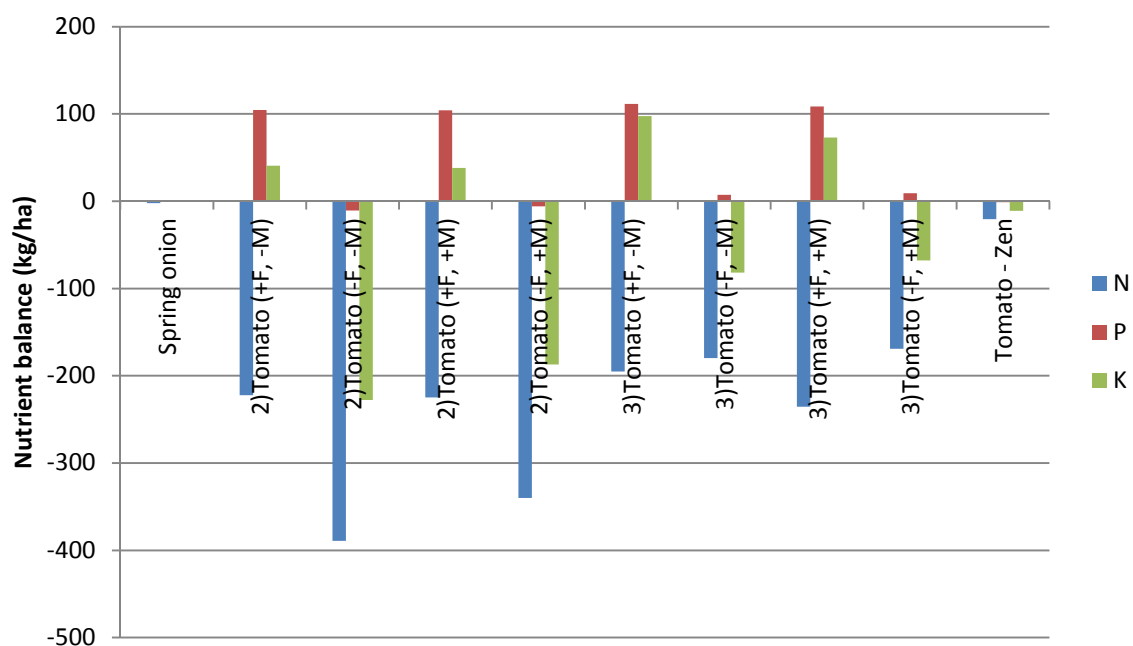


Figure 6.10: NPK Balances for the 4th season crops at Mzilela farm, where (F, -M): treatment 1, fertilizer added and not mulched; (-F, -M): treatment 2, no fertilizer added, not mulched. (F, M): treatment 3, fertilizer added and mulched. (-F, M): treatment 4, no fertilizer and mulched.

## Soil sample P and K nutrient balance compared to Monqi estimations

The 2<sup>nd</sup> WP season plots were used to compare the P and K nutrient balances, according to soil analysis, to the MonQI estimations. The P balance comparison, as illustrated in Figure 6.11, shows that the MonQI estimations and the soil derived balances had the same trend. The fertilized treatments had positive balances, while the unfertilized treatments had negative P balances. The soil derived P balance was smaller compared to the MonQI

estimations for all 4 treatments. Overall, the P balance was fairly accurately estimated in MonQI.

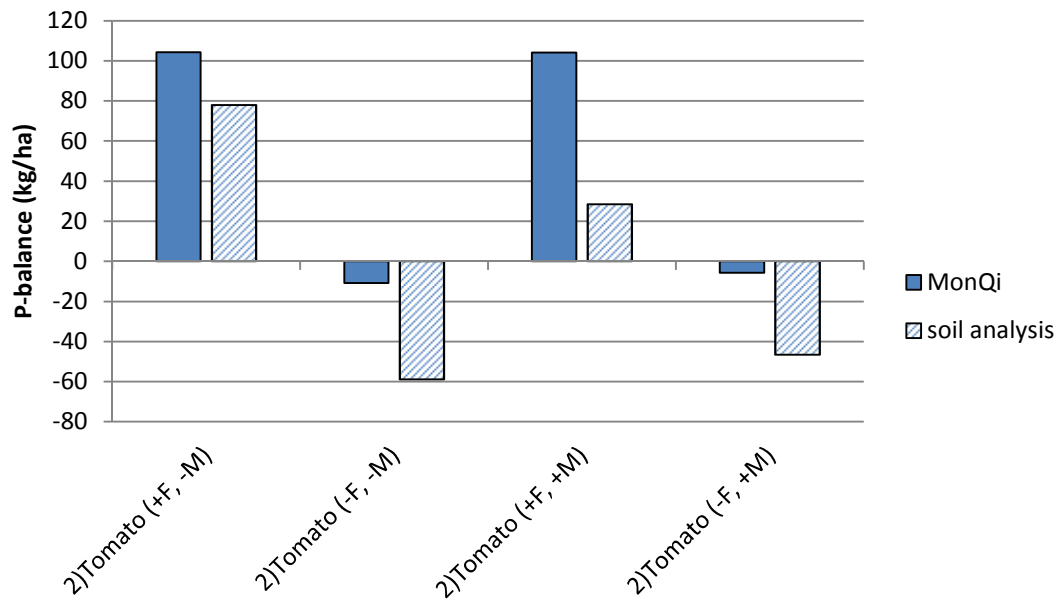


Figure 6.11: P-balances for the 2nd WP trial of season 4 at Mzilela farm, where (F, -M): treatment 1, fertilizer added and not mulched; (-F, -M): treatment 2, no fertilizer added, not mulched. (F, M): treatment 3, fertilizer added and mulched. (-F, M): treatment 4, no fertilizer and mulched.

The K balances were in the same range for the unfertilized treatments, while for the fertilized treatments the MonQI estimation was larger compared to the soil derived balances. The difference can be ascribed to the fact that soil sampling may not have been representative of the whole treatment plot and therefore yielded larger balances.

When looking at both the P and K balance results between estimated and the observed, the MonQI is a fairly accurate estimator of soil nutrient balances.

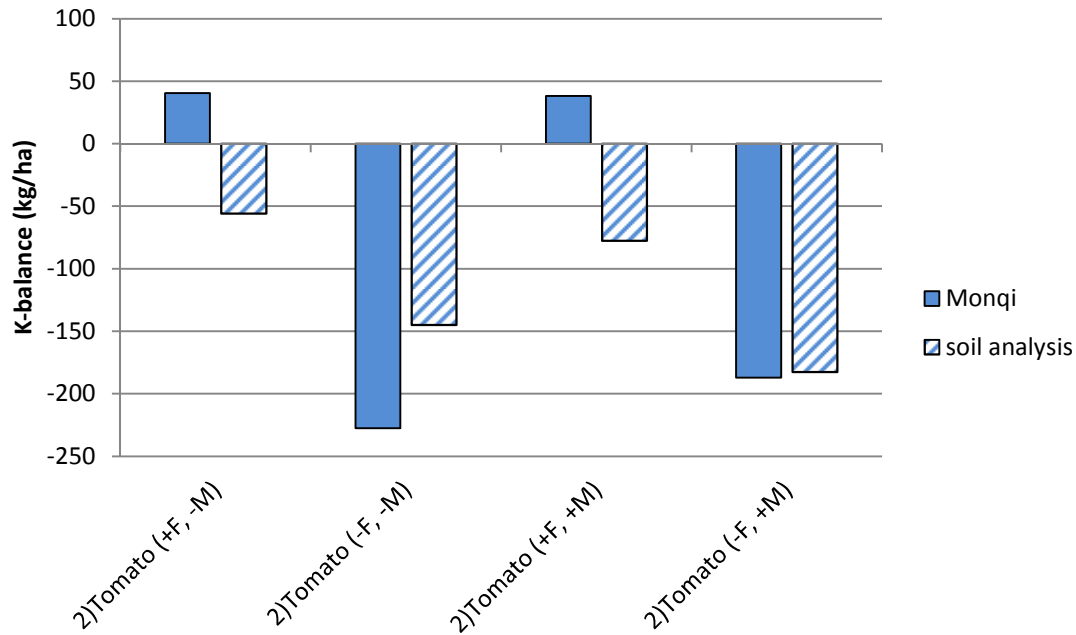


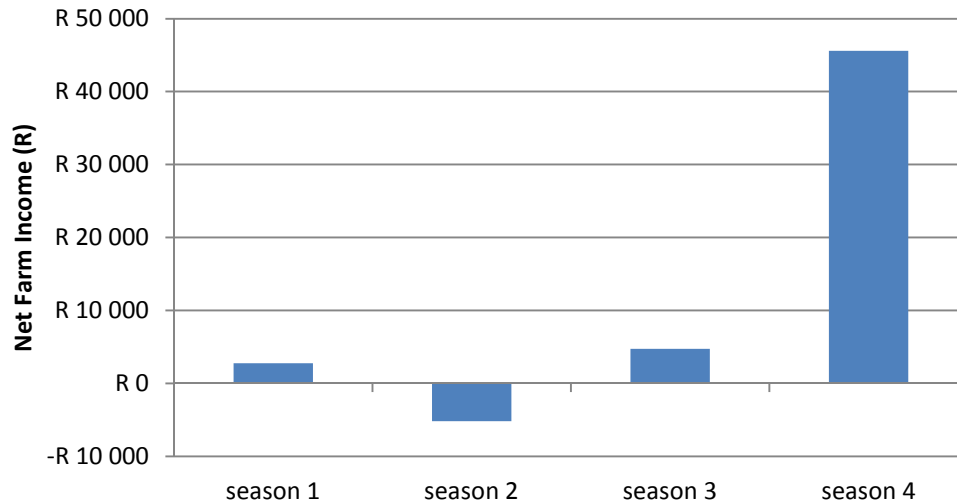
Figure 6.12: K-balances for the 2nd WP trial of season 4 at Mzilela farm, where (F, -M): treatment 1, fertilizer added and not mulched; (-F, -M): treatment 2, no fertilizer added, not mulched. (F, M): treatment 3, fertilizer added and mulched. (-F, M): treatment 4, no fertilizer and mulched.

### 6.3.6 Combined results

#### Financial indicators

The financial return (profit/losses) to the farmers was calculated to see if the crop production per season was adding to the household income. Farm income results showed fairly small profits were made for season 1 and 3 over the respective 6 months periods. The NFI of season 1 was very low with R2768 and R4740 was made in season 3. Season 2 showed a total loss of R-5176 and this was mainly because of low yield and crops being destroyed by heat-waves.





*Figure 6.13: Net farm income for each season on Mzilela farm*

NFI result for season 4 showed a substantial improvement with a total of R42486 made over 6 months. This marked a NFI increase of more than 800% from season 1 to 3. The reason for the great financial return was the high productivity of the WP tomato trials, with the subsequent fruits being sold to the Spar in Giyani for a good, market related price. The NFI was further increased by the high demand for the B-grade tomatoes, which was sold in the local village. The people in the village were very impressed with the long-shelf-life tomatoes, and were willing to buy them.

The benefit from the great increase in NFI was further highlighted when the irrigation pump broke during season 4. The farmers could buy a new pump shortly after the old pump was deemed unable to be fixed. Normally when such a breakdown occurs, the farmers do not have the financial means to solve the problems and therefore it may take weeks or even months to fix. The financial gains from the tomato production also inspired farmers to order and plant their own tomatoes, based on the management style they learnt from the WP trial sites. These are currently being sold to the Spar at good prices and more income is coming into the households at Mzilela.

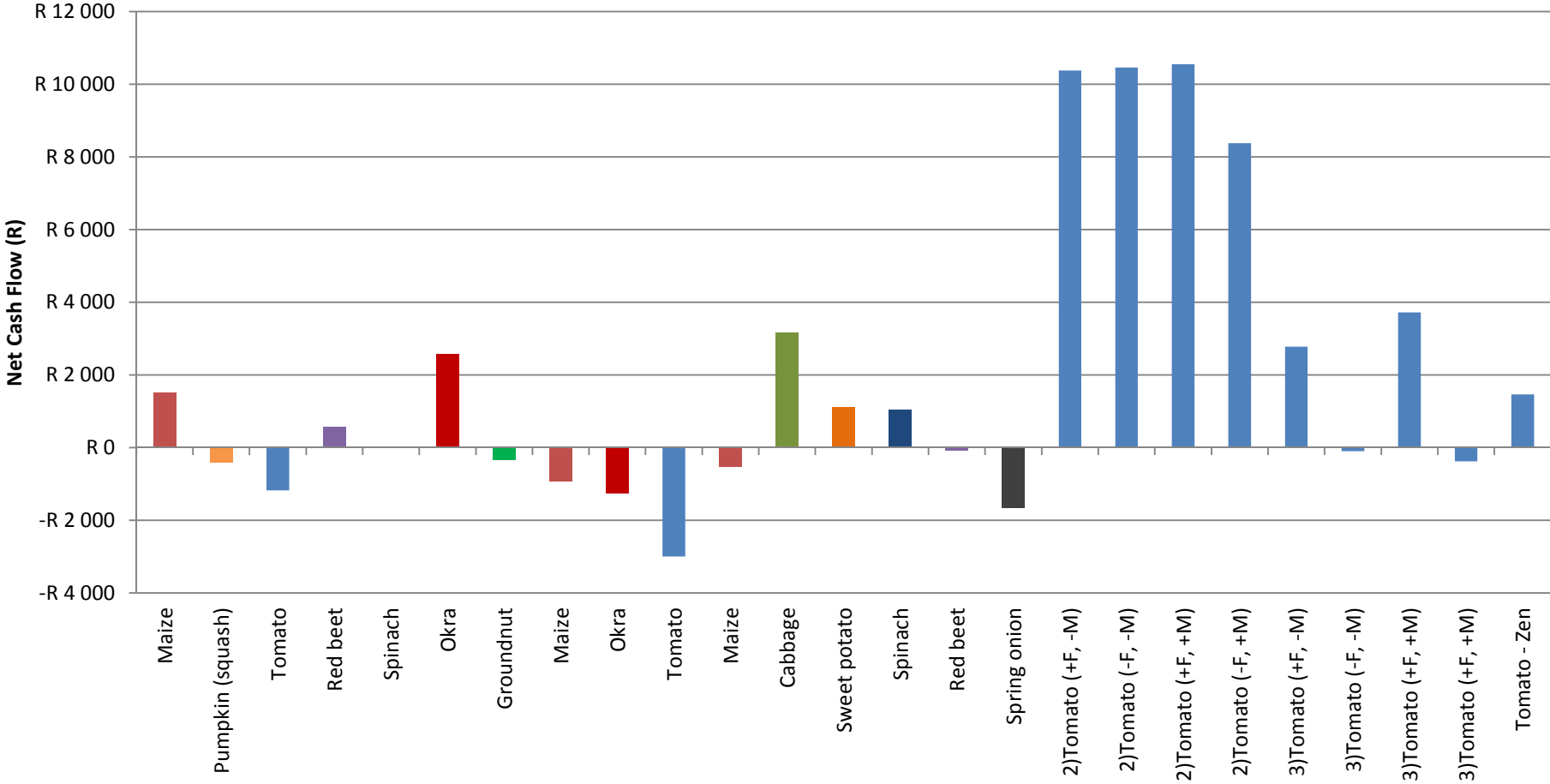


Figure 6.14: NCF per planted crop for the four seasons at Mzilela farm.

When the cash return per crop is evaluated as seen in Figure 6.14, the results show little income from the cropping of the 1<sup>st</sup> 3 seasons. Only okra and cabbage showed net cash return larger than R2000, while maize (season 1), red beetroot, sweet potato and spinach had returns smaller than R2000 per crop. All other crops planted at Mzilela, except the tomato production showed negative return values.

#### **6.4 Conclusion**

Farm productivity in terms of yield was very low for most of the crop production during season 1, 2 and 3. Many factors contributed to the low yield which includes the use of conventional farming practices, no fertilizer addition to the soil, poor pest control and extreme weather events. The NPK balances, as estimated in MonQI showed negative values for most crops which show the nutrient mining effect from continuous cropping without any nutrient application. When fertilizer was applied, and the best cultivar was selected, the crops performed better in terms of yield and financial return.

Season 4 showed a remarkable increase in productivity due to the WP trial sites. This increase affected the financial return into these households substantially. We conclude that smallholder farming can be profitable when farm management practices improve. With better cultivar selection and sufficient soil nutrient inputs the crop product, the crop product can be up to the quality standard required by the supermarket and therefore can be sold at a good price for extra household income.

## CHAPTER 7

### CONCLUSION

#### 7.1 Conclusion

Soil and water resources must be used more efficiently and also more productively if future global food needs are to be met. The aim of this study was to work with smallholder farmers in order to implement innovations for improved farm productivity (yield) and WP at field-scale. Three research themes were studied, which included NIR spectroscopy as a possible soil nutrient management tool, WP increases with fertilizer and mulch treatments and farm monitoring throughout the research period using MonQl. Two farms in the Giyani area, namely Zava and Mziela, were selected for research in order to gain valuable information regarding production challenges in the former homeland area of the Limpopo Province.

Smallholder farmers in the Giyani area are in need of a cost-effective and speedy soil chemical analysis, which will aid in soil nutrient management on farm level. NIR spectroscopy and chemometrics was studied as a possible replacement for expensive soil chemical characterization done in soil laboratories. 159 soil samples from Mzilela was used to calibrate and separately validate NIR scan's ability to predict various soil chemical properties used in fertilizer requirement calculations. Results showed impressive prediction models for pH, EC, P, K, Mg, Na and CEC, with  $R^2$  values greater than 0.60 and RPD values larger than 1.4. Only Ca yielded poor predictability, with a  $R^2$  value of 0.44. Results of all the main soil chemical properties, except Ca, yielded good to excellent models for prediction (Bellon-Maurel, et al., 2010; Mashimbye, 2013). Therefore this study concludes that NIR spectroscopy can effectively be used in smallholder agriculture as a replacement for the expensive laboratory soil tests. A 60% accurate fertilizer requirement is far better than not having any means of fertilizer requirement calculation.

In order to improve the productivity of the water used to produce their crops, WP needs to be improved at farm level. The aim of the study was to improve WP, which would also lead to improved yields. Different farm-scale management practices, such as irrigation method, irrigation scheduling, fertilizer application and mulching, were evaluated and tested. In the 1<sup>st</sup> season, evaluation of the current conventional farming practices used for tomato production on both farms, were tested. The results confirmed that smallholder produce are very low and of poor quality. Ineffective irrigation management, as well as ineffective soil nutrient management and also the cultivar selection choice were among the main reason for poor performances. Drip irrigation performed better than furrow irrigation in terms of yield and WP. The average tomato yield on both farms was below 32 t/ha for their conventional smallholder production systems in season 1. Improvements in cultivar selection and

management in term of irrigation and soil nutrient application, the yield and WP were greatly increased in season 2 and 3. These improvements led to yield and WP increases of between 350-450%. Fertilizer application significantly increased crop yield and WP, while the mulch treatments did not. Mulching was more beneficial when water became a limiting factor. Fertilized treatments generally had larger canopies as LAI results indicated. The study concludes that there are great prospects for yield and WP improvements in the former homeland areas. These improvements will not only save more water and results in more food produced for their households, but the extra produce can now also be sold as a source of extra income.

The monitoring of smallholder farms is essential in order to improve management at farm level. The MonQI methodology was applied throughout the study period and results revealed that the yields for conventional smallholder farming were very low. Weather events, such as hail and heat-waves, are placing many farming households at risk when food crops are lost. Nutrient mining, as estimated in MonQI, showed that farmers at Mzilela is mining the soil from its nutrients, with most of the production sites having negative NPK balances. With the subsequent low yields due to no fertilizers being applied, the amount of food and extra income into the 16 representative households remains low. With the tomato production introduced through the WP trial sites, yields and income into the farm improved greatly. With proper fertility management of the fertilized treatments and fertilizers being applied as required based on soil samples, the NPK balances improved remarkable. MonQI NPK estimates proved to be in the same ranges when compared to soil derived NPK balances.

## 7.2 Future Research and recommendations

NIR technology for soil chemical characterization for smallholder farmers needs to be further explored and studied in order to improve the application thereof. A possible method for model improvements can be achieved by grouping soils into main soil forms and top or subsoil samples. A possible drawback of the study was that the soil samples were possibly not grounded finely enough, which may have caused scattering in the scans and may have affected prediction results. To increase the number of scans per sample could also have improved the prediction models. Due to time limitations and access to the equipment, these model improvement possibilities were not further explored. A controlled trial on tomatoes yield with treatments of no fertilizer added and treatments with fertilizer requirements calculated with both standard soil chemical results and NIR predicted results could aid in showing how this technology may increase production. If this method is further developed and implemented for smallholder farmers, large production increases may be achieved.

Future research is needed in the smallholder agricultural sector in order to improve the productive use of water and to increase yields. More transdisciplinary research is needed in the former homeland areas in order to introduce more farmer-accepted innovation, which will continue after the research project is completed. This remains a massive challenge in these areas. If yields and WP can be sustainably increased, food security among resource poor farmers will surely be improved.



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**APPENDIX 1**

Table A1: Selected soil profile description at Mzilela. Profile number 6.

<i>Profile number:</i>	<i>6</i>	<i>Aspect:</i>	<i>North</i>
<i>Lat/Long:</i>	<i>-23.590904 S/30.81772 E</i>	<i>Terrain unit:</i>	<i>Crest</i>
<i>Soil form:</i>	<i>Hutton 2200</i>	<i>Altitude:</i>	<i>430</i>
<i>Soil family:</i>	<i>Suurbekom</i>	<i>Surface coarse fragments:</i>	<i>5-10 %</i>
<i>Slope:</i>	<i>2%</i>	<i>Wetness:</i>	<i>none</i>
<i>Slope form:</i>	<i>Convex</i>	<i>Crop:</i>	<i>Maize</i>

Horizon	Depth (mm)	Description	Diagnostic horizon/material
A	0-200	Dry; dry colour: red 10R 3/3; structure: structureless; consistence: loose, slightly firm; loamy sand; common gravel 2-5mm	Orthic
B1	200-400	Dry; dry colour: red 10R 4/8; structure: structureless; consistence: loose, slightly firm; sandy loam; common gravel 2-7mm	Red apedal
B2	400-700	Dry; dry colour: red 10R 4/8; structure: structureless; consistence: loose, slightly firm; sandy loam; common gravel 2-50mm; 20-50 % coarse fragments	Red Apedal
C	700-	-	Unspecified

Table A2: Selected soil profile description at Mzilela. Profile number 5

<i>Profile number:</i>	5	<i>Aspect:</i>	South east
<i>Lat/Long:</i>	-23.59144S/30.81957E	<i>Terrain unit:</i>	Crest
<i>Soil form:</i>	Oakleaf 1220	<i>Altitude:</i>	434
<i>Soil family:</i>	Dipene	<i>Surface coarse fragments:</i>	5-8%
<i>Slope:</i>	2%	<i>Wetness:</i>	None
<i>Slope form:</i>	Concave	<i>Crop:</i>	Citrus

Horizon	Depth (mm)	Description	Diagnostic horizon/material
A	0-100	Dry; dry colour: brown to pale brown 7.5YR 5/2; structure: loose structureless; consistence: loose, slightly firm; sandy clay loam; common gravel 2-7mm	Orthic
B	100-400	Dry; dry colour: brown to pale brown 7.5YR 3/2; structure: weak subangular blocky; consistence: firm; sandy clay loam; common gravel 2-7mm	Neocutanic
C	400-	-	Unspecified

Table A3: Texture analysis of WP season 1 sites at Zava and Mzilela.

Sample	Sand (%)	Silt (%)	Clay (%)	Texture class
ZV-p1s1	69	18	13	loam sand
ZV-p1s1	69	16	15	loam sand
ZV-p1s1	63	15	22	sandy loam
ZA-p2s1	64	26	10	sandy loam
ZA-p2s1	68	21	11	sandy loam
ZA-p2s1	60	17	23	sandy loam
ZA-p3s1	67	15	17	loamy sand
ZA-p3s1	57	13	30	Sandy clay loam
ZA-p3s1	57	12	31	Sandy clay loam
MZ-p1s1	71	17	12	loamy sand
MZ-p1s1	72	15	13	loamy sand
MZ-p1s1	67	14	19	loamy sand
MZ-p2s1	69	17	14	loamy sand
MZ-p2s1	63	20	18	sandy loam
MZ-p2s1	60	16	23	sandy loam

Table A4: Soil chemical analysis for WP season 2 before planting at Mzilela.

plot	depth (cm)	lab nr	% rock	pH (KCl)	C	N	C:N	EC (mS/m)	P	K	Exchangeable cations (cmolc/kg-1) (1:10)				Σ sum of basic cations (s-value)
											Ca	Mg	Na	K	
1A	10	1	7	6.96	0.98	0.15	6.31	11.81	117.47	361.19	6.61	4.69	0.17	0.93	12.39
1A	30	2	23	6.84	0.80	0.13	6.05	6.73	10.86	310.72	4.72	4.73	0.34	0.80	10.59
1A	50	3	40	6.77				3.52	9.16	343.54	4.31	3.89	0.36	0.88	9.45
1B	10	4	8	7.51	0.82	0.11	7.57	5.94	56.07	372.07	5.42	4.21	0.17	0.95	10.76
1B	30	5	12	7.64				4.63	44.12	287.28	5.14	3.50	0.14	0.74	9.51
1B	50	6	15	7.63				4.96	30.48	198.50	3.61	3.37	0.12	0.51	7.60
2A	10	7	9	7.4	0.91	0.10	8.65	5.55	54.05	196.01	3.89	4.68	0.20	0.50	9.28
2A	30	8	22	6.83				10.18	69.40	115.11	2.74	4.10	0.28	0.30	7.42
2A	50	9	41	6.58				13.94	71.96	114.31	2.62	4.25	0.38	0.29	7.54
2B	10	10	6	7.23	1.01	0.11	9.08	12.75	81.76	261.74	3.67	3.85	0.21	0.67	8.40
2B	30	11	12	7.23				4.97	32.72	198.50	5.83	6.04	0.56	0.51	12.93
2B	50	12	15	6.97				13.38	22.06	275.51	5.79	5.61	0.70	0.71	12.81
3A	10	13	7	7.03	1.26	0.13	9.95	8.61	29.31	163.89	6.08	5.72	0.27	0.42	12.50
3A	30	14	24	6.82				3.17	18.22	245.08	5.82	5.15	0.32	0.63	11.92
3A	50	15	49	6.77				3.97	11.83	258.55	5.59	5.22	0.36	0.66	11.84
3B	10	16	8	7.34	1.02	0.09	11.60	4.31	51.49	232.72	7.07	5.82	0.11	0.60	13.59
3B	30	17	16	6.99				3.07	13.53	122.29	4.80	5.40	0.12	0.31	10.63
3B	50	18	26	6.76				3.76	22.06	112.62	4.54	4.68	0.16	0.29	9.67
4A	10	19	9	7.06	0.78	0.07	11.87	3.75	20.78	153.02	4.77	5.03	0.20	0.39	10.39
4A	30	20	17	6.5				10.38	8.42	107.43	5.09	5.76	0.42	0.28	11.55



4A	50	21	76	6.17				15.19	5.86	137.85	5.12	5.63	0.51	0.35	11.61
4B	10	22	10	7.46	1.55	0.14	11.24	5.91	303.94	337.45	11.72	5.94	0.10	0.87	18.62
4B	30	23	22	7.45				5.67	124.41	197.50	9.74	5.90	0.27	0.51	16.41
4B	50	24	65	7.32				7.63	149.14	196.51	10.41	5.81	0.40	0.50	17.12
5A	10	25	7	7.31	0.76	0.06	13.04	9.24	26.33	180.25	5.91	4.78	0.21	0.46	11.36
5A	30	26	11	7.4				5.06	14.81	181.94	4.75	4.18	0.16	0.47	9.56
5A	50	27	31	6.84				9.84	7.56	185.73	5.11	4.45	0.36	0.48	10.39
5B	10	28	8	7.41	0.95	0.05	17.44	4.57	37.84	265.43	6.36	3.98	0.07	0.68	11.09
5B	30	29	32	7.03				3.34	7.99	150.42	4.48	4.66	0.15	0.39	9.68
5B	50	30	40	6.78				3.51	11.83	144.04	4.37	4.67	0.16	0.37	9.56
6A	10	31	8	7.24	1.63	0.08	21.39	9.96	96.26	330.57	7.88	5.89	0.16	0.85	14.78
6A	30	32	16	7.24				3.85	94.98	150.52	6.33	5.22	0.24	0.39	12.17
6A	50	33	64	6.93				11.9	64.71	181.94	6.23	4.10	0.32	0.47	11.12
6B	10	34	7	7.38	1.01	0.07	14.79	4.8	67.26	345.13	6.47	4.44	0.10	0.88	11.90
6B	30	35	29	7.54				5.86	38.69	273.21	8.33	5.08	0.12	0.70	14.23
6B	50	36	58	7.53				6.1	30.16	314.51	8.93	4.99	0.13	0.81	14.85
7A	10	37	6	7.54	1.22	0.06	18.86	4.95	23.77	265.13	6.66	5.13	0.15	0.68	12.62
7A	30	38	14	7.29				5.19	13.53	155.71	6.13	5.55	0.19	0.40	12.27
7A	50	39	9	7.17				4.07	13.96	143.74	5.77	4.99	0.24	0.37	11.37
7B	10	40	10	7.2	0.87	0.02	36.46	2.58	17.37	153.61	5.06	4.49	0.19	0.39	10.13
7B	30	41	10	6.88				8.06	21.11	154.71	5.59	4.79	0.24	0.40	11.02
7B	50	42	14	7.09				2.48	12.90	150.62	5.11	4.62	0.20	0.39	10.31
8A	10	43	14	6.88	1.08	0.03	39.98	6.94	18.65	263.64	5.11	4.44	0.21	0.68	10.45
8A	30	44	19	5.73				11.65	14.13	171.47	5.90	3.32	0.42	0.44	10.07
8A	50	45	22	5.47				13.45	9.61	135.86	5.32	2.79	0.57	0.35	9.02
8B	10	46	8	6.93	0.98	0.02	40.30	2.13	17.42	240.60	4.90	4.07	0.12	0.62	9.70
8B	30	47	12	5.24				12.04	7.56	159.70	5.47	2.87	0.41	0.41	9.15
8B	50	48	16	5.41				2.5	3.45	138.35	5.10	3.50	0.33	0.35	9.29

Table A5: Soil chemical analysis for WP season 2 after harvest at Mzilela.

plot	depth (cm)	lab nr	% rock	pH (KCl)	C	N	C:N	EC (mS/m)	P	K	Exchangeable cations (cmolc/kg-1) (1:10)				
											Ca	Mg	Na	K	Σ sum of basic cations (s-value)
1A	10	49	9	7.66	1.09	0.02	58.36	5.66	97.50	174.36	6.84	7.05	0.36	0.45	14.69
1A	30	50	7	7.5				4.67	57.66	201.49	6.02	5.96	0.40	0.52	12.89
1A	50	51	16	7.32				5.75	37.54	337.45	6.25	4.71	0.60	0.87	12.43
1B	10	52	8	7.76	1.81	0.10	18.53	6.56	60.54	378.15	5.94	5.99	0.30	0.97	13.20
1B	30	53	12	7.51				4.2	21.11	301.84	5.62	5.69	0.29	0.77	12.38
1B	50	54	22	7.24				3.54	7.15	433.81	4.97	5.15	0.23	1.11	11.46
2A	10	55	15	7.66	0.95	0.04	22.19	5.36	35.90	104.84	5.51	6.01	0.32	0.27	12.10
2A	30	56	14	7.52				4.72	18.24	124.69	5.34	5.78	0.37	0.32	11.81
2A	50	57	13	7.32				4.28	6.33	183.34	4.87	5.73	0.25	0.47	11.32
2B	10	58	9	7.63	1.08	0.03	41.38	5.95	87.23	203.19	7.61	8.14	0.34	0.52	16.61
2B	30	59	8	7.53				5.71	86.82	182.24	8.05	7.30	0.39	0.47	16.21
2B	50	60	13	7.69				4.79	60.54	180.25	6.75	6.53	0.37	0.46	14.11
3A	10	61	14	7.21	0.91	0.04	24.57	11.17	289.70	260.25	6.53	6.82	0.54	0.67	14.56
3A	30	62	12	7.56				8.79	58.48	279.70	6.42	6.65	0.46	0.72	14.24
3A	50	63	25	7.2				3.51	7.97	188.03	5.56	6.08	0.28	0.48	12.40
3B	10	64	9	7.78	0.92	0.06	15.91	6.53	78.20	136.16	6.15	7.08	0.33	0.35	13.92
3B	30	65	16	7.72				7.18	151.30	114.31	5.73	6.78	0.59	0.29	13.39
3B	50	66	25	7.35				3.28	14.13	116.01	4.68	5.55	0.30	0.30	10.82
4A	10	67	13	7.72	0.83	0.02	38.86	5.56	9.20	142.94	5.40	6.77	0.26	0.37	12.79
4A	30	68	15	7.62				5.36	3.86	93.66	5.25	5.95	0.38	0.24	11.83
4A	50	69	38	7.2				3.58	0.99	93.17	4.54	5.79	0.33	0.24	10.90
4B	10	70	10	7.91	1.61	0.10	16.48	7.26	231.79	182.64	8.78	6.54	1.78	0.47	17.57

4B	30	71	16	7.58				5.95	53.97	117.50	5.10	2.78	1.47	0.30	9.65
4B	50	72	32	7.41				5.22	25.22	126.58	6.62	2.29	0.92	0.32	10.15
5A	10	73	6	7.62	1.20	0.05	22.72	5.92	45.75	115.41	5.77	1.76	0.93	0.30	8.76
5A	30	74	16	7.72				5.12	23.99	130.57	3.27	2.22	0.84	0.33	6.67
5A	50	75	14	7.47				4.37	2.63	133.66	2.55	1.70	0.89	0.34	5.48
5B	10	76	9	7.81	0.93	0.03	29.68	5.23	80.66	136.96	3.13	2.09	1.24	0.35	6.81
5B	30	77	15	7.75				6.01	49.45	131.47	3.97	2.41	0.86	0.34	7.58
5B	50	78	33	7.47				3.88	5.10	150.62	3.77	1.43	0.95	0.39	6.53
6A	10	79	8	7.72	1.02	0.02	58.21	5.12	35.49	142.64	3.30	1.75	0.89	0.37	6.31
6A	30	80	18	7.62				3.77	20.70	157.80	4.55	2.11	1.07	0.40	8.13
6A	50	81	18	7.2				4.63	12.08	150.82	4.53	1.80	1.50	0.39	8.22
6B	10	82	7	7.63	1.37	0.03	48.39	7.83	52.32	135.76	5.32	3.15	1.25	0.35	10.06
6B	30	83	10	7.57				4.67	21.11	143.04	4.09	2.17	1.24	0.37	7.87
6B	50	84	16	7.34				4.43	3.04	189.62	4.38	1.71	1.61	0.49	8.19
7A	10	85	9	7.66	0.93	0.09	10.33	6.04	53.15	156.01	3.53	1.84	1.48	0.40	7.24
7A	30	86	8	7.73				4.71	23.99	165.78	2.39	2.35	1.16	0.43	6.32
7A	50	87	16	7.46				4.82	12.08	152.62	2.61	2.46	1.27	0.39	6.73
7B	10	88	6	7.44	1.00	0.09	11.11	6.24	46.99	168.68	3.46	2.69	1.40	0.43	7.99
7B	30	89	5	7.5				6.42	16.60	126.48	2.47	2.82	1.01	0.32	6.62
7B	50	90	9	7.22				4.48	5.51	148.83	1.95	2.10	1.15	0.38	5.59
8A	10	91	6	7.53	0.89	0.08	11.13	8.2	23.17	134.76	4.98	3.31	1.14	0.35	9.77
8A	30	92	11	7.08				4.47	9.61	141.64	4.50	2.84	1.27	0.36	8.98
8A	50	93	7	6.89				6.92	4.69	127.08	4.55	4.13	1.30	0.33	10.30
8B	10	94	8	7.38	0.84	0.07	12.00	5.14	10.85	128.98	4.90	2.18	1.32	0.33	8.74
8B	30	95	9	7.31				4.82	6.74	117.70	4.96	2.43	1.45	0.30	9.13
8B	50	96	6	7.24				4.21	1.40	100.85	3.72	2.88	0.73	0.26	7.59

Table A6: Soil chemical analysis for WP season 3 before planting at Mzilela.

plot	depth (cm)	lab nr	% rock	pH (KCl)	C	N	C:N	EC (mS/m)	P	K	Exchangeable cations (cmolc/kg-1) (1:10)				
											Ca	Mg	Na	K	Σ sum of basic cations (s-value)
1A	10	97	16	6.64	0.66	0.06	11.00	2.51	20.41	88.18	5.76	0.70	0.68	0.23	7.36
1A	30	98	17	6.47				2.79	13.23	84.09	3.68	0.56	0.70	0.22	5.16
1A	50	99	61	5.82				1.69	17.54	70.52	3.99	1.67	0.62	0.18	6.47
1B	10	100	19	5.2	0.72	0.07	10.29	8.93	19.59	102.44	7.70	0.67	0.69	0.26	9.32
1B	30	101	23	5.78				5.48	16.72	106.23	5.12	0.54	0.72	0.27	6.66
1B	50	102	49	5.77				5.56	18.36	83.79	5.55	0.55	0.64	0.21	6.95
2A	10	103	14	5.76	0.53	0.03	17.67	4.76	18.98	121.59	5.18	0.68	0.87	0.31	7.05
2A	30	104	21	5.99				4.55	14.66	98.05	2.76	1.24	0.72	0.25	4.98
2A	50	105	53	6.08				3.54	15.28	73.91	2.25	1.42	0.78	0.19	4.64
2B	10	106	13	5.21	0.85	0.06	14.17	7.86	14.25	103.04	6.03	1.18	0.95	0.26	8.42
2B	30	107	12	4.9				5.14	15.28	118.90	4.23	1.43	1.02	0.30	6.99
2B	50	108	41	5.01				4.81	15.07	80.50	3.61	1.54	0.82	0.21	6.18
3A	10	109	17	5.67	0.69	0.03	23.00	5.18	19.39	113.71	5.42	0.87	0.90	0.29	7.48
3A	30	110	28	5.82				5.09	16.51	133.17	3.83	0.94	1.16	0.34	6.27
3A	50	111	65	5.86				5.19	16.31	95.76	3.43	1.05	0.68	0.25	5.40
3B	10	112	16	6.06	0.74	0.03	24.67	3.04	19.39	488.67	7.21	0.52	2.16	1.25	11.14
3B	30	113	24	5.22				3.89	14.25	89.67	4.50	1.03	0.72	0.23	6.48
3B	50	114	46	4.48				3.38	13.64	85.98	3.19	1.63	0.72	0.22	5.76
4A	10	115	11	6.58	0.64	0.11	5.92	3.99	24.72	101.94	3.90	0.51	0.67	0.26	5.34
4A	30	116	17	6.49				4.4	16.31	117.40	3.06	1.12	0.83	0.30	5.31
4A	50	117	45	6.35				3.06	41.24	96.16	2.29	1.37	0.71	0.25	4.61
4B	10	118	14	6.01	0.76	0.09	8.54	3.77	51.50	66.13	9.38	0.70	0.82	0.17	11.07
4B	30	119	19	5.95				2.37	44.52	84.29	####	0.76	0.96	0.22	12.28

4B	50	120	47	5.55				2.33	32.61	75.11	####	1.09	1.12	0.19	16.08
5A	10	121	16	5.53	1.05	0.11	9.55	2.36	16.92	80.90	7.06	0.61	0.69	0.21	8.56
5A	30	122	30	5.33				2.03	11.79	77.80	5.90	0.67	0.83	0.20	7.60
5A	50	123	35	5.05				1.967	12.61	75.91	4.66	0.71	0.78	0.19	6.34
5B	10	124	21	5.64	1.12	0.10	10.76	3.91	17.95	50.97	7.26	0.97	0.80	0.13	9.16
5B	30	125	21	6.96				7.06	12.61	36.61	5.08	0.50	1.53	0.09	7.20
5B	50	126	17	5.5				1.924	11.79	62.64	5.70	0.67	0.65	0.16	7.18
6A	10	127	23	5.24	1.19	0.11	11.04	2.63	14.66	59.05	5.62	0.59	0.62	0.15	6.97
6A	30	128	27	4.96				1.993	11.58	51.57	4.96	0.61	0.57	0.13	6.27
6A	50	129	44	4.76				2.26	11.17	56.06	4.36	0.78	0.62	0.14	5.90
6B	10	130	26	5.63	0.71	0.07	10.92	2.02	13.84	75.91	4.18	0.63	0.58	0.19	5.58
6B	30	131	30	4.59				1.715	9.94	58.75	4.39	0.54	0.61	0.15	5.70
6B	50	132	59	4.62				2.19	11.17	103.04	2.44	1.29	0.57	0.26	4.56
7A	10	133	19	5.15	0.81	0.06	14.26	1.858	15.28	60.75	5.67	0.47	0.64	0.16	6.93
7A	30	134	17	5.12				1.523	12.82	56.46	5.43	0.48	0.63	0.14	6.69
7A	50	135	38	4.57				2.23	11.79	71.32	2.85	0.69	0.62	0.18	4.34
7B	10	136	32	4.85	0.74	0.05	15.10	5.67	11.58	58.55	4.44	0.83	0.54	0.15	5.97
7B	30	137	42	5.84				2.02	12.61	44.29	3.85	0.61	0.94	0.11	5.52
7B	50	138	60	4.53				2.85	11.58	84.79	2.84	1.03	0.50	0.22	4.59
8A	10	139	31	4.71	0.65	0.05	13.44	3.22	14.46	50.37	5.49	0.54	0.57	0.13	6.73
8A	30	140	58	4.81				2.38	12.61	58.35	7.17	0.61	0.62	0.15	8.54
8A	50	141	66	4.89				1.903	11.99	56.36	5.05	0.64	0.56	0.14	6.39
8B	10	142	-	4.96	0.82	0.05	15.42	7.06	16.10	57.46	6.29	0.71	0.59	0.15	7.74
8B	30	143	46	5				1.816	11.38	55.76	3.44	0.87	0.48	0.14	4.93
8B	50	144	56	4.73	0.60	0.04	15.79	1.812	11.79	65.04	2.99	0.78	0.40	0.17	4.33

Table A7: Soil chemical analysis for WP season 3 after harvest at Mzilela.

plot	depth (cm)	lab nr	% rock	pH (KCl)	C	N	C:N	EC (mS/m)	P	K	Exchangeable cations (cmolc/kg-1) (1:10)				
											Ca	Mg	Na	K	Σ sum of basic cations (s-value)
1A	10	170		6.89	0.83	0.05	15.64	35.4	18.98	312.22	3.22	4.33	0.72	0.80	9.06
1A	30	171		6.78				11.45	11.58	238.50	3.90	4.23	0.36	0.61	9.11
1A	50	172		6.8				7.6	7.68	371.37	3.62	3.80	0.28	0.95	8.65
1B	10	173		6.54	0.80	0.04	20.03	8.32	9.53	271.32	2.86	2.86	0.25	0.70	6.67
1B	30	174		6.54				9.3	6.86	310.32	2.99	3.31	0.29	0.80	7.38
1B	50	175		6.13				6.2	7.07	265.33	2.58	2.67	0.24	0.68	6.17
2A	10	176		6.32	0.87	0.08	11.50	6.75	5.01	221.54	2.91	2.52	0.26	0.57	6.26
2A	30	177		6.69				1.375	7.68	146.63	3.46	3.01	0.22	0.38	7.07
2A	50	178		6.33				6.09	5.83	191.52	2.86	2.49	0.24	0.49	6.08
2B	10	179		6.6	0.87	0.03	34.60	22.9	9.32	306.43	3.24	2.31	0.39	0.79	6.72
2B	30	180		5.8				13.48	6.86	410.87	3.92	1.79	0.22	1.05	6.98
2B	50	181		5.2				5.26	4.19	262.64	2.30	1.31	0.20	0.67	4.48
3A	10	182		6.35	0.65	0.04	15.21	13.49	19.18	206.18	3.50	2.83	0.35	0.53	7.20
3A	30	183		5.96				5.25	11.99	237.90	3.02	2.06	0.21	0.61	5.90
3A	50	184		6.09				9.75	12.20	267.23	3.18	2.34	0.26	0.69	6.46
3B	10	185		5.89	0.77	0.05	15.71	37.4	19.39	469.72	3.34	2.69	0.31	1.20	7.55
3B	30	186		5.43				6.1	11.58	382.64	3.15	2.09	0.17	0.98	6.38
3B	50	187		5.12				22.8	20.62	324.29	3.18	2.32	0.25	0.83	6.58
4A	10	188		7.81	0.64	0.02	31.80	71.6	14.25	202.19	3.72	4.57	1.07	0.52	9.88
4A	30	189		5.56				93.7	7.27	443.78	3.30	2.87	1.22	1.14	8.53
4A	50	190		7.4				13.96	8.71	166.88	3.44	3.98	0.37	0.43	8.21
4B	10	191		6.64	0.81	0.01	#####	9.82	16.51	348.82	3.16	2.68	0.32	0.89	7.05
4B	30	192		6.74				15.48	11.17	298.25	3.47	2.89	0.29	0.76	7.41



4B	50	193	6.64				13.31	11.38	375.06	3.79	2.88	0.26	0.96	7.89
5A	10	194	5.55	0.92	0.04	24.97	12.16	11.17	413.46	3.56	1.66	0.24	1.06	6.53
5A	30	195	5.66				11.68	10.35	387.53	3.97	1.71	0.22	0.99	6.90
5A	50	196	4.57				8.47	3.78	208.48	2.24	2.23	0.25	0.53	5.25
5B	10	197	4.76	0.76	0.03	27.29	5.35	2.55	227.53	2.50	2.04	0.22	0.58	5.34
5B	30	198	5.99				20.6	11.99	342.64	4.24	1.98	0.41	0.88	7.51
5B	50	199	5.71				30.5	5.01	322.89	3.14	2.85	0.35	0.83	7.16
6A	10	200	6.25	0.96	0.03	38.20	33.8	15.90	332.17	3.40	2.72	0.43	0.85	7.39
6A	30	201	5.24				9.08	4.60	263.64	2.35	1.45	0.25	0.68	4.73
6A	50	202	5.96				51.7	7.89	322.59	3.41	2.35	0.76	0.83	7.36
6B	10	203	6.15	0.87	0.03	34.96	20.5	8.09	332.76	4.38	1.89	0.40	0.85	7.52
6B	30	204	6.35				23.5	6.86	270.72	3.35	2.23	0.47	0.69	6.74
6B	50	205	6.17				11.18	6.65	299.85	4.34	1.86	0.33	0.77	7.30
7A	10	206	6.12	0.80	0.07	11.94	76.3	47.93	738.24	2.85	3.21	0.59	1.89	8.55
7A	30	207	5.44				9.99	5.42	240.40	2.25	2.25	0.22	0.62	5.33
7A	50	208	5.44				30.1	17.13	282.99	2.27	2.47	0.32	0.73	5.78
7B	10	209	5.4	0.71	0.02	32.18	19.53	7.68	37.21	2.42	1.66	0.07	0.10	4.24
7B	30	210	5.05				12.91	8.91	194.01	2.77	2.09	0.28	0.50	5.64
7B	50	211	4.94				7.89	3.99	167.48	2.55	1.85	0.20	0.43	5.02
8A	10	212	5.64	0.76	0.04	20.08	95.5	6.24	380.84	3.55	3.59	1.18	0.98	9.29
8A	30	213	5.37				29.3	5.22	294.96	2.57	1.93	0.36	0.76	5.62
8A	50	214	5.29				17.43	4.19	266.03	2.17	1.60	0.30	0.68	4.75
8B	10	215	6.9	0.69	0.04	19.66	13.52	11.58	184.14	3.03	3.61	0.29	0.47	7.41
8B	30	216	5.42				1.218	9.32	288.87	2.54	1.81	0.19	0.74	5.28
8B	50	217	5.33				4.91	7.48	257.85	2.31	1.79	0.19	0.66	4.94

Figure A1: MonQI form 2 containing all the household information of the farmers at Mzilela.

F	Full name	Sex	Year	Relation to HF	Main occupat	Main occupat	Education lev	Year	Pres
1	Matsimbi, Lizzy	female	1984	household head	farming	family f	5-8	7	30
2	Mahasha, Manakambe	female	1936	household head	farming	family f	non-educated	0	30
3	Hlungwane, Mamala	female	1943	household head	farming	family f	non-educated	0	30
4	Makhubele, Nkyasi	female	1932	household head	farming	family f	non-educated	0	30
5	Ngobeni, Mhlava	female	1937	household head	farming	family f	non-educated	0	30
6	Manyama, Esther	female	1948	household head	farming	family f	non-educated	0	30
7	Ngobeni, Norah	female	1969	household head	farming	family f	9-10	9	30
8	Tsonga, Mamala	female	1939	household head	farming	family f	non-educated	0	30
9	Manave, Fanisa	female	1956	household head	farming	family f	non-educated	0	30
10	Nkuna, Salva	female	1950	household head	farming	family f	1-4	2	30

Figure A2: MonQI form 10-I containing all input data for all crop planted in season 1 at Mzilela.

Time	Source	Destination	F	Product	Qual	Measure	Price per	Total
09 (sep '11)	EXT 0: extern: LA 1: Maize	CP		Maize seed		1 bag (10 Kg)	315	315
09 (sep '11)	EXT 0: extern: LA 2: Pumpkin	CP		Pumpkin (squash) seed		1 kg	1	1
09 (sep '11)	EXT 0: extern: LA 3: Tomato	CP		Tomato seed		660 piece	0.17	112.2
09 (sep '11)	EXT 0: extern: LA 5: Spinach	CP		Spinach seeds		1 kg	140	140
09 (sep '11)	EXT 0: extern: LA 7: Groundn	CP		Maize seed		10 kg	315	3150
09 (sep '11)	EXT 0: extern: LA 7: Groundn	CP		Groundnut seed		5 kg	95	475
09 (sep '11)	EXT 0: extern: LA 1: Maize	OP		tractor ploughing		1 days (person c	650	650
09 (sep '11)	EXT 0: extern: LA 2: Pumpkin	OP		tractor ploughing		1 days (person c	250	250
09 (sep '11)	EXT 0: extern: LA 4: Red beet	OP		tractor ploughing		1 days (person c	215	215
09 (sep '11)	EXT 0: extern: LA 5: Spinach	OP		tractor ploughing		1 days (person c	430	430
09 (sep '11)	EXT 0: extern: LA 4: Red beet	CP		African indigenous vegetable seeds		1 kg	620	620
09 (sep '11)	EXT 0: extern: LA 1: Maize	OP		electricity		4.5 c/kwh	37.35	168.07
09 (sep '11)	EXT 0: extern: LA 2: Pumpkin	OP		electricity		4.5 c/kwh	37.35	168.07
09 (sep '11)	EXT 0: extern: LA 3: Tomato	OP		electricity		4.5 c/kwh	37.35	168.07
09 (sep '11)	EXT 0: extern: LA 4: Red beet	OP		electricity		4.5 c/kwh	37.35	168.07
09 (sep '11)	EXT 0: extern: LA 5: Spinach	OP		electricity		4.5 c/kwh	37.35	168.07
09 (sep '11)	EXT 0: extern: LA 6: Okra	OP		electricity		4.5 c/kwh	37.35	168.07
09 (sep '11)	EXT 0: extern: LA 7: Groundn	OP		electricity		4.5 c/kwh	37.35	168.07
10 (oct '11)	EXT 0: extern: LA 1: Maize	PE		Insecticide		2 kg	360	720
10 (oct '11)	EXT 0: extern: LA 5: Spinach	PE		Insecticide		2 litres	80	160
10 (oct '11)	EXT 0: extern: LA 3: Tomato	OP		sticks for trussing		10 bundle	72	720

Figure 8.3: MonQI form 10-O containing all output data for season 1 at Mziela farm.