NITROGEN VARIABILITY ASSESSMENT IN TOMATOES USING THE REMOTE SENSING TECHNIQUE FOR PRECISION FARMING

by

KGASHANE BETHUEL BODIRWA

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SUPERVISOR: Mrs P Shaker

CO-SUPERVISOR: Prof HA Shimelis

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DECLARATION

I declare that the mini-dissertation I hereby submit to the University of Limpopo, for the degree of Master of Science in Agriculture (Soil Science and Remote Sensing) has not been submitted by me for a degree at this or anu other university; that is my own work in design and in execution, and that all material contained herein has been duly acknowledged.

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K.B. BODIRWA (Mr) Date

[redacted]

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ABSTRACT

The purpose of the study was to assess nitrogen variability in tomato using the Remote Sensing Technique. The assessment was carried out through three growth stages (seedling, 50% flowering, and 50% fruiting stage). The GreenSeeker optical sensor unit that records NDVI values and total leafy nitrogen analyzer, "The Primacs^{sn} Nitrogen Analyzer," was used in this study for data collection. Fertilizers were applied to the soil (Urea - 46% N, Superphosphate) every two weeks in the pots only for the treated experiment, and no nitrogen application for the untreated experiment.

Tomato cultivars Flora Dade and Roma VF were used during the experimentation. The mean NDVI values for cultivars Flora Dade and Roma VF were 0.83 with N application. This value was 0.81 without N-application. The mean N-content for cultivars Flora Dade and Roma VF were 3.30 g/plant with N application. This value was 2.94 g/plant without N-application. The cultivar Flora Dade with N applied had higher N-content (3.38 g/plant) than the cultivar Roma VF with 3.22 g/plant when no N is applied across the three growth stages. The number of fruits' means values at 50% fruiting stage for cultivars Flora Dade and Roma VF were 8.9 fruit per plant with N application. These mean values were 5 fruit per plant without N application.

It was also evident that plants likely to have lower N content (untreated) had delayed maturation unlike those with nitrogen applied (treated), which had rapid/early maturation. Untreated plants took an average of 120 days till maturity, whereas the treated plants took an average of 100 days till maturity. Ground measurement of NDVI by the GreenSeeker sensor in this study showed potential for assessing nitrogen variability in tomato.

CHAPTER 1

INTRODUCTION

1. Introduction and Background

Advances in information technology and their application in crop production, also known as precision agriculture, are creating the potential for substantial change in management and decision-making in agriculture. Over the last 10 years, research has provided evidence of heterogeneous fields leading to non-uniformity in crop yields at the subfield scale. The purpose of this research was to assess nitrogen variability in tomato using the Normalized Differential Vegetation Index (NDVI) throughout the growing season (Gitelson *et al.*, 1996).

Various types of plant stress have been identified using remote sensing techniques. These include disease stress, water stress, and nutrient stress (Filella & Penuelas, 1994; and Botha, 2001). Physiological changes resulting from nitrogen limitations can be translated into clear spectral differences between treatments, thus demonstrating the relationship among leaf reflectance and leaf chlorophyll and nitrogen concentrations (Penuelas *et al.*, 1994; and Botha, 2001).

In the broadest sense, remote sensing is the measurement or acquisition of information of an object or phenomenon by a recording device that is not in physical or intimate contact with the object. In practice, remote sensing is the utilization, at a distance (as from aircraft, spacecraft, satellite, or ship), of any device for gathering information about the environment. Thus, an aircraft taking photographs; Earth observation and weather

satellites; monitoring of a pregnancy via ultrasound; and space probes, are all examples of remote sensing (Dusek *et al.*, 1985).

Remote Sensing techniques have a unique capability of recording data in visible as well as invisible (i.e., ultraviolet, reflected infrared, thermal infrared and microwave etc.) parts of electromagnetic spectrum, where the spectral characteristics of plants are good indicators of their health and N content in the tissues (Blackmer *et al*., 1996). Chlorophyll is the most important factor affecting reflectance in the visible spectrum (VIS) of most field crops, but it has no influence on the reflection properties in the near infrared (NIR). Several mathematical combinations of spectral information have been found to be good descriptors of N taken up and chlorophyll concentration. The Normalized Difference Vegetation Index (NDVI), and especially the Red Edge Inflection Point (REIP), were highly correlated with N uptake. Several studies have been made to use real-time sensor based spectral measurements to derive N fertilizer requirements of crops (Blackmer *et al*., 1996). The NDVI has been used as a powerful tool in crop nutrient (Nitrogen) monitoring in tomato production. Nitrogen availability is an important determinant of crop productivity and an excessive application of nitrogen can result in poor colouring, flavour and texture in tomatoes (Thomas & Oerther, 1972).

The objective of variable Nitrogen management is to adjust the amount of Nitrogen to the varying yield potential of sub-areas of fields so as to optimize yield, farmer's profit, and Nitrogen Use Efficiency (NUE). Therefore, nitrogen based fertilizer needs to be applied in sufficient amounts to achieve the highest possible crop yield without over applying it,

because this may also lead to serious environmental effects. Since existing methods of soil and plant analysis have proven to be too costly and time consuming (Peoples *et al*., 1995; and Oertli, 1980), to fulfil this requirement the focus is shifting from map-based variable rate application towards approaches using remote sensing technologies.

Decisions on fertilizer use require knowledge of the expected crop yield response to nutrient application, which is a function of crop nutrient needs, supply of nutrients from indigenous sources, and the short- and long-term fate of the fertilizer applied. Most fertilizer recommendations are based on empirical crop response functions derived from factorial fertilizer trials conducted across different locations (Wollenhaupt *et al*., 1994). Recommendations can be of a general nature for larger regions, or they can include diagnostic indices to assess soil or plant nutrient status so as to make field-specific decisions on fertilizer rates and the timing of nutrient applications. Although process-oriented models of crop response to nutrients have been developed, they are still rarely used in practical fertilizer management (Angus *et al*., 1993).

There are two types of tomatoes, namely, determinate and indeterminate types. Determinate types are bushier and more compact than indeterminate types. Indeterminate types have sprawling vines and need support. Determinates are better suited to smaller growing areas. Tomatoes are warm-season plants that grow best at temperatures of 18 to 25°C during the day and 10 to 20°C during the night. Tomato plants may be started indoors from seed, or transplants may be purchased from a reputable garden centre. Tall, spindly transplants are usually caused by low light levels.

A soil test is always the best method for determining the fertilization needs of a crop. The desired soil pH for tomatoes is between 5.8 and 6.5 (Tarpley *et al*., 2000).

Tomato is a rapidly growing crop with growing period of 90 to 150 days. It is a day-length neutral plant. Optimum mean daily temperature for growth is 18 to 25°C, with night temperatures between 10 and 20°C. Larger differences between day and night temperatures adversely affect yield. Tomatoes are very sensitive to frost. Temperatures above 25°C, when accompanied by high humidity and strong winds, result in reduced yield. Dry climates are therefore preferred for tomato production. The transition of a flower into a young fruit is very sensitive to several environmental factors (Tarpley *et al*., 2000).

CHAPTER 2

LITERATURE REVIEW

2.1 Remote Sensing

Remote sensing is a means of getting reliable information about an object without being in physical contact with the object (Gitelson *et al*., 2001). It is based on the observation of an object by a device separated from it by some distance utilizing the characteristic response of different objects to emissions in the electromagnetic energy measured in a number of spectral bands for the purpose of identification (Beck & Vyse, 1995). Remote Sensing techniques have a unique capability of recording data in visible as well as invisible (i.e., ultraviolet, reflected infrared, thermal infrared and microwave etc.) parts of electromagnetic spectrum. Remote Sensing can be used to monitor crops in terms of their identity, stage of growth, predicted yields (productivity) and health (Blackmer *et al*., 1994).

There are four basic components of a remote sensing system, viz., the energy source e.g. Sun; transmission path e.g., the atmosphere; the target, e.g., Plant; and sensor. Electromagnetic energy serves as a medium for transmitting information from target to sensor (Fig 1 below).

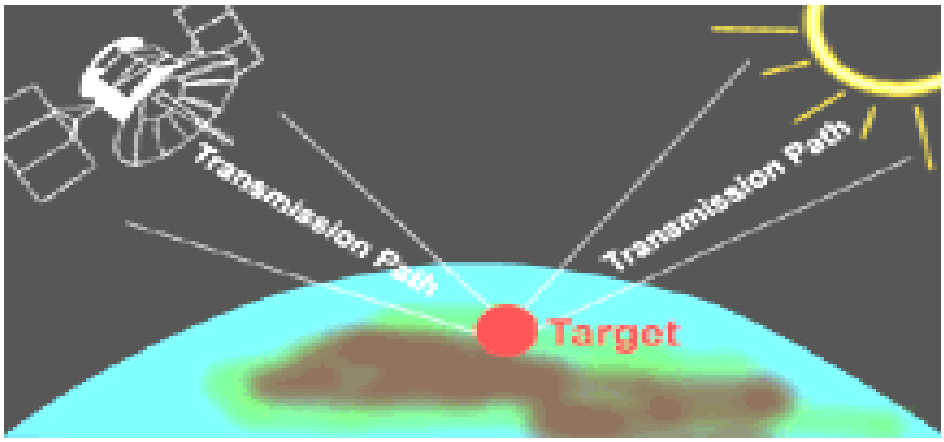

Fig 1: A representation of remote sensing components by (Gitelson *et al*., 1996)

Solar radiation (500 to 2600nm) that reaches the earth's surface may be absorbed, transmitted, scattered or reflected by plants leaves (Gitelson *et al*., 1996). As a receptor, the human eye only perceives the visible wavelengths (400 to 700nm)), while remote sensing instruments have the ability to measure reflected radiation beyond 5000nm (Hatfield, 1990). The electromagnetic spectrum can be divided into three agronomically important regions, namely: (a) visible light absorption (400 to 700nm) which is dominated by pigments (chlorophyll a and b, carotene, and xanthophylls); (b) the near infra red (NIR) region (700 to 1300nm) of high reflectance and low absorptions affected most by internal leaf structure; and (c) the far infrared region (1300 to 2600nm) which is most affected by the amount water in the tissue (Thomas & Oerther, 1972).

Remote-sensing techniques, in particular, multispectral visible and infrared (IR) reflectance, can provide an instantaneous, nondestructive, and quantitative assessment of the crop's ability to intercept radiation and photosynthesize (Ma *et al*., 1996). The input of reflectance into yield production models has been shown to improve yield estimates (Clevers *et al*., 1994; and Clevers, 1997). Colwell (1974) was the first to use aerial IR photographs to monitor plant disease in the field. The amount of reflectance in the near

IR (NIR) range (λ = 700–1300 nm) is determined by the optical properties of the leaf tissues: their cellular structure and the air–cell wall–protoplasm–chloroplast interfaces (Kumar & Silva, 1973). These anatomical characteristics are affected in turn by environmental factors such as soil water and/or nutrient status (Gausman *et al*., 1970; Thomas *et al*., 1971; and Blackmer *et al*., 1994), soil salinity (Gausman & Cardenas, 1968), and leaf age (Gausman *et al*., 1970). Reflectance in the visible red (R) range (λ = 550–675 nm) has been used to estimate leaf chlorophyll and carotenoid (Benedict & Swidler, 1961; Thomas & Oerther, 1972; and Filella *et al*., 1995) levels and, by extension, the photosynthetic capability of the crop.

Remote sensing has proven a powerful "tool" for assessing the identity, characteristic and growth potential of most kinds of vegetative matter at several levels (from biomes to individual plants). Vegetation behaviour depends on the nature of the vegetation itself, its interactions with solar radiation and other climate factors, and the availability of chemical nutrients and water within the host medium (usually soil, or water in marine environments (Guoliang, 1989; and Guyot, 1990).

Green leafy material has an influence on incoming and reflected radiation. Absorption centred at about 650nm (visible red) by chlorophyll pigment in green leaf chloroplast that resides in the outer or palisade leaf and to a similar extent blue, removes these colours from white light, leaving the predominant but diminished reflectance for visible wavelength concentrated in the green (Wood *et al*., 1992). Thus, most vegetation has a green leafy colour. There is also a strong reflectance between 700nm and 1000nm (near IR) in the spongy mesophyl cells located in the interior or back of a leaf, within which light

reflects mainly at cell wall/air space interfaces, much of which emerges as strong reflection rays. The intensity of this reflectance is commonly greater (higher percentage) than from most inorganic materials so vegetation appears bright in the near IR wavelength, (Fig 2) (Guoliang, 1989; and Guyot, 1990).

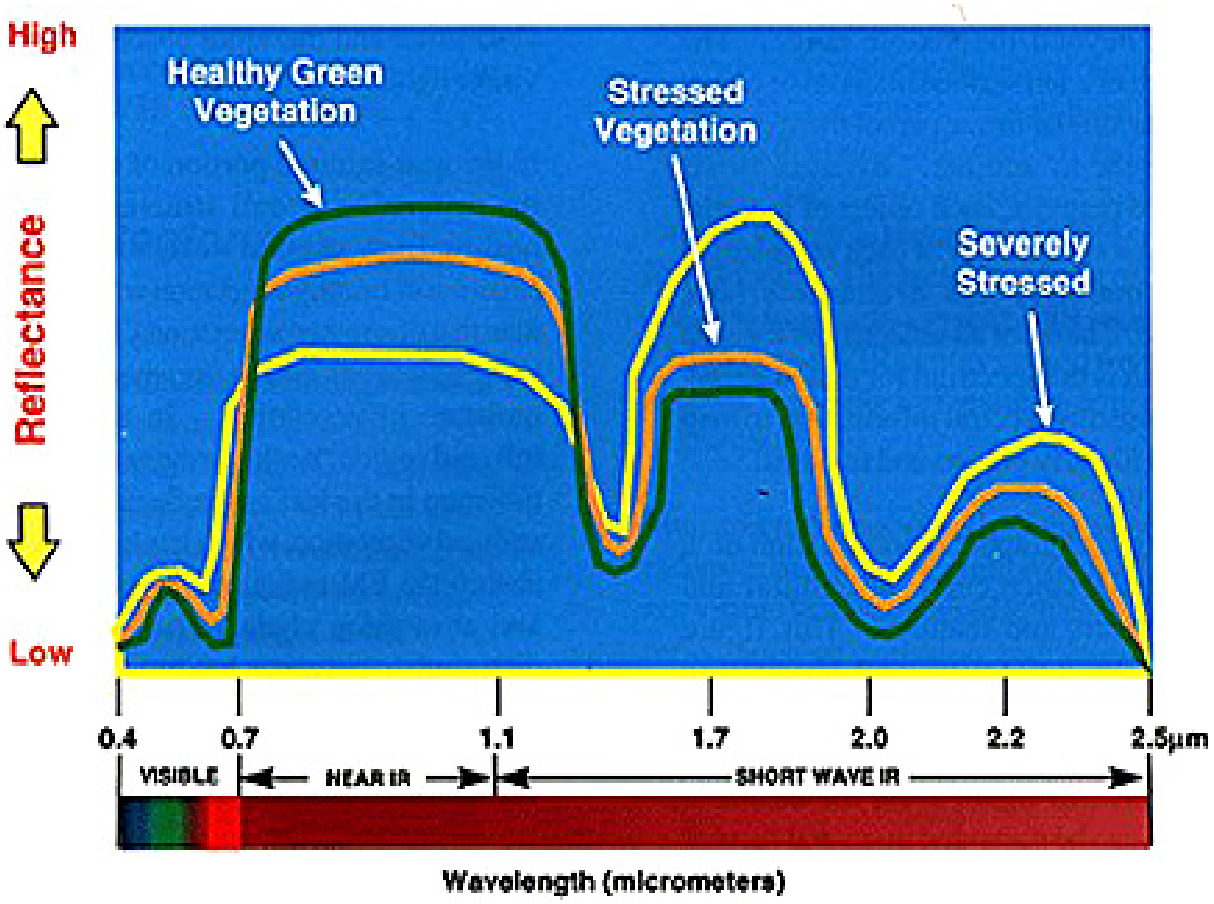

Fig 2. Spectral reflectance by vegetation (Botha, 2001)

This reflectance behaviour is evidenced quantitatively in this set of field spectral measurements of leaves taken from soybean plants as these underwent increasing stress

that caused loss of water and breakdown of cell walls (Thomas *et al.*, 1971; and Guyot, 1990).

Healthy green vegetation has a spectral reflectance that is quite different from, e.g., dry soil, clear water or snow. One observes that green vegetation has a low reflectance in the visible portion of the spectrum. This occurs because chlorophyll strongly absorbs energy in the wavelengths centered about 450nm and 670nm. We also notice that the reflectance from healthy green vegetation increases dramatically as we reach the near infrared portion of the spectrum. The reflectance on the near-infrared plateau varies with vegetation type, water content, and canopy architecture, Fig 3 (Sabins, 2000).

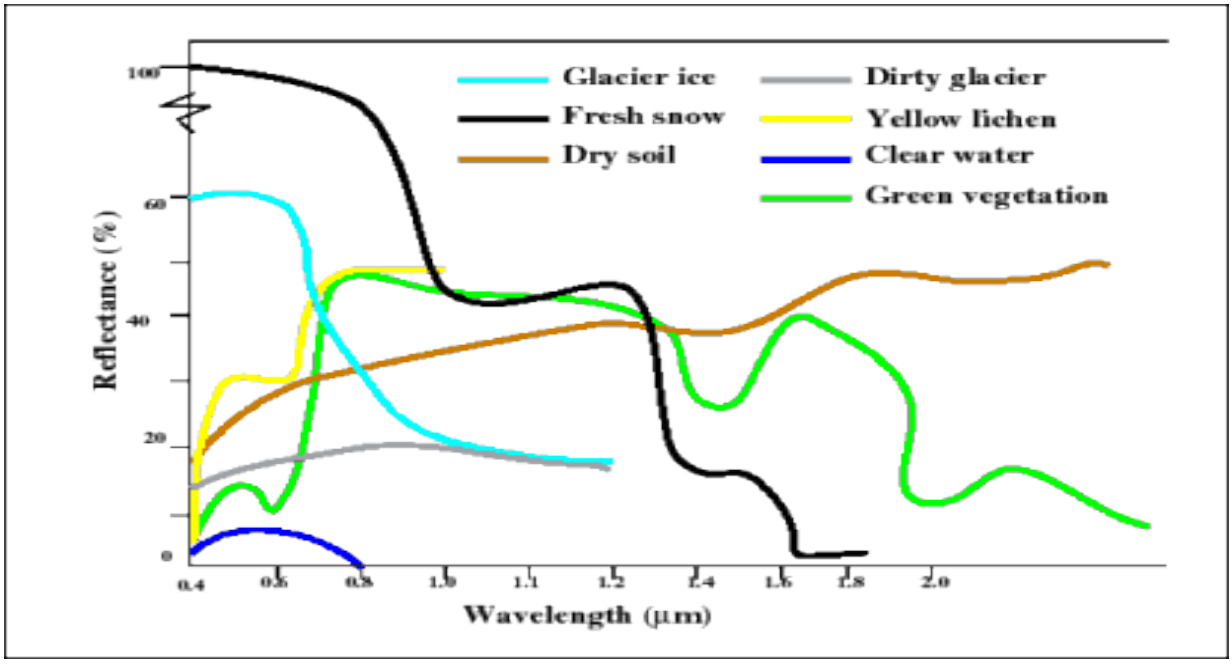

Fig 3: The generalized spectral reflectance curves for various natural surfaces by (Aulakh *et al*., 1992)

Total chlorophyll mass in vegetative material is the product of chlorophyll concentration and vegetative mass. It is reasonable to expect then that spectral absorption in red

wavelengths should be proportional to the product of tissue nitrogen concentration and vegetative mass. A wheat plant with greater nitrogen availability (assuming other factors are not limiting and yield potential has not been reached) will produce greater biomass. The expectation based on these arguments is that as wheat plants have increasing nitrogen availability, red absorption should increase more than linearly with nitrogen uptake. This would be reflected in flattening of the upper end of the curves in Figure 3 (Wanjura & Hatfield, 1987).

In contrast, bare soil has approximately the same reflectance in both the visible and near-infrared portion of the spectrum. The reflectance characteristics in the visible and the near infrared bands have been used to monitor vegetation with multi-spectral remote sensing images. A range of different vegetation indices has been proposed in order to estimate the amount, productivity and health condition of vegetation. Various mathematical combinations of spectral channels have been applied as sensitive indicators of the presence and condition of green vegetation (Banerjee *et al*., 1990; and Bacon & Freney, 1989).

Understanding the interaction between plant leaves and solar radiation was the basis for development of canopy remote sensing applications. Early research examining the spectral properties of leaves resulted in the basic observation that plants absorb solar radiation efficiently where they require energy (visible wavelength) and poorly in the NIR where the wavelengths are longer and have less energy (Gitelson *et al.*, 1996).

2.2 GreenSeeker

GreenSeeker is a hand held optical sensor unit which has been extensively used for vegetation monitoring, crop yield assessment and drought detection (Fig 4). The unit can be used to monitor changing field conditions during the growing season and the effects of different levels of inputs. It has an HP iPAQ receiver to which the data can be serially transmitted and then later be exported to a desktop computer for analysis. It is also connected to a bluetooth GPS (Global Positioning System) receiver. The data collected are logged into the HP iPAQ using the GPS coordinates (Sabins, 2000).

This hand-held optical sensor unit uses an index called Normalized Differential Vegetation Index (NDVI). NDVI is an index calculated from reflectance measured in the visible and near infrared channels of the electromagnetic spectrum. It is typically a Remote Sensing technique that can be used to indicate vegetation photosynthetic activity. This index uses radiances or reflectance from the red channel around 660nm and near Infra-red of 860nm. The NDVI is calculated as (NIR - RED)/(NIR + RED, where NIR is the reflectance radiated in the near-infrared waveband and RED is the reflectance radiated in the visible red waveband (located at the strong chlorophyll absorption region) of the satellite radiometer. This ratio provides an indicator such that the higher the NDVI, the greater the level of photosynthetic activity in the vegetation (Sabins, 2000).

Fig 4: GreenSeeker (Sabins, 2000)

The normalized vegetation index provides values between -1 and 1 units. Vegetated areas will generally yield high values, caused by relatively high near-infrared reflectance and low visible reflectance. The typical range for vegetation is between -0.1 units (damaged or sparsely vegetated areas) to 0.7 units for very green vegetation. Clouds, water and snow yield negative values because they have a higher reflectance in the visible than in the near-infrared. Bare soils have similar reflectance in the visible and near-infrared, and yield a value near zero. Thus, the NDVI provides a crude estimate of vegetation vitality and thereby a simple method for monitoring changes in vegetation over time. The NDVI has been demonstrated to offer a means for objective evaluating phenological characteristics of land cover regions, and assessing their variability over a large geographical area (Justice *et.al*., 1985; and Haynes, 1986).

Wetzel (1983) determined reflectance curves in the visible and NIR bands and used the data to select Vegetative Indices (VIs) and wavelengths for vegetation detection. They

examined interferences from soil type, soil surface moisture, and surface organic matter and examined various types of vegetation. The (VIs), NIR/Red and NDVI ((NIR-Red)/(NIR+Red)) were evaluated and NDVI with long NIR wavelengths (800-850 nm) was found to be most effective in detecting living plant matter.

2.3 The role of Nitrogen in crops

Nitrogen availability is an important determinant of crop productivity. One of the most important functions of nitrogen is the production of chlorophyll A, which is, in general, related to crop yields (Fillela *et al*., 1995; and Botha, 2001). Ordinarily green leaves absorb 75% to 100% of the light in the blue (about 450nm) or red (about 675nm) part of the spectrum. Absorbance is smallest in the wavelength region around 550 nm. Nitrogen deficiency changes the whole electromagnetic reflectance spectrum of vegetation. Since nutrient deficiency decreases pigment formation and subsequent leaf colour, it would increase the reflectivity because of decreased radiation absorbance. Reflectance measurements can detect changes in leaf colour before visual detection is possible (Bowmer & Muirhead, 1987; and Black *et al*., 1989).

Of the three major nutrients (N, P and K), plants require nitrogen in the largest amounts. This is because nitrogen promotes rapid growth; increases leaf size and quality; hastens crop maturity; and promotes fruit and seed development. Because nitrogen is a constituent of amino acids, which are required to synthesize proteins and other related compounds, it therefore plays a role in almost all plant metabolic processes (Cassman & Plant, 1992).

Broadbent *et al*., (1957) reported that nitrogen is an integral part of chlorophyll manufacture through photosynthesis. Photosynthesis is the process through which plants utilize light energy to convert atmospheric carbon dioxide into carbohydrates. Carbohydrates (sugars) provide energy required for growth and development. The chemical equation for photosynthesis is as follows:

$$6CO_2 + 12H_2O + 672 \xrightarrow{\text{Kcal radiant energy}} C_6H_{12}O_6 + 6H_2O + 6O_2$$

Soils containing low levels of nitrogen require annual applications so as to sustain crop growth. Little of the applied nitrogen is carried over to subsequent growing seasons due to crop removal, leaching and denitrification. Of all the elements required for crop production, nitrogen poses the greatest potential environmental threat through contamination of surface and ground water (Campbell *et al*.,1993).

Boman *et al*., (1995) noted that nitrogen fertilizer is available in both organic (manures) and inorganic forms. The amount of nitrogen in organic sources varies with the source of the material and its state of decomposition. However, for commercial crop production, the following inorganic fertilizers are primarily used: ammonium nitrate (33.5% N), potassium nitrate (13% N), sodium nitrate (16% N), calcium nitrate (15.5% N), urea (46% N), mono-ammonium phosphate (18% N), di-ammonium phosphate (46% N) and liquid nitrogen (30% N). Legume crops require little or no nitrogen fertilizer. The reason for this is that beneficial bacteria that live in the roots of these plants capture nitrogen from the atmosphere. Hence, this nitrogen becomes available for use by the plant. Nitrogen is

also used by microbes to break down organic matter (Bundy & Bremner, 1973; and Buresh & Datta, 1991).

2.4 Nitrogen Deficiency

Plants exhibit slow stunted growth and their foliage is pale green when nitrogen is insufficient. Deficiency symptoms generally appear on the bottom leaves first. In severe cases, the lower leaves have a “fired” appearance on the tips, turn brown, usually disintegrate, and eventually fall off (Dalal & Henry, 1986; and Chancellor & Goronea, 1994). In leafy crops such as tobacco, vegetables forage and pasture crops, low nitrogen results in low yield and poor quality. When grain crops, such as corn and small grains, are deficient in nitrogen, they generally exhibit yellow leaf tips, stunted growth with spindly stalks, and low yields of poor quality grain. In contrast, too much nitrogen causes excessive vegetative growth, delays maturity, increases lodging, fosters disease, and poses an environmental threat to surface and ground water (Chalk *et al*., 1975; Chalk & Smith, 1983; and Chen *et al*., 1994).

Nitrogen deficiency generally stems from inadequate fertilizer application, denitrification by soil microbes, or leaching loss due to excessive rainfall. Leaching occurs most commonly in sandy-textured coastal plain soils during periods of excessive rainfall. Nitrogen is also lost through volatilization of ammonia from surface applications during periods of hot, dry weather (Chalk & Crawford, 1992). Nitrogen deficiency can be corrected with an application of nitrogen fertilizer. Crop response to fertilization with nitrogen is generally very prompt, depending on the source of nitrogen, stage of plant growth, rainfall, and temperature (Jordan, 1969)

2.6 Nutrient monitoring

2.6.1 Bloom to early fruiting stage

Akin and Gray (1984) and Hoeft (1984) reported that plant tissue testing can be done to help identify any growth-limiting nutrient deficiency. Whole leaf total N/P/K analysis evaluates overall nutrient status, while Petiole Analysis provides a measure of unassimilated nutrients (NO_3-N, PO_4-P, and K) taken up but not yet incorporated into plant structures. Tissue analysis is most useful from early flowering through full bloom. Nutrient deficiency is rare before flowering (with the possible exception of P). After full bloom, tissue nutrient concentration, particularly for potassium, is heavily influenced by fruit load; low tissue values may not reflect nutrient deficiency as much as nutrient export to the fruit (Den- mead *et al*., 1988).

Table 1 below lists nutrient sufficiency guidelines for processing tomato. The whole leaf values were developed by Keller and Mengel (1986) from a large-scale field survey of more than 100 fields and are broadly representative of the industry. Conversely, the petiole guidelines were developed from more limited data, much of it from trials in conventionally irrigated fields. These values should be considered provisional until additional information from drip-irrigated fields becomes available (Keller & Mengel, 1986).

Table 1: Nutrient sufficiency guideline for processing tomato by (Keller & Mengel, 1986)

Whole leaf and petiole nutrient sufficiency guidelines			
Plant part	**Nutrient**	**Sufficiency range by growth stage**	
		First flower	***Full bloom***
Whole leaf	% N	4.6–5.2	3.5–4.5
	% P	0.32–0.49	0.25–0.41
	% K	2.2–3.5	1.6–3.1
Petiole	NO_3-N (ppm)	8,000–12,000	4,000–8,000
	PO_4-P (ppm)	2,500–3,500	2,000–3,000
	% K	5.0–8.0	3.0–5.0

Key:

N = nitrogen

P = phosphorus

K = potassium

ppm = parts per million

If tissue analysis suggests that the crop is nutrient-deficient, supplemental fertilization can be applied in several ways (Evans *et al*., 1997). If the vines have not covered the bed top, an additional side dressing can be applied, taking care to place the fertilizer at the edge of the bed to minimize root damage. Soluble nutrients can also be applied by dissolving them in irrigation water. The drawback of this approach is that the uniformity of application is limited to the distribution uniformity of the irrigation (Muirhead *et al*., 1985).

The most efficient management practice to maximize plant uptake and minimize losses is to synchronize the N supply with the plant demand for this nutrient (Garrido-Lestache *et al*., 2004). This general concept of balancing supply and demand implies maintaining low levels of mineral N in soil when there is little or no plant growth, and providing sufficient N to meet plant requirements during periods of rapid growth (Peoples *et al.,* 1995).

It is generally agreed that more efficient use of fertilizer N results when the application of fertilizer coincides with the period of rapid plant uptake (Oberti & De Baerdemaeker, 2000). Several applications of small amounts of fertilizer N during the growing season, therefore, may be a more effective means of supplying N for plant growth, than one large dose at the beginning of the season. Unfortunately, multiple applications of fertilizer are not always practical because of rainfall patterns and the difficulty of applying fertilizer within a maturing crop canopy (Doerge *et al.,* 1991). However, split applications of N have proven useful in increasing crop production in some systems.

2.7 Tomato Fruit Set

The transition of a flower into a young fruit is very sensitive to several environmental factors over which producers need to take control. These factors include temperature, humidity, plant nutrition and photoperiod. Temperature and humidity play a pivotal role in fruit setting. Daytime temperatures above 25°C and night temperatures above 20°C result in reduced flowering and fruit set. There is considerable evidence that night temperatures is the critical factor in setting tomato fruit, the optimal range being 18°C to 25°C. With night temperatures much below or above this critical range, fruiting is reduced or absent. Low temperatures reduce the production and viability of pollen. High

temperature, especially if accompanied by low humidity and moisture, hinders fruit set through failure in pollination and/or fertilization (Tarpley *et al*., 2000).

In tomato, plant density, number of fruits per plant and average fruit weight determine the ultimate yield (Thomson & Kelley, 1971). The growth and yield attributing characters were recorded in the study conducted by Thomson and Kelley (1971) to evaluate the yield potential of tomato at different plant spacing between plants and rows. Among the different spacing, closer spacing of 30 x 15 cm increases the plant height and dry matter (Fig 5) significantly and other vegetative parts such as number of nodes and internode length increase considerably, but these increments are not significantly different.

Thomson and Kelley (1971) continued and reported that closer spacing will increase plant growth and decrease the plant dry matter. Plant height increases as spacing decreases but the dry matter increases with wider spacing of 75 x 60cm. The more dry matter in wider spacing might be due to slightly higher temperature prevailing inside the greenhouse (Tiwari & Chaudhury, 1986). Papadopoulos and Ormrod (1991) also reported a consistent increase in plant height and internode length with closer spacing.

According to Papadopoulos and Pararajasingham (1997), the average fruit weight, number of fruits per plant and yield per plant (Fig. 6) increases with wider spacing of 75 x 60cm compared to closer spacing of 30 x 15cm. Wider spacing of 75 x 60cm gave the highest yield of 3555g per plant followed by 60 x 45cm spacing with a yield of 2779g per plant. The superiority of wider spacing (75 x 60cm) for higher yield is due to increased light penetration into the canopy. Wider spacing of 75 x 60cm leads to production of a greater number of fruit per plant and increases average fruit weight. Papadopoulos and

Pararajasingham (1997) concluded that tomato production with a spacing of 75 x 60cm could be adopted in areas that have limited land resources. Adaptation of such techniques would help in increasing the productivity of a unit area thereby helping in utilization of the land resource in an optimum manner.

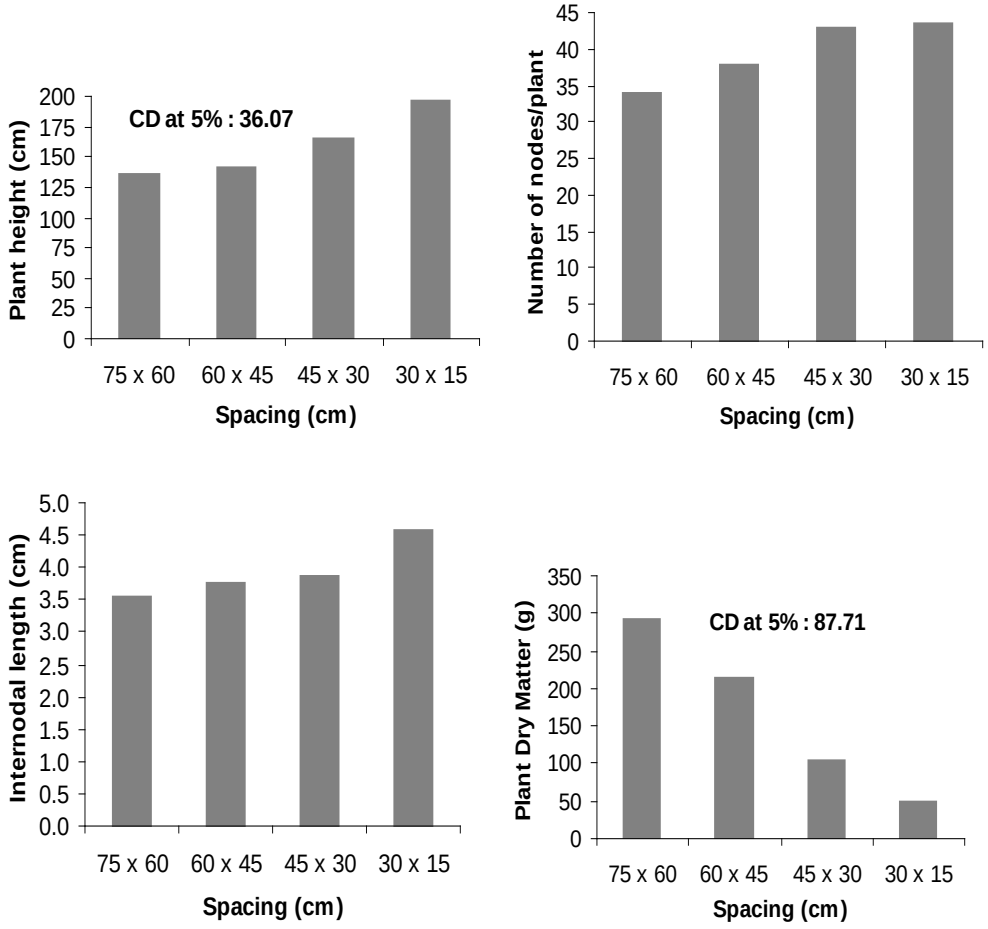

Fig 5. Effect of different spacing on plant height, number of nodes, internode length and plant dry matter of tomato (Papadopoulos & Pararajasingham, 1997)

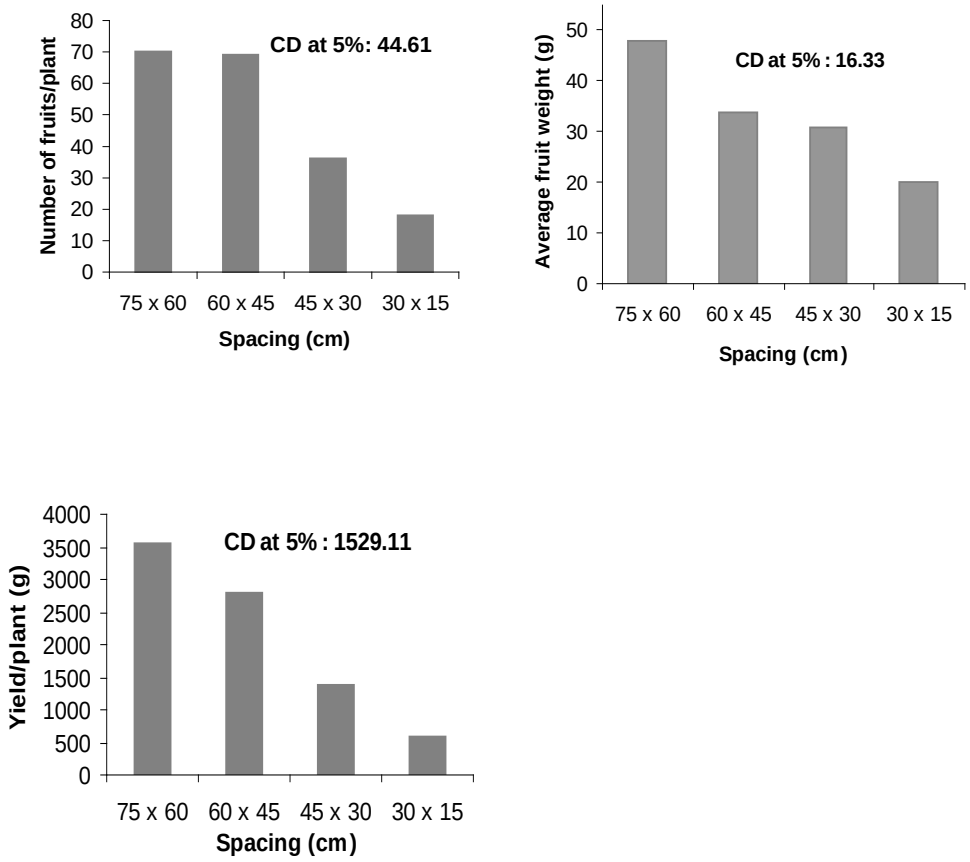

Fig 6. Effects of different spacing on number of fruits, average fruit weight and yield of tomato (Papadopoulos & Pararajasingham, 1997)

Plant nutrition also has an impact on fruit setting, thus reduced fruiting may result from either stunted or excessively vigorous vegetative growth. Injury from disease and insects, especially sucking insects such as aphids and thrips, can severely affect plant growth. Inadequate moisture and/or available nitrogen can hinder growth and flower production. Conversely, abundant water and nitrogen can stimulate rapid vegetative growth with low levels of carbohydrates remaining for the normal processes involved in fruit set (Angus *et al*., 1993).

Wuest and Cassman (1992) found that late-season applied N has greater uptake efficiency and is more effective in increasing grain N levels than N applied at planting time. Similar work by Boman *et al*. (1995) found significant increases in grain yield from topdress N applied. Early-season N must be managed to optimize grain yield, but adding excess N at that time reduces overall partitioning efficiency (Wuest & Cassman, 1992).

CHAPTER 3

NITROGEN VARIABILITY ASSESSMENT IN TOMATOES USING REMOTE SENSING TECHNIQUE FOR PRECISION FARMING

3.1 Introduction

Spectral reflectance of leaves provides several options for the derivation of their structure and physiology by quantifying the patterns in both the visible and the near IR and the red-near-infrared contrast. The remote sensing of chlorophyll is expected to be a valuable tool in the evaluation of plant nitrogen status and is of great interest in agricultural communities because nitrogen stress is often an important limitation of crop productivity. Thus, accurate spectral characterization at both the leaf and the canopy levels would allow improved optical determination of nitrogen deficiency (Fillela & Penuelas, 1994; Penuelas *et al*., 1994; and Botha, 2001).

Site-specific farming helps farmers determine crop yield variability across their fields. The goal of site-specific farming is to allow more efficient use of inputs across the field, whether they are fertilizers, pesticides, management or labour. The farming system recognizes the inherent spatial variability associated with soil characteristics and crop growth, and uses this information to prescribe the most appropriate management strategy on a site-specific basis (Brisco *et al*., 1998). The end result is to maximize financial advantage and minimize production risks while at the same time ensuring environmentally sound production practices. Site-specific farming has emerged as a management practice with the potential to increase profits by utilizing more precise information about agricultural resources (Bakhsh, 1999).

Remote sensing techniques will be a valuable tool to help farmers in decision making for variable rate application control of inputs in crops to improve product quality, and to avoid severe environmental impacts. The most important fact regarding the analysis of profitability of precision agriculture is that the value comes from the application of the data and not from the use of the technology. Factors and processes that regulate and control the crop performance in terms of yield vary in space and time, therefore potential improvements in environmental quality and economic impacts are often cited as a reason for using precision farming. Once the variation is adequately assessed, farmers need to match the agronomic inputs to known conditions employing management recommendations.

New technologies, such as field sensors and remote sensors provide information that may have added value to conventional ways of crop-soil monitoring. In agricultural research, eco-physiological processes in soils and crops are studied to unravel the complexities of underlying principles as a basis for identification of solutions to the negative side effects of mismanagement. The use of crop growth simulation models enables timely and quantitative prediction of the dynamics of crop requirements for a specific location (Tucker, 1979). Further improvements in fine-tuning management practices can be achieved by assessing the spatial variation in the crop growth environment as a basis for spatial fine-tuning of crop management. Applying this concept to a single field is known as Precision Agriculture (PA). The concept of PA illustrates that agricultural management is in need of geo-referenced information that can be generated through new techniques, such as Remote Sensing (RS) or through conventional

measurement techniques in combination with a Geographical Positioning System (GPS) (Richardson & Berlyn, 2002).

Availability of temporal and spatial information might provide detailed information for guiding management aimed at efficient use of inputs and prevention of environmental pollution or degradation. Remote Sensing observations, acquired in the course of the growing season, can assist in assessing variability in crop performance and provide information of, and for, management interference. Technological developments, such as automated application equipment for fertilizers, irrigation and phyto-sanitary products make it possible to vary management within a field. Crop management could thus be improved on the basis of information generated through combining dynamic crop growth simulation with temporal remotely sensed information. In addition to applications in high-input farming, this method of linking crop growth simulation models to spatial remote sensing information has potential in low-input arable farming. Linking dynamic crop growth simulation models to spatial information provides a possibility to extend the use of an advanced and sophisticated research and advisory tool, originally developed for point-specific analyses to larger areas. The purpose of the study is to assess nitrogen variability in tomato using a GreenSeeker NDVI sensor for precision farming (NTech Industries 2006).

3.2 Materials and methods

3.2.1 Study Area

The study was conducted at the University of Limpopo, Mankweng, Limpopo Province, South Africa, situated about 40 km from Polokwane (Fig 9 below). The area is characterized by hot dry summers and cool winters, with an annual rainfall from 400 to 500 mm/a. The temperature ranges from an average minimum of 6°C in winter to an average maximum of 28°C in summer. The location is situated between latitudes 23.46° and 23.48°S and longitudes 29.42° and 29.47°E and lies at an average altitude of 1400 m above sea level. The study area has sandy-loam soil of the Hutton form, Glenrosa family, with a pH ranging from 6.0 to 6.2. The study was conducted outside a greenhouse in an open area wherein pots were put outside of the greenhouse.

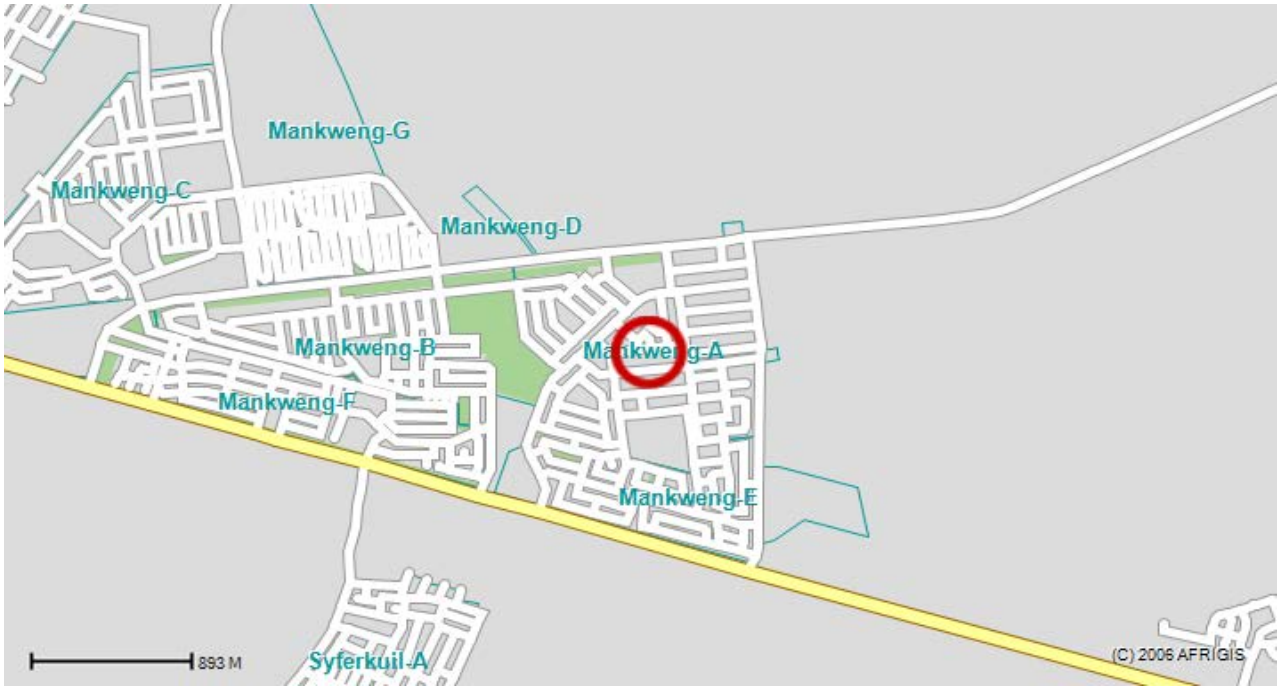

Fig 9: Location map of study area

3.2.2 Growing plants

Commercial tomato seeds of cultivars Roma VF and Flora Dade were planted in small pots of about 30 x 30cm and placed in the greenhouse for a period of 2 to 3 weeks. The pots were later taken outside the greenhouse to an open space. The study was carried out for a period of 3 to 5 months (September 2007 to January 2008). A number of 24 Roma VF plants were planted; 12 plants with nitrogen applied (treated) and 12 plants with no nitrogen applied (untreated control). Twenty-four Flora Dade plants were planted in the same way. Both tomato cultivars produce well under a variety of conditions, are good for commercial purposes, fast growing and easily manageable and can grow to a height of 1 to 1.5m.

3.2.3 Irrigation

The tomato cultivars were irrigated 3 times a week. An amount of 500ml of water was applied uniformly in all the plot plants to keep the moisture content of the soil stable.

3.2.4 Fertilizer application

Plastic pots of 30cm diameter were used in the study. The pots were filled with 4 kg sterilized soil of the Hutton form and were fertilized optimally for all nutrients based on total fertilizer for tomato pot trial. The soil was collected at the Syferkuil experimental farm of University of Limpopo. The soil was analyzed for inherent present nutrients (P and K) as well as pH. The fertilizers were weighed into a glass beaker using a Mettler AC100 balance with o.ooo1g readability. Distilled water was added and the fertilizer salts were allowed to dissolve. The soil was weighed using a Mettler PE 6000 balance accurate up to 0.01g readability. The fertilizers Urea [$(NH_2)_2CO$] (46%N), Superphosphate [Ca (H_2

$PO_4)_2$] (10%P) and KCL (50%) were added to the soil. The soil was analyzed for the presence of nutrients (N, P and K) as well as pH before the experiment. The nutrient status of the soil sample used in the pot trial was determined by the following methods: Phosphorus was determined using Bray 1 extraction method, Potassium was determined using ammonia acetate extraction and atomic absorption spectrophotometer and the pH was determined using water extraction method. The results of soil analysis are presented in Table 2. The pots with nitrogen applied were referred to be the treated experiment while the pots with no nitrogen applied were said to be control/untreated experiment.

Table 2. Nutrient status of soil sample used in pot

P(ppm)	K(ppm)	pH(H_2O
17	382	5.92

The fertilizer application was then calculated based on fertilizer requirements of tomato (Keller & Mengel, 1986) (Table 3). The weight of the soil of 1 ha of soil at 30cm plough depth was calculated at a soil bulk density of 1.33 g/cm^3:

100m X 100m X 0.3m (plough depth) X 1333kg m^3 (bulk density) = 3.999x 10^6 kg/ha

The weight of the soil in one 30cm diameter plastic planting pot used in the trial was 4kg. the ratio of one pot to one hectare was thus calculated to be: 1:1999750

Utilizing this ratio for calculations of fertilizers to be applied in plastic pots (30 cm diameter) with drainage holes at the bottom were filled with soil. Soil was sterilized using autoclaving method at 121^0C for a minimum of 30 minutes before it was put into plastic pots. The soil was fertilized optimally for all nutrients based on tomato fertilizer

requirements. The soil was mixed with the fertilizers by spreading the soil in a black refuse bag and the fertilizer solution (drawn up in a 100ml pipette) was evenly sprinkled onto the soil surface. The bag was closed and the soil and fertilizer solution thoroughly mixed. Coarse sand was put at the bottom of each pot to ensure good drainage. The prepared soil was then added to the pot and lightly firmed.

Table 3: Total fertilizer for tomato pot trial

Fertilizer	Treated with N		Not treated with N	
	Kg/ha	g/ha	Kg/ha	g/ha
Urea	260.87	0.261	0	0
Superphosphate	761.91	0.762	761.91	0.762
KCl	60	0.060	60	0.060

3.2.6 Instruments for data collection

A GreenSeeker hand held optical sensor unit was used for ground measurement of NDVI. The unit can be connected to a bluetooth GPS receiver. The receiver is mostly used in large scale farming to determine the location when working in the field by showing the latitude and longitude values from the navigation satellite (Sabins, 2000). The data from the sensor are logged into the COMPAQ iPAQ pocket PC using the GPS coordinates. However, in this study, data was collected while holding the GreenSeeker above the pot.

3.2.7 Data collection

During this study, the following data were collected:

I. NDVI values were recorded at three growth stages: seedling, 50% flowering and 50% fruiting using the green seeker hand held optical sensor unit;
II. N-content was determined (see section 3.2.8) at three growth stages using leaf tissue samples of the two cultivars *Roma VF* and *Flora Dade* after every strip using the optical sensor unit (GreenSeeker) at three stages;
III. Number of fruits per plant was determined twice (90 days; 110 days after planting); and
IV. Fruit yield was collected in grams per pot and converted to kg/ha.

3.2.8 Leaf Nitrogen Analysis

Total Leaf Nitrogen analysis was done using "The Primacs^{sn} Nitrogen Analyzer". This machine uses high temperatures of about 1100^{o}C to burn samples and the method is called "Dumas Combustion". These provide fast, reliable, accurate, total nitrogen results on sample weights of 10-1000 mg. Whole leaf total N analysis evaluates overall nutrient status of a single plant.

3.2.9 Data analysis

Analysis of Variance (ANOVA) was carried out on measured variables at three growth stages for comparison. The descriptive statistics including the mean, coefficient of variation, R^2 (coefficient of determination) were calculated using Statistics Package of

Social Science (SPSS, 2006). NDVI values, total nitrogen (N) on leaf samples, Number of fruits (NF) and fruit yield (FW) were correlated with and without N-application.

3.3 Results

3.3.1: Normalized differential vegetation index

The NDVI readings were determined among the two tomato cultivars at three growth stages with and without the application of N. The analysis of variance (Appendixes 8.1a and b) for the NDVI shows significant differences between cultivars only when N was applied (Appendix 8.1a). There were no significant differences among stages and cultivar*stage for NDVI reading. The results shows no significant variation between stage, cultivar and cultivar+stage when there was no application of N.

The mean values together with grand mean, LSD and coefficient of variation of NDVI on cultivar and stages are presented on Table 4. The grand mean value for cultivars Flora Dade and Roma VF was 0.83 with N application. This value was 0.81 without N-application. The cultivar Roma VF with N applied had higher NDVI values than the cultivar Flora Dade with N applied across the three growth stages by about 0.03 units. However, there is no significant difference between the two cultivars without N applied across the three growth stages. The NDVI mean values for tomatoes with nitrogen applied was found to be 0.04 units higher than that of tomatoes without nitrogen applied. In both stages, CV values were relatively small, thus indicating the precision of this comparative experiment.

Table 4. The NDVI readings during the experiment involving three growth stages, with and without N-application in tomatoes

Cultivar	NDVI reading					
	Seedling		50% Flowering		50% Fruiting	
	Without N	With N	Without N	With N	Without N	With N
Flora Dade	0.81	0.83	0.81	0.83	0.80	0.83
Roma VF	0.81	0.86	0.81	0.86	0.81	0.87
Grand Mean	0.81	0.85	0.81	0.85	0.80	0.85
LSD 5%	0.06	0.06	0.06	0.06	0.05	0.06
CV%	8.22	8.36	8.03	7.77	7.20	7.31
R^2	0.139	0.455	0.213	0.510	0.240	0.603

3.3.2 Nitrogen content

The N-contents of tomato cultivars during the experiment were recorded at the three growth stages, with and without N-application. The analysis of variance (Appendixes 8.2a and b) for the N-content shows highly significant differences between cultivars at P=0.01 only when N was applied (Appendix 8.2a) and also highly significant differences between the growth stages when N is not applied. There were no significant differences between stages and cultivar*stage for N-content when N is applied, and there were also no significant differences between cultivars and cultivar*stage without N application. For N-content, the R^2 value for tomatoes with N applied was 0.59, which was greater than for tomatoes without supplied N fertilizer (0.38) (Appendixes 8.2a and 8.2b).

Mean values, grand mean, LSD, coefficient of variation and R squared of nitrogen content for cultivars, stage and control (not supplied with N) are presented in Table 5. The grand mean value for cultivars Flora Dade and Roma VF were 3.30 g/plant with N application.

This value was 2.94 g/plant without N-application. The cultivar Flora Dade with N applied had higher N-content (3.38 g/plant) than the cultivar Roma VF with 3.22 g/plant when no N is applied across the three growth stages. However, there was no significant difference between the two cultivars without N applied across the three growth stages. The N-content mean values for tomatoes with nitrogen applied were found to be 0.36 g/plant higher than that of tomatoes without nitrogen applied.

Table 5. The leaf N-content of tomato cultivars during the experiment involving three growth stages, with and without N-application in tomatoes

	N-content (g/plant)					
	Seedling		50% Flowering		50% Fruiting	
Cultivar	Without	With	Without	With	Without	With
Flora Dade	3.01	3.49	3.01	3.33	2.72	3.33
Roma VF	3.07	3.14	3.04	3.13	2.80	3.38
Grand Mean	3.04	3.31	3.03	3.23	2.76	3.35
LSD 5%	0.24	0.16	0.25	1.70	0.24	0.28
CV%	8.81	5.33	9.07	7.36	10.07	9.13
R^2	0.78	0.79	0.650	0.789	0.190	0.823

3.3.4: Number of fruits (NF)

The numbers of fruits during the experiment were recorded for the two tomato cultivars at 50% fruiting stage with and without the application of N. The analysis of variance (Appendixes 8.3a and b) for the number of fruits shows no significant differences between the growth stages, tomato cultivars and cultivar*stage with and without N. For number of fruits, the R^2 value for tomatoes with N applied was 0.44, which was greater than tomatoes with no application of N fertilizer (0.40).

The mean values of the number of fruits together with grand mean, LSD and coefficient of variance are presented in Table 6. The mean values of the number of fruits at 50% fruiting stage for cultivars Flora Dade and Roma VF were 9 fruit per plant with N application. These mean values were 5 fruit per plant without N application. The mean differences between tomatoes with nitrogen applied and those with no nitrogen application was found to be 4 fruit per plant, which is more or less the same with the mean values of tomatoes with no nitrogen application (5 fruit p/plant).

3.3.5 Fruit yield

The fruit yield during the experiment was recorded for the two tomato cultivars at 50% fruiting stage with and without the application of N. The analysis of variance (ANOVA) for fruit yield in kilograms per hectare is presented in Appendixes 8.4a and b with and without N application. The analysis of variance (Appendixes 8.4a and b) for fruit yield shows highly significant differences between the two tomato cultivars with and without N at P=0.01 and, in addition, no significant differences between the growth stages and cultivar*stage with and without N application. The fruit yield R^2 value for tomatoes with N applied was 0.74, which was greater than tomatoes with no application of N fertilizer (0.70). This shows that N-content of tomato cultivars was explained by the application of N-fertilizer.

The mean values for the fruit yield together with grand mean, LSD and coefficient of variance are presented in Table 6. The mean values for fruit yield at 50% fruiting stage for cultivars Flora Dade and Roma VF were 438.52 g/pot with N application. These mean

values were 170.71 g/pot without N application. The mean differences between tomatoes with nitrogen applied and those with no nitrogen application was found to be (267.83 g/pot), which is conversely much higher than the mean values of tomatoes with no nitrogen application (170.71 g/pot). Tomato cultivars Roma VF had higher fruit yield mean values than Flora Dade when N was applied.

Table 6. Mean number of fruits per plant and fruit yield for tomato cultivars during the experiment with and without N-application

	Number of Fruits/pot		Fruit yield (g/pot)	
	Without N	With N	Without N	With N
Flora Dade	5	9	157.70	419.73
Roma VF	5	9	183.71	457.30
Grand Mean	5	9	170.71	438.51
LSD 5%	0.65	1.70	2.78	5.36
CV%	14.81	20.67	18.15	13.61
R^2	0.407	0.446	0.701	0.744

3.4. CORRELATION ANALYSIS

Correlation coefficients for pair-wise comparison between NDVI readings, Nitrogen content, Number of fruits and Fruit yield with and without application of N fertilizer is given in Tables 7 and 8, respectively.

Table 7: Correlation coefficient for pair-wise comparison between NDVI readings, Nitrogen content, Number of fruits and Fruit yield with application of N fertilizer[a].

	NDVI	NC	NF	FY
NDVI	1	0.512	-0.981**	0.981**
NC		1	0.649	-0.649
NF			1	-1.000**
FY				1

**Correlation is significant at the 0.01 level.
[a] NDVI=Normalized Differential Vegetations Index, NF=Number of fruits, FY=Fruit yield, NC=Nitrogen Content

As indicated in the Table 7, there was a positive relationship between NDVI values and leaf N content. There are also strong and positive relationships between NDVI values and fruit yield. However, NDVI readings were negatively and significantly related to the number of fruits. There is also a highly significant negative correlation between NF and FY denoted with a value of -1.000** and no significant relation between NDVI and NC, NC and NF, NC and FY. Correlations between NDVI reading for plants supplied with N were higher than correlations between NDVI reading for plants supplied with no N. At low N, the crop was less healthy, less green, and therefore the correlation was lower. This study correlates with the study conducted by Bakhsh (1999) for NDVI measurement on the ground system and aerial system. He reported that both NDVI measurements were best related to nitrogen in the grain crop. Correlation coefficients were 0.84 and 0.91 for NDVI of the aerial system and NDVI of the ground system, respectively. Likewise, both measurement systems could measure total nitrogen well in the wheat crop.

Table 8: Correlation coefficient for pair-wise comparison between NDVI readings, Nitrogen content, Number of fruits and Fruit yield without application of N fertilizer

	NDVI	NC	NF	FY
NDVI	1	0.751*	0.632	-0.447
NC		1	0.410	-0.669
NF			1	0.00
FY				1

*Correlation is significant at the 0.05 level.
[a] NDVI=Normalized Differential Vegetations Index, NF=Number of fruits, FY=Fruit yield, NC=Nitrogen Content.

Table 8 above for correlation coefficient for pair-wise comparison on tomatoes without N applied shows highly significant variations only between NDVI and NC. There are also strong positive relationships between NDVI and NF but not significant. However, NDVI

readings were negatively and slightly or not significant related to fruit yield. Nitrogen concentration in the leaves of the tomato increased with increasing N rates. This study confirms findings of the study conducted by Tucker *et al*., (1995) on grapefruit. On the basis of a linear regression of the pooled data across three years, he reported that leaf N concentration increased by 0.01 g kg^{-1} N increment. The relationship provides a basis for establishing a critical leaf N concentration range to develop leaf N concentration standards and maximum yield needs. Maximum yield is defined as the highest possible yield under a given set of conditions, when the factor under consideration is not limiting. This does not mean the greatest potential yield under all conditions.

The number of fruits without N applied bears no significant relationship with N-content and fruit yield. Fruit number was significantly affected by N application. Application of N consistently and markedly increased number of fruit per plant (Table 6) and subsequently fruit yield. The relationship between fruit number and fertilizer application was described by a linear model that fruit number increased with increasing leaf N concentration.

Finally, a quadratic relationship with regard to fruit yield and N applied on tomatoes was reported by Smith (1966) and Obreza and Rouse (1993). The relationship of fruit yield to leaf N concentration fitted a linear model. Fruit yield increased with increasing leaf N concentration. However, it must be pointed out that the increase in fruit yield might diminish when the leaf N concentration approached higher levels at higher N applications (He *et al*., 2000).

CHAPTER 4

DISCUSSION

4.1 Discussion

The remote sensing technique using NDVI as a dependent variable calculated from reflectance measured in the visible and near infrared channels, using a GreenSeeker hand-held optical sensor unit, indicated its capability as an important tool that can be used effectively and efficiently to determine the tomatoes photosynthetic activity. Relatively few studies have been conducted using this remote sensing technique, i.e., the NDVI. However, the NDVI (0.81) and (0.83) mean values in Table 4 confirm the findings of the studies conducted by Guolian, (1989) and Guyot, (1990). They reported similar reflectance behaviour that is quantitatively evident in this set of field spectral measurements of leaves from soybean plants with mean values of 0.78 and 0.85, respectively. Sabins (2000) also reported corresponding results with mean NDVI values (0.76) and (0.80), and he concluded his findings by saying that: “healthy green vegetation has a spectral difference that is quite different from unhealthy, dry and stressed vegetation”. This significant variation occurs because chlorophyll strongly absorbs energy in the wavelength centred about 450nm and 650nm. He also noticed that the reflectance from healthy green vegetation increases dramatically as one reaches the near infrared portion of the spectrum. Therefore, the reflectance on the near infrared plateau, using NDVI, varies with regard to nitrogen content. The NDVI readings, therefore, provide an indicator such that the higher the NDVI, the greater the level of photosynthetic activity in the crops.

There is a highly significant variation in terms of tomato plants with nitrogen applied (i.e., treated) and the ones without nitrogen application (i.e., control), because cultivar 1 (viz., Flora Dade) and cultivar 2 (viz., Roma VF) showed more or less the same behavioural patterns with nitrogen application, which is probably due to their physiological make-up. The cultivars responded similarly during the growing stages (namely, seedling, flowering, and fruiting stage). The NDVI has been proven a good detector of nitrogen variability.

Factors and processes that regulate and control the crop performance in terms of yield vary in space and time. Therefore, potential improvements in environmental quality and the economic impacts are often cited as a reason for precision farming. Once the variation is adequately assessed, farmers need to match the agronomic inputs to known conditions by employing management recommendations.

The total leaf nitrogen analyzed using "The Primacs^{sn} Nitrogen Analyzer" showed a significant correlation with the NDVI values. These NDVI reflectance values showed a direct proportionality with regard to the total nitrogen content of leaf tissues. The higher the NDVI, the higher the total leaf nitrogen content, and vice versa. The nitrogen mean values calculated with N applied were 3.22 g/plant and 3.38 g/plant, respectively for and together with the mean values without N applied of 2.91 g/plant and 2.97 g/plant respectively, showed contrasting results in comparison to the results by Akin and Gray (1984). They confirmed the mean nitrogen values of 3.5 g/plant and 4.5 g/plant on nutrient sufficiency guideline (see Table 1). This significant variation on nitrogen variability on leaf tissues may be the result of irregular nutrient monitoring, which then

may confirm what was also reported by Hoeft (1994) that plant tissue testing should be done to help identify any growth-limiting nutrient deficiency. Whole leaf total N/P/K analysis evaluates overall nutrient status.

Plants with adequate nitrogen have a dark green colour because of high concentrations of chlorophyll. Conversely, nitrogen deficiency leads to reduced chlorophyll concentrations, and thus *chlorosis* (yellowing) of leaves, more especially on older or matured leaves. This confirms the study conducted by Chancellor and Goronea (1994) on tobacco, vegetable forage and pasture crops. They reported that "lower leaves with mean nitrogen values less than 2.5 % N have a 'fired' appearance on the tips, turn brown, usually disintegrate and fall off". The mean nitrogen values of 2.9 % N and 3.5 % N are also acceptable for tomato production, though they may inhibit optimum growth and yield the potential of tomatoes. Therefore, adequate Nitrogen application should be applied to promote good healthy plants.

Tomato plants with high NDVI reflectance values and high nitrogen content on leaf tissue samples produced fruit with high mean fruit weight of 311 g/pot and those with low NDVI reflectance values yielded fruits with lower mean fruit weight of 121 g/pot. These results can be correlated with the results founded by Thomson and Kelley (1971) for tomato growth and yield attributing characters to evaluate the yield potential of tomato. They reported mean values of 277 g/plant and 355 g/plant. There was quantitative evidence of variation in fruit weight. In this study, the results show constructive comparisons to the findings by Thomson and Kelly (1971). During the study, only one plant was planted in one pot. This allowed the plant to maximize its yield potential subsequently better fruit

weight was achieved without plants competing for nutrients, unlike when two or more plants were planted in one pot.

Availability of nitrogen in tomato also played a essential role in fruit weight. This is because nitrogen is part of amino acids, which in turn make up proteins. Cassman and Plant (1992) reported that “nitrogen promotes rapid growth, increases leaf size and quality, hastens crop maturity, and promotes fruit and seed development”. Adequate treatment of nitrogen should be taken into consideration when planting tomatoes, especially for commercial purposes because that enhances efficient photosynthetic activity and allows plant metabolic processes to take place effectively and increase the fruit weight. Fruit weight can play a very significant role in our markets today, whereby farm products are given prices in terms of their weight, the more the weight, the higher the price (product value).

The productivity of every plant is also determined by the number of fruits the plant can produce. A significant variation on productivity of plant with nitrogen and plant without nitrogen was evident. Greener plants with high NDVI reflectance values and efficient amount of nitrogen available on leaf tissue produced a large number of fruits. The mean values 8 (5 and 10) of number of fruits per plant recorded in this study were found to be different as compared with the mean values 45 (20 and 70) recorded by Papadopoulos and Pararajasingham (1997). The greater the tomato yield, biomass and N taken up by plant have resulted from increased N concentration or accumulation. Plants that produce a large number of fruits with evident outstanding fruit weight can be good for commercial

purposes whereby some will be exported to other countries and will be rendered competent.

In tomato, plant density, number of fruits per plant and average fruit weight determine the ultimate yield (Thomson & Kelley, 1971). The growth and yield attributing characters were recorded to evaluate the yield potential of tomato at different nitrogen application. The fruit yield showed a significant difference between plants with nitrogen applied (treated) and those without nitrogen applied (untreated/ control). The mean yield values of 438.12 g/pot showed efficient and optimum yield for tomatoes with nitrogen than mean yield values of 170.69 g/pot for control. Thomson and Kelley (1971), in their study, reported a yield of 500.72 g/pot and 320.98 g/pot. Their yield mean shows optimum production and is approximately 62.60 g/pot much higher than that of the present study. The mean results of tomatoes without nitrogen (170.69 g/pot) cannot be compared with the mean value tomatoes with nitrogen applied (438.48 g/pot).

4.2 Conclusion

The purpose of the study was to assess nitrogen variability in tomato using Remote Sensing Technique (Ground measurements of NDVI by GreenSeeker NDVI sensor).

- NDVI showed highly significant variation in tomato cultivars with and without nitrogen application. Non stressed plants showed higher NDVI values than stressed plants
- Non stressed plants had higher N content than stressed plants. Plants with adequate nitrogen had more and darker green leaves while the plants with lower N had fewer, pale green leafs.

- Fruit yield: plants with N applied had more yield than plants with no nitrogen applied.
- Number of fruits: stressed plants had fewer fruits than non-stressed plants.
- The plants with lower nitrogen content (untreated/ control) had delayed maturation unlike those with nitrogen applied (treated), which had rapid/ early maturation. Untreated plants took an average of 120 days to maturity while the treated took an average of 100 days to maturity.

The hand held GreenSeeker proved to be a potential tool for assessing nitrogen variability in tomatoes. This technique can be recommended for commercial farming and precision agriculture because of its efficient and effective use in terms of nitrogen variability assessment. It is also time effective, less demanding and can be used with ease.

4.3 Recommendation

The is a need for further research to be conducted on large scale farming since the study showed promising results when conducted under controlled conditions.

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APPENDIXES

ANOVA tables with and without N-application

Appendix 8.1a: The ANOVA of NDVI reading among the two tomato cultivars at three growth stages with the application of N

Sources of variations	SS	DF	MS	F	Fprob
Cultivar	.014	1	.014	4.914	.031*
Stage	.000	2	.000	.074	.929ns
Cultivar*stage	.000	2	.000	.074	.929ns
Error	.162	55	.003		
Total	52.123	72			

R Squared = 0.472
* significantly different at P=0.05

Appendix 8.1b: The ANOVA of NDVI readings among the two tomato cultivar at three growth stages without the application of N

Sources of variations	SS	DF	MS	F	Fprob
Cultivar	6.81E-005	1	6.81E-005	.027	.870ns
Stage	.001	2	.000	.100	.905ns
Cultivar*stage	.000	2	.000	.040	.961ns
Error	.139	55	.003		
Total	46.870	72			

R Squared = 0.150

Appendix 8.2a: The ANOVA of N-content among the two tomato cultivars at three growth stages with the application of N

Sources of variations	SS	DF	MS	F	Fprob
Cultivar	.508	1	.508	9.431	.003**
Stage	.201	2	.101	1.868	.164ns
Cultivar*stage	.492	2	.246	4.565	.015ns
Error	2.965	55	.054		
Total	788.688	72			

R Squared = 0.594
** significantly different at P=0.01

Appendix 8.2b: The ANOVA of N-content among the two tomato cultivars at three growth stages without the application of N

Sources of variations	SS	DF	MS	F	Fprob
Cultivar	.061	1	.061	.604	.440ns
Stage	1.203	2	.602	5.992	.004**
Cultivar*stage	.011	2	.005	.052	.949ns
Error	5.521	55	.100		
Total	636.719	72			

R Squared = 0.38
**significantly different at P=0.01

Appendix 8.3a: The ANOVA of Number of fruits among the two tomato cultivars at three growth stages with the application of N

Sources of variations	SS	DF	MS	F	Fprob
Cultivar	4.500	1	4.500	2.089	.154ns
Stage	.000	2	.000	.000	1.000ns
Cultivar*stage	.000	2	.000	.000	1.000ns
Error	118.500	55	2.155		
Total	6264.000	72			

R Squared = .446

Appendix 8.3b: The ANOVA of Number of fruits among the two tomato cultivars at three growth stages without the application of N

Sources of variations	SS	DF	MS	F	Fprob
Cultivar	.500	1	.500	1.571	.215ns
Stage	.000	2	.000	.000	1.000ns
Cultivar*stage	.000	2	.000	.000	1.000ns
Error	17.500	55	.318		
Total	1770.000	72			

R Squared = .407

Appendix 8.4a: The ANOVA of fruit yield among the two tomato cultivars at three growth stages with the application of N

Sources of variations	SS	DF	MS	F	Fprob
Cultivar	254.172	1	254.172	11.887	.001**
Stage	.000	2	.000	.000	1.000ns
Cultivar*stage	.000	2	.000	.000	1.000ns
Error	1175.981	55	21.381		
Total	142357.958	72			

R Squared = 0.744
**significantly different at P=0.001

Appendix 8.4b: The ANOVA of fruit yield among the two tomato cultivars at three growth stages without the application of N

Sources of variations	SS	DF	MS	F	Fprob
Cultivar	122.417	1	122.417	21.270	.000**
Stage	.000	2	.000	.000	1.000ns
Cultivar*stage	.000	2	.000	.000	1.000ns
Error	316.543	55	5.755		
Total	22213.329	72			

R Squared = 0.701
**significantly different at P=0.001