WATER USE, GROWTH AND DEVELOPMENT OF SUGARCANE AS AFFECTED BY A TRASH MULCHING

By

MATOME FREDDY RABOTHATA

Submitted in partial fulfilment of the requirements for the
Degree M. Inst Agrar (Agronomy)
In the Faculty of Natural and Agricultural Sciences
University of Pretoria

Supervisor: Prof. J.M. Steyn
Co-Supervisor: Prof. J.G. Annandale

August 2009

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

DECLARATION

I hereby certify that this dissertation is my own work, except where duly acknowledged.

I also certify that no plagiarism was committed in writing this dissertation**.**

Signed

Matome Freddy Rabothata

ACKNOWLEDGEMENT

First and foremost I want to thank God Almighty for giving me strength throughout the study.

This work is dedicated to my late Grandmother Maite Mmamini Rabothata, and my late Father, Alfred Rabothata, for being the best parent to me.

I just cannot forget to express my heartfelt gratitude to my supervisor, Prof JM Steyn, for his continuous support and supervision. Without his encouragement I would not have completed this work.

I greatly acknowledge my co-supervisor Prof JG Annandale and the Departmental staff for creating a favourable environment for learning.

Many thanks go to the ‘sugar people’, the South African Sugar Research Institute, for their experimental fields in Komati and technical assistance.

My appreciation also goes to the Water Research Commission for their financial assistance, without which execution of the field work was impossible.

Last, but not least, ARC-Infruitec-Nietvoorbij (Horticulture Division) for their financial support to study at the University of Pretoria.

ABSTRACT

Retention of a sugarcane mulch blanket, following green cane harvesting could increase soil water conservation, soil health (organic matter content and micro-organism activity) and soil nutrient status. However, little is known about the effect of such a mulch layer on sugarcane crop growth and development. To study the latter, an experiment was carried out in Komatipoort at the South African Sugarcane Research Institute's Experimental Station. Row spacing arrangement was either 1.5 m or 1.2 m x 0.6 m tram rows. N14 was planted as a fast canopy growing cultivar and N26 as a slow canopy growing cultivar. Plots were either covered by a mulch layer or left as bare soil. Stalk population, stalk height and radiation interception were measured every second week. Soil temperature readings were logged hourly at a depth of 0.15 m. Preliminary results indicated that early growth and development of sugarcane was delayed under mulch treatments. Stalk length of N26 was reduced more than that of N14. Stalk population of both cultivars were significantly lower under the mulch treatment. Fractional interception of solar radiation was only 50% at 150 days after planting for the mulch treatment, compared to 70% for bare plots. Slow initial growth and delayed canopy development in mulch treatments were associated with low soil temperatures in the period leading up to full canopy closure. Soil temperature in the mulch treatments remained between 3 to 4°C lower than the bare soil treatments. Early indications are that the presence of a mulch layer may reduce early growth and development of sugarcane.

TABLE OF CONTENTS

PAGES

LIST OF TABLES

PAGES

LIST OF FIGURES

PAGES

GENERAL INTRODUCTION

The practice of burning sugarcane before harvesting is widespread in South Africa. The main reason for this is to improve harvesting, handling and milling of the sugarcane. However there are a number of disadvantages to burning, such as poor soil water conservation and low soil carbon content (Graham, 2002). Studies by Graham & Haynes (2005a,b) indicated that mulch retention could improve soil organic matter content (SOM) and microbial activity. According to Yadav *et al*. (1994), apart from increasing nutrient-use efficiency, mulch retention can also improve soil fertility and maintain growth of sugarcane over a longer time.

Trash burning involves careful planning, particularly in and around sensitive areas such as towns, school, clinics, roads and power lines. Conditions are worse in winter due to airflow in the morning that carries smoke from the land to sea coast. This results in fallout of smuts on the residential areas situated along the seaboard. This condition is exacerbated by high temperature inversions and berg winds experienced prior to arrival of cold fronts. In addition, winter is a risk time for runaway fires. The Department of Environmental affairs and Tourism has implemented air pollution legislation (the National Environmental Management: Air Quality Act 39 of 2004) that has some implications (e.g., fines) for individual emitters (Tucker, 1998).

Generally, the main benefits of retaining a mulch blanket (instead of burning the trash) include soil water conservation (Tominaga *et al*., 2002), reduced erosion, increased soil fertility, increased soil organic matter levels (Vallies *et al*., 1996), improved soil structure (Blair, 2000), better weed control (Meyer *et al.*, 2005) and increased yield (Wood, 1991). Disadvantages include higher harvesting and transport costs, slower ratooning, an upsurge of incest pests (such as trash caterpillar, trash worm and *Eldana* stalk borer) and difficulty of undertaking remedial tillage operations (Meyer *et al.*, 2005).

In countries such as Swaziland sugarcane cannot be grown without irrigation. In the case of Australia, almost 60% of sugarcane produced is under irrigation (Inman-Bamber & Smith, 2005). Available irrigation scheduling methods are mostly applied as an approach or strategy to use water efficiently. In a water scarce country such as South Africa, the use of sugarcane residues as a mulch material can be considered to be a good cultural practice to reduce soil evaporation and to increase water-use efficiency.

Although it has been shown that straw mulch could improve soil water conservation by reduction in evaporation and increase in infiltration, interception of precipitation and irrigation water by the mulch can also reduce the amount of water that reaches the soil. Reduction in infiltration amount mostly occurs in case of frequent but small rainfall events (Doring *et al*., 2005). The same detrimental effects may be present if sugarcane residues are used as a mulch. However, little is known about the effect of mulch retention on growth and development of sugarcane grown under irrigation. Therefore, the primary objective of the study was to study the effect of trash mulch on growth, development and water use of sugarcane under irrigation.

CHAPTER 1: LITERATURE REVIEW

1.1. Introduction

The South African sugar industry retains position ten in the world by producing cost-competitive and high quality sugar. The area under production is divided into 14 regions, which extend from Northern Pondoland (Eastern Cape Province) through the coastal belt and midlands (KwaZulu-Natal) to the Mpumalanga Lowveld (Figure 1.1). Apparently, 68% of the total cultivated land is within 30 km of the coast, whereas 17% is within the Midlands of KwaZulu-Natal, characterized by high summer rainfalls. In these regions, the traditional method of burning prior to harvesting is still widespread and aimed to facilitate harvesting and handling of sugarcane (South African Sugar Association, 2005).

Figure 1.1: Sugarcane producing areas of South Africa (Eastern Cape Province, the coastal belt and midlands of KwaZulu-Natal to the Mpumalanga Lowveld). (South African Sugar Association, 2005).

According to Hurley (2002) Local Environmental Committees were established around the sugarcane belt of Mpumalanga and Kwa-Zulu Natal to deal with issues of burning practices. On the other hand, the South African Sugar Association (SASA) had already established an Environmental Sub-committee that advices and regulates burning practices. Tucker (1998) reported that burning of sugarcane creates smut that is carried away by strong winds to residential areas situated along the seaboard. To avoid such incidence, the Department of Environmental Affairs and Tourism had introduced new air pollution legislation, namely, the National Environmental Management Air Quality Act 39 of 2004, which was implemented in 2005. The Act implicates all farmers to take into account factors such as starting date of burning, time, duration, and weather conditions. The practice of burning is also condemned by many environmental activists who encourage sustainable use of land. Furthermore, the burning practice is associated with loss of nitrogen (Lefroy *et al*., 1994) and has a negative impact on the long term status of soil organic matter (SOM) (Biederbeck *et al*., 1980). According to Basanta *et al*., (2003) burning of trash also contributes directly to the “greenhouse effect” associated with global warming.

The benefits of trash mulch management on the other hand were reported by numerous studies (Wood, 1991; Vallies *et al*., 1996; Blair, 2000; Oliveira *et al*., 2000). Although the effect of trash mulch practices on growth and development of sugarcane is not known in particular, various researchers had revealed the effects of mulches on soil temperature, soil water content, the process of SOM decomposition by soil microbes, and soil fertility status (Luo, 1992). It can be assumed that the effects on soil temperature, soil water content and soil fertility status will determine the extent to which crop growth, development and yield will be influenced (Ellis *et al*., 1985; Inman-Bamber, 1994).

1.2. The effect of mulch on soil conditions and sugarcane growth

1.2.1. Soil temperature

Mulching is associated with the ability thereof to modify the soil thermal regime, which may contribute favourably to agricultural practices. By increasing or decreasing soil temperature, specifically under cultivation of sugarcane, one can control germination and plant growth (Whitman et al., 1963). The soil surface temperature can be manipulated through coverings with crop residue. Mulching with crop residue is mainly used to cool or warm the soil surface (Lei *et al*., 2004). The objective is to modify the temperature amplitude at the soil surface and consequently throughout the profile. The albedo of mulching materials is a determining factor in whether the soil will be kept warmer or cooler. Accordingly, a highly reflective material will lower the temperature by reducing the radiant flux reaching the soil surface. A denser and less reflective material will increase the soil temperature by inhibiting evaporation. It will further have an effect of increasing water use efficiency through water conservation (Gupta *et al*., 1981).

According to Gupta *et al*., (1981) and Unger (1978) mulch amongst other things affects the heat balance of the soil surface. In a simple way, the energy balance of the soil surface can be defined as all incoming shortwave and longwave radiation minus all shortwave and longwave radiation reflected or emitted. A simplified equation of the energy balance of the soil surface was described by Campbell & Norman (1998) in equation 1.1:

$$R_n = G + H + LE \tag{1.1}$$

R_n represents net radiation, whereas G, H and LE are soil heat flux, sensible heat flux and latent heat flux respectively; all are flux densities with units of W m^{-2}. Soil heat flux is the energy flux transported from one soil position to another through the process of conduction. Conversely, latent heat flux is defined as the loss of heat through the process of convection from the soil surface to air layers over the soil. Due to the fact that evaporation is related to energy leaving the soil surface, the energy balance can be used to estimate evaporation rate (Campbell & Norman, 1998).

Heat will move mainly through conduction in the soil profile and through convection in the air layer along temperature gradients. When the soil surface is warmer than the air above the mulch, heat will be transferred upwards where free convection dominates. When the soil surface is cooler than the air above the mulch, heat transfer is downward. The process of downward heat transfer is evident during the daytime hours, whereas upward heat transfer occurs during nighttime hours. In most cases, heat transfer by conduction, radiation, free and forced convection is evident. However, free convection is always considered to be effective when forced convection (wind speed) is negligible (Shen & Tanner, 1990).

A study by Bristow *et al*., (1986) concluded that mulching with organic matter could reduce convective heat transfer. It can be concluded that organic mulches have a significant effect on the partitioning of energy at the soil-atmosphere interface (Novak *et al*., 2000). In addition, Luo (1992) came to the conclusion that the effect of mulch on soil temperature is soil water content dependant. On dry and semi-mulched ground, most R_n is dissipated as sensible heat, whereas T_o (soil surface temperature below mulch) is greater than T_a (air temperature above mulch) during the day. However, during the night T_o is lower than T_a. On wet and semi-mulched ground, most of R_n is converted to latent heat and T_o was only a few degrees higher than T_a during the day. This is related to deeper conducted heat in the soil profile (Olasantan, 1999). On the other hand, dry and heavily covered soil result in less or no intercepted solar radiation reaching the soil (Luo, 1992).

Thermal conductivity values of different materials were provided in reviewed literature (Campbell & Norman, 1998). Thermal conductivity of organic materials is as low as around 0.25 W m^{-2} K^{-1} , compared to other soil materials such as soil minerals, quarts and granite, which range from 0.8 to 8.8 W m^{-2} K^{-1}. It is, therefore, true that organic mulches reduce transfer of heat to the soil surface and thus delay increase in soil temperature (Ross *et al*., 1985).

Ham *et al*., (1993) measured soil temperature of plots mulched with trash and black polyethylene at a depth of 0.1 m. The higher temperature under black polyethylene was due to its high short-wave absorptance and conductance of absorbed radiation to the soil. On the other hand, low temperature under trash was related to big air spaces within the 0.075 meter layer of mulch. Olsen & Gounder (2001) further explain the advantage of trash in precluding the conductance of a large amount of absorbed heat from the mulch to the soil due to its low thermal conductivity. However, they concluded that the minimum soil temperature under trash was always higher, compared to other treatments. Accordingly, trash mulch could effectively reduce the soil temperature amplitude.

The effect of mulch on soil temperature could have both positive and negative outcomes on plant growth and depends greatly on the climate. In most temperate areas, soil tend to be cold and wet; as a result mulching practice will reduce evaporation and keep soil colder, which may delay growth and development of a crop. The opposite is also true: in hot regions mulch reduces heat and vapour transfer by conduction, convection and evaporation. As a result, water use efficiency is increased by less evaporation and increasing transpiration (Horton *et al*., 1996). Tucker (1998) stated that trashing in spring is not recommended, especially at high altitude, due to low soil temperature that could slow down the emergence of ratoon crops.

It may be true that trash mulch could have a negative impact on sugarcane by reducing the initial growth rate, tillering and amount of radiation intercepted (Sandhu *et al*., 1980; Venkataramana *et al*., 1984). According to Francois Olivier (Irrigation Scientist, South Africa Sugar Association, 30 January 2006, Personal Communication) these negative effects will depend on various factors, namely, season of harvest, amount of trash material applied and field management practices.

1.2.2. Water use efficiency

Crop residues protect soil surface from solar radiation and reduce wind velocity at the soil surface. This results in increased water infiltration into the soil. The combined effects of increased infiltration and low soil evaporation also result in more available soil water for crop uptake and deep drainage. Consequently, many research findings showed that the main benefit of mulching practice is to increase water use efficiency (Chung & Horton, 1987; Bussiére *et al*., 1994; Yang *et al*., 2006).

The term, water use efficiency (WUE), was described by Tanner & Sinclair (1983) as:

$$WUE = Y/ET \qquad (1.2)$$

where Y is the yield of the crop (total harvestable biomass or marketed yield), and ET is evaporation from soil, plant leaves and through the stomates (transpiration). In fact, the idea was proposed way back by de Wit (1958) who observed a good relationship between crop yield and transpiration. It is almost impossible to separate transpiration from evaporation, hence the loss is termed evapotranspiration. Mulching is one of the cultural practices aimed at reducing soil evaporation and intensifying transpiration. The impacts of mulches on the soil-atmosphere interface were related to modification of the energy balance components (Stewart & Power, 1983). The practice of mulching or green cane harvesting was proven to save up to 100 mm of water per annum (Stranack, 1998), Mulching is therefore recommended for crops such as sugarcane, which is sensitive to soil water deficits (Gascho, 1985).

A study way back by Greb (1966) on mulch practices concluded that mulching reduces soil evaporation by reducing soil temperature, hindering vapour diffusion, absorbing water vapour onto mulch tissue, and reducing wind speed gradient at the soil-atmosphere interface. Sauer *et al*., (1996) also found mulches to reduce soil water evaporation by 34% to 50%. Similarly, Deibert *et al*. (1986) reported mulch to increase precipitation storage efficiency. Precipitation storage was defined as the amount of soil water stored in the upper 1.2 m soil, relative to the precipitation during the part of the growing season when no active growth occurs. In another study, Zhai *et al*., (1990) compared the effect of mulch on the amount of intercepted precipitation under tillage and no-tillage practices. The interaction of mulches and no-tillage practices showed a significant amount of precipitation being intercepted and low soil water evaporation.

According to Unger & Jones (1981) and Dekker & Ritsema (1997) the effect of mulch in reducing soil evaporation is short-lived and only effective during the early stages of crop development. This is due to the fact that the plant canopy size increases with time to shield the soil surface and substitute the benefits of mulching (Fabrizzi *et al*., 2005). In addition, Unger & Parker (1976) concluded that the thickness of residue are more effective than mass per unit area in controlling evaporation.

According to Army *et al*., (1961) crop residues reduce vapour diffusion from the site of evaporation to the atmosphere by increasing the thickness of non-turbulent air above the soil surface. There are factors which predict the effectiveness of mulching materials on the evaporation reduction, including soil type, atmospheric evaporativity, interactions between soil type and evaporativity, and mulch rates. According to Wind (1961) the effect of mulch on reducing the evaporation from the soil surface also depends on wetness of the surface. In another words, drier soil behave like a mulched surface. The upper drier soil layer protects soil water in the deeper layers from evaporating. However, mulching a wet soil surface will reduce evaporation and keep the upper layer wet for longer periods, compared to unmulched surfaces (Movahedi-Naeni & Cook, 2000). Accordingly, mulching reduce drying of the upper layer of the soil, and as a result, more soil water is stored for uptake by the finer upper plant roots (Wind, 1961).

1.2.2.1. Effect of mulch and soil type on evaporation reduction

There is a relationship between soil type and the effectiveness of mulching materials on evaporation reduction (Tolk *et al*., 1999). In fine-textured soil with high water holding capacity, soil remains wet for longer than course textured soil. In fine textured soil the upper layer stays wet for longer, thus making mulching more effective. On the other hand, course textured soils dry up quicker and maintain higher hydraulic conductivity in the drier range than fine-textured soil, thus mulching is less effective. In most cases, sandy loam soils exhibit intermediate behaviour, compared to other soil types (Wind, 1961; Steiner, 1989).

1.2.2.2. Effect of mulch and atmospheric demand on evaporation reduction

Atmospheric demand (E_o) could be a vital factor when evaluating effectiveness of mulch in evaporation reduction. According to Jalota & Prihar (1990) when E_o is high, evaporation reduction by mulching is high compared to an unmulched surface. However, evaporation reduction under mulch will continue as long as the soil surface is kept wet under the mulch. If the soil surface under mulch dries up, the rate of evaporation will be equal to the rate from bare soils. Under low $E_{o,}$ due to the low rate of drying up of the soil surface, the cumulative evaporation reduction increases more gradually but continues to increase for a longer period (Jalota & Prihar, 1990).

1.2.2.3. Interaction of soil type, atmospheric demand, and mulch on evaporation reduction

An interaction exists between soil type and evaporativity (atmospheric demand), which affect the evaporation reduction by mulching. Soils with high water retention can keep more soil water on the soil surface for longer periods due to its low infiltration rate. As a result more soil water is lost through evaporation when E_o is high, and thus mulching is more effective. Course textured soils, and sandy soils in particular, self-mulch more quickly after irrigation than fine-textured soils when E_o is high, and thus mulching is less effective in course textured soils (Prihar *et al*., 1968).

1.2.2.4. Effect of mulch rates on evaporation reduction

The rates at which mulch is applied affect the rate of evaporation reduction. According to Unger & Parker (1976) the percentage of the soil surface covered by residue (or amount of residue per unit area) or the thickness of the mulch materials are vital factors which influence reduction in evaporation. The area covered and the thickness of mulch materials is determined by the dry mass applied per unit area and the density (Unger & Parker, 1976). On the other hand, reduction in evaporation from soil cropped with sugarcane depends on row spacing, leaf area index and soil shading (Adams *et al*., 1976).

1.2.3. Soil chemistry and fertility

Srivastava & Sigh (1987) agreed that trash is a source of nitrogen (1.0 – 1.5%), phosphorus (0.005 – 0.01%) and potassium (1.5 – 1.8%). Rita-Dahiya *et al.,* (2003) discovered that sugarcane trash could also reduce surface bulk density and electric conductivity by almost 2 and 6%, mainly if incorporated with inorganic fertilizers such as nitrogen and phosphorus. Trash mulch could also be more efficient in recycling nitrogen and as a result less input of nitrogen fertilizer is required (Basanta *et al*., 2003).

Singh & Singh (2002) found that application of both sugarcane trash and nitrogen increased cane yield significantly. It could be attributed to the importance of nitrogen required for initial trash decomposition. A study by Jamuna *et al.*, (2003) revealed that the integrated use of a 100% recommended dose of fertilizer and sugarcane trash mulching at three tons per hectare, applied with compost culture at one kg/ton of mulch, increased yield of rainfed sugarcane by 33.7%. However, Rana *et al*. (2002) warned that mulching practices with sugarcane trash could also be associated with reduced soil pH.

1.2.4. Mulch and soil microbial activity

The importance of creating suitable soil conditions for soil microbes was summarized in reviewed literature (Bottner, 1985, Gupta & Germida, 1988). By trash retention, one can improve soil microbial activity which contributes directly or indirectly to soil fertility through the process of decomposition and transformation (Tucker, 1995).

According to Wick *et al*. (1998) microbial biomass content (MBC) is referred to be one of the most important general guides to assess soil microbial activities. As a result, any adopted tillage and other management practices, including trash burn or retention, will effectively influence soil MBC and soil organic content (Carter, 1986; Zhang *et al*., 1999).

It can be concluded that microbial activity determines the availability and ultimately utilization of soil nutrients by plants. As a result, self-maintaining capacity of the soil can be improved (Wick *et al*., 1998). It is therefore important to manage soil organic content which in turn will enhance soil quality and ecosystem functioning. Accordingly, limiting the practice of trash burning prior to harvesting can improve microbial activity and soil organic content (Srivastava & Singh, 1987).

1.3. Weed control

Very little weed growth occurs under mulches as the mulch prevents penetration of light or excludes certain wavelengths of light that are needed for the weed seedlings to grow (Ossom *et al*., 2001). Ma & Selim (2005) reported that sugarcane trash could reduce the efficacy of applied herbicides and identified a need to understand the movement of herbicides in soils amended with sugarcane trash. As a result, a model was developed to predict transport of pesticides within mulch-amended soils (Ma & Selim, 2005).

A report by Dwivedi (1999) proved the success of using sugarcane trash to control weeds over Paraquat and hand hoeing, and further recommend trash mulch in an integrated weed management strategy. Mahender-Singh *et al*., (2002) also agreed that sugarcane trash can be an efficient method to control weeds. Sugarcane trash could increase the chances of total elimination of applied herbicides, since they are a threat to a healthy environment. In addition, the practice will directly contribute to reduction in production costs (Tucker, 1998).

1.4. Decomposition of mulch

Girijesh & Chandrasekhar (2002) managed to interview 77% of farmers who practiced trash burning in Karnataka, India. Most farmers agreed on five main reasons for burning: scarcity of labour, lack of time, timely land preparation for ratooning, eradication of pests and diseases, and last but not least, lack of knowledge on trash decomposition.

According to Spain & Hodgen (1994) in Australia a period of 12 months is required to decompose 81% of trash blankets. However, temperature and rainfall play a significant role in the process of trash decomposition (Stott *et al*., 1986). Amanto *et al*., (1987) found a linear correlation between wheat residue levels and rainfall from 12 locations in southern Australia. According to Robertson (2003) the relationship between decomposition rate, rainfall and temperature may vary considerably from one region to another, depending on soil type, trash or field management practices. Yadav *et al*., (1987) recommended the initial application of N fertilizer to reduce the C:N ratio and enhance rate of decomposition.

1.5. The objectives of the study

The objectives of the research project were to study the effect of trash blanket on:

- sugarcane canopy development,
- soil temperatures,
- sugarcane stalk height,
- sugarcane stalk population,
- and sugarcane water use.

CHAPTER 2: MATERIALS AND METHODS

A field experiment was conducted on the South African Sugarcane Research Institute‘s Experiment Station based in Komatipoort (25° 33’S; 31° 57’E, 187 m.a.s.l.). The soil type was a relatively shallow (0.6m) red sandy clay loam soil, classified as a Shortlands with a total available soil water content of 70mm. The soil profile was well drained with no restricted layers.

The primary treatments consisted of two row spacing arrangements, namely, a 1.5m single row spacing (Figure 2.1 & 2.2) and a double or tram row spacing of 1.2 x 0.6 m (Figure 2.3 & 2.4). Approximately 8 tons per hectare of sugarcane mulch was applied immediately after planting and control blocks were left without mulch as the conventional method (simulating the burn practice). Two contrasting cultivars were selected, namely N14, which is a fast canopy growing cultivar, and N26, a slower canopy growing cultivar. Each treatment was replicated five times and completely randomized within the block to give a total of 40 plots (Figure 2.5). The total area occupied by the field experiment was 75m x 120m (0.9 ha) and the size of each plot was 8m x 11m (0.0088 ha). The crop was planted on 25 April 2005.

The above layout was duplicated (80 plots in total) for the purpose of applying two secondary irrigation treatments. One half of the trial (containing all primary treatment combinations, 40 plots) was irrigated according to crop water requirements of control plots (bare soil plots with no mulch cover) – Standard irrigation treatment. The other half of the trial (containing all primary treatment combinations, 40 plots) was irrigated according to crop water requirements of mulched plots – Savings irrigation treatment.

Figure 2.1: Single row spacing (1.5m) of N26 cultivar with no mulch cover simulating the burn practice.

Figure 2.2: Single row spacing (1.5m) of N26 cultivar mulched with sugarcane trash.

Figure 2.3: Double or tram row spacing (1.2 x 0.6 m) of N14 with no mulch.

Figure 2.4: Double or tram row spacing (1.2 x 0.6 m) of N14 cultivar mulched with sugarcane trash.

Figure 2.5: The layout of the trial on the South African Sugarcane Research Institute's Experiment Station based at Komatipoort.

Irrigation was scheduled according to soil water content measurements made by a calibrated 503 DR Hydroprobe (Campbell Pacific Nuclear International Inc. /Boart Longyear Corporation, USA) twice a week, just before and after each irrigation. Irrigation was applied with an overhead floppy irrigation system (on a 12m X 14m grid) on reaching a measured deficit of 30 mm. Twenty rain gauges were placed randomly over the trial to measure rainfall and irrigation accurately.

An automatic weather station was based 100 m from the experimental site to measure daily air temperature, wind speed, solar radiation, relative humidity and rainfall. Soil temperature was measured at a depth of 0.15 m with Copper-Constantan thermocouples linked to a CR10X data logger (Campbell Scientific, Logan, Utah, USA). One sensor was installed in a plot with no mulch cover (bare soil) and one sensor in a plot with a mulch cover. For the determination of fractional interception (FI) of solar radiation, a ceptometer (Model PAR-80, Decagon Devices, Inc., Pullman, Washington, USA) was used to measure photosynthetically active radiation (PAR). Ten measurements were taken above and 10 below the canopy. Fractional interception was calculated according to equation 2.1:

$$FI = 1 - (Rb/Ra) \tag{2.1.}$$

where Ra represents the average radiation reading above and Rb the average radiation reading below the canopy. Measurements of PAR were taken weekly.

Stalk height and stalk population measurements were taken once every 14 days. Stalk population was determined by counting the number of stalks per m^2 and expressing it as the number of stalks per m^2. Height of 15 marked stalks were measured (from the base up to the first visible dewlap) using a measuring tape.

Anova (Analyisis of variance) was performed using the general linear model (GLM) (SAS, 2005). Data from measured parameters (stalk population, height and FI) were pooled and treatment means of all variables measured were separated using the least significance test (LSD) at P<0.05 (Steel *et al*., 1997).

CHAPTER 3: RESULTS AND DISCUSSION

Measurements were taken during the first five months (between April 22 and September 21, 2005) of the growing season and thus only these results are presented. Although the presence of a mulch layer had similar effects on water use, crop growth and development, both results are reported on, irrespective of the irrigation treatments (Standard or Savings).

3.6. Soil temperature

Air and soil temperatures were measured for a period of 150 days after starting the trial (DAS). Due to the winter season, mean soil temperature under both mulch and bare treatments decreased over time, following the same trend as air temperature (0-70 DAS) (Figure 3.1). However, soil temperature under trash plots experienced less daily fluctuation, compared to bare plots. By mid-June (60-80 DAS), mean soil temperatures under both mulch and bare treatments were below 20^{o}C with averages of around 18^{o}C. Soil temperatures under both mulched and bare plots showed an increasing trend just after June (70 DAS) and continued rising to reach about 24^{o}C by mid-September 2005 (150 DAS).

The daily fluctuation in soil temperature below both mulch and bare treatments was much smaller and almost the same towards the end of the study (September 2005, 150 DAS). The similar trends in soil temperature fluctuation under both mulched and bare treatments could be attributed to the increase in canopy size as the crop grew older. Towards the end of 150 DAS plant canopy was well developed, and as a result more surface area was shaded, which provided the same effect as a trash mulch (see Section 3.3). Similar findings were reported by Sadhu *et al*., (1980) and Lei *et al*., (2004). It should be noted that soil temperature has a major effect on the growth rate of roots. Low soil temperatures could drastically reduce root growth, early germination and canopy development.

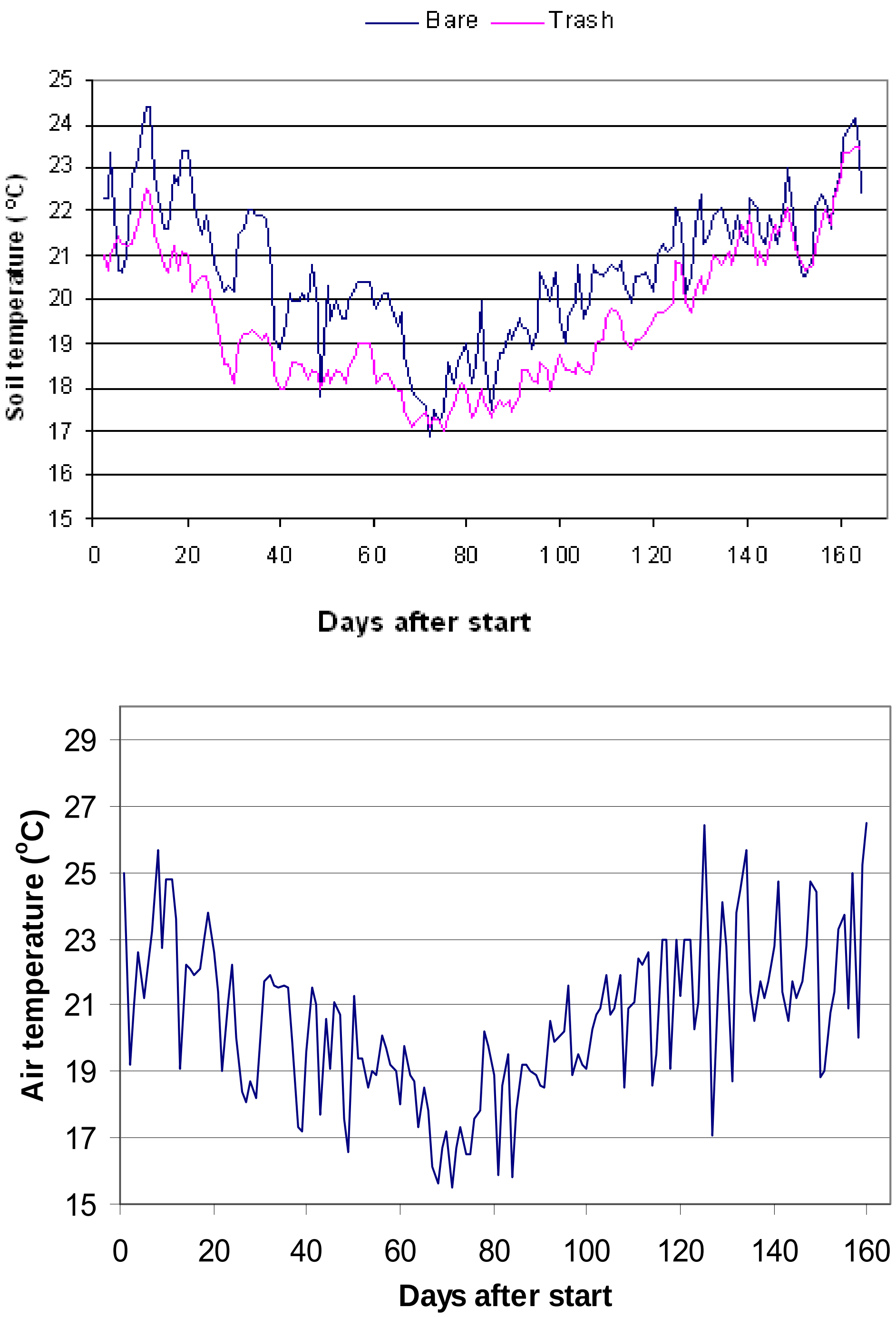

Figure 3.1: (a) Average daily soil temperature measured at 0.15 m depth under a bare soil and a soil covered by mulch, (b) average daily air temperature measured at a height of 1.5 m.

According to Horton *et al*., (1996), the benefits of mulching are climate dependent. During cold seasons, for example, soil evaporation is reduced due to mulches and as a result, the soil remains wet and cold, which hinder grow and development of the crop.

The positive benefits of a trash mulch were evident during summer when it was hot and when the plant canopy was not yet fully developed. Novak et al., (2000) developed a model which focused mainly on understanding radiation transfer within barley-straw mulches and aims at advancing to a microclimate model for soil-mulch-atmosphere systems. This could help to model and understand better the temperatures of mulched and unmulched soil surfaces.

Mulch depth was also measured from the third day after planting until the middle of September 2005 (140 DAS) (Figure 3.2). Mulch depth reduced gradually, not as a result of decomposition, but rather due to compaction of the trash material. The original depth of mulch was between 10 cm and 13 cm, and gradually compacted to between 6 cm and 4 cm. This could, however, not be related to the trend in soil temperature fluctuation displayed under both mulched and bare treatments towards the end 150 DAS. This could be attributed to the increase in plant canopy size, rather than a decrease in thickness of mulch. Accordingly, the effect of mulch on soil temperature becomes less effective as the crop grows older. Simmilar trends towards the end of 150 DAS could also be related to different seasons (e.g., winter and summer seasons, could display different trend of soil temperatures). Although Dekker & Ritsema (1997) agreed that the thickness of mulch is more important than the amount per unit area, the contribution of a well-developed plant canopy in reducing soil temperature during growing later stage should not be ignored.

The results of this study contradict the findings of Olasantan (1999) and Fabrizzi *et al*. (2005), who found that soil temperature under mulch was higher than under bare soils during a cooler season. However, Fabrizzi *et al*., (2005) agreed with Horton *et al*., (1996) that the effect on soil temperature depends on mulch application rates and climatic conditions. Olasantan (1999) further explains that crop residues have a higher albedo and lower thermal conductivity, and as a result solar energy reaching the soil surface is reduced, which consequently lowers soil temperature during warmer seasons. Furthermore, high temperature under mulched treatments during a cooler season is attributed to the ability of bare treatments to loose heat faster than mulched treatments. However, according to Figure 3.1 the opposite was also true in this study. Mulched plots responded differently by keeping soil temperature lower compared to bare plots, even during the winter season.

According to a study by Whitman *et al*., (1963) the optimum temperature for sprouting of sugarcane is around 30^{o}C, whereas a radical reduction in growth parameters is detected at temperatures of around 22^{o}C. The growth was therefore negative when temperature reached between 16 and 10^{o}C. In this study (Figure 3.1 (b)) air temperature fluctuated from as little as 10^{o}C to 35^{o}C during summer, and averaged around 22^{o}C. Accordingly, the growth of sugarcane could have ceased between 50 and 90 DAS (around June and July), due to low air temperatures (average below 22^{o}C). In particular, the combination effect of both low air and soil temperatures could have reduced the number of stalks, growth and yield of sugarcane, mainly under mulched treatments during the winter season.

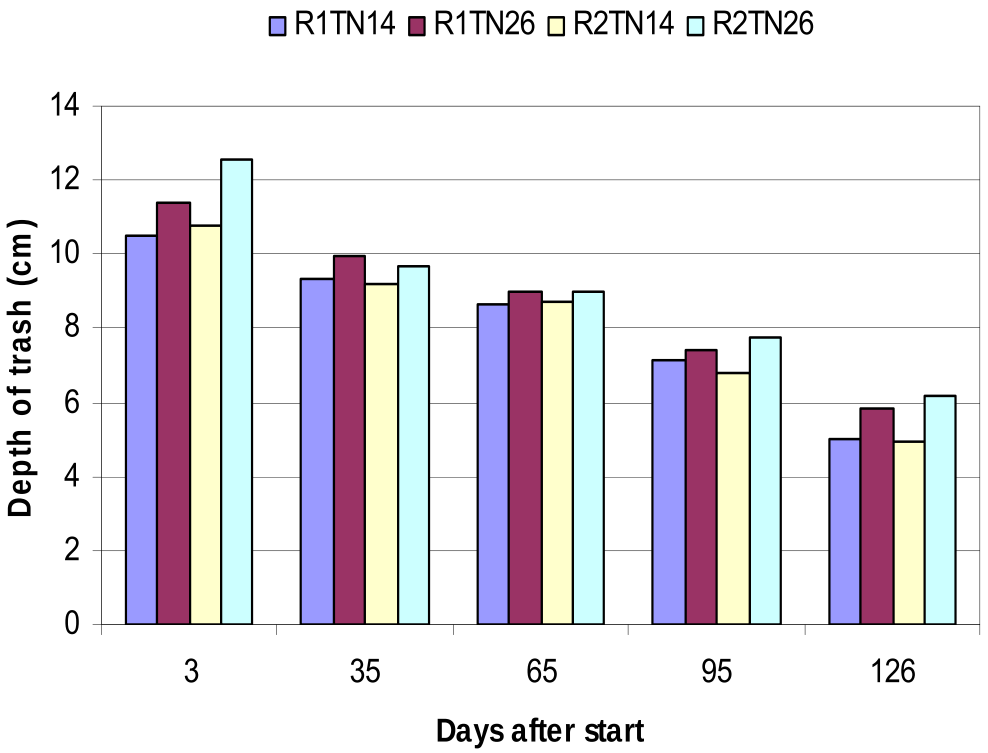

Figure 3.2: Reduction in depth of mulch layers over a period of four months.

3.7. Effect of mulch on stalk population

The number of stalks per unit area is a good measure of sugar yield. In most cases, more stalks per unit area correlate well to higher sugar yield. In this study, irrigation treatments did not affect stalk population (Figure 3.3 and 3.4). The suppressing effect of mulch on the emergence of sugarcane stalks was evident under both row spacing arrangements and for both varieties (Figure 3.3 and 3.4).

In both standard and saving irrigation treatments the final stalk population at 141 DAS was significantly reduced by mulch for both spacing arrangements and varieties (Table 3.1). Emergence of sugarcane stalks under mulch treatments compared to bare treatments was delayed by about 6 days (Figure 3.4). This was true for both row spacing arrangements. From July (100 days after start) the number of stalks per m^2 increased rapidly. This response could be attributed to the gradual increase in air and soil temperatures just after the winter season. This supports findings by Whitman *et al.*, (1963) that air and soil temperature, in particular, affect sugarcane stalk growth and yield. Despite the suppressing effect of trash mulch on stalk emergence, the number of stalks per unit area improved rapidly after the winter season. As already explained, the effect of trash mulch was short lived, as development of a larger plant canopy shaded the soil surface and moderated soil temperatures later in the growing season.

The number of stalks under double row spacing was high compared to single row spacing. In both standard and saving irrigation treatments the final stalk population at 141 DAS was significantly higher in the double row spacing arrangement compared to single rows for both varieties (Figure 3.3 and 3.4). Higher stalk population in double row spacing arrangements was associated with higher planting density per m^2. Although the final stalk population will be determined during the early growth stages of sugarcane, the number will increase until a pre-determined number of stalks is reached. According to Figures 3.3 and 3.4 the combination of mulch, variety and row spacing arrangements had a direct effect on the stalk population that could ultimately affect cane yield. A study carried out by Yang *et al*., (2006) on winter wheat concluded that extreme soil temperature is a critical environmental factor which influences growth and tillering. Similarly, the delay in emergence of stalks under mulch could be related to decrease in soil temperature as the winter season approached. As the winter season faded away, the number of stalks per unit area increased due to improved soil temperature. For instance, soil temperature at 120 days after start reached an average of 22^{o}C for both treatments (Figure 3.1), and the number of stalks per unit area increased under mulch as a result. Although the current increase in soil temperature could be seen as insignificant compared to bare treatments, it seemed to be sufficient to improve plant growth and stalk population.

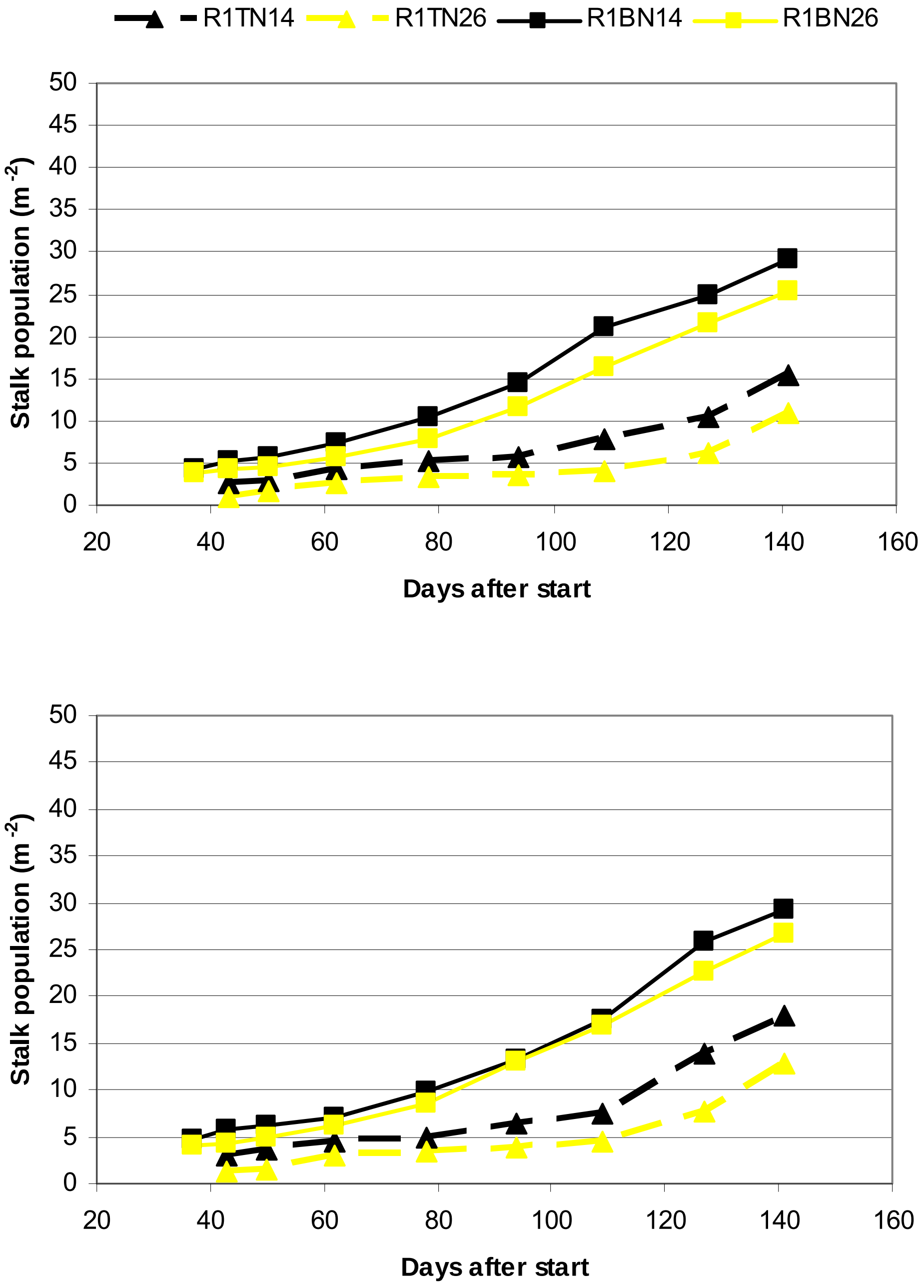

Figure 3.3: Stalk population of bare (B) and mulch (T) plots in a single row (R1) spacing arrangement, (a) Standard and (b) Saving treatments for cultivar N14 and N26.

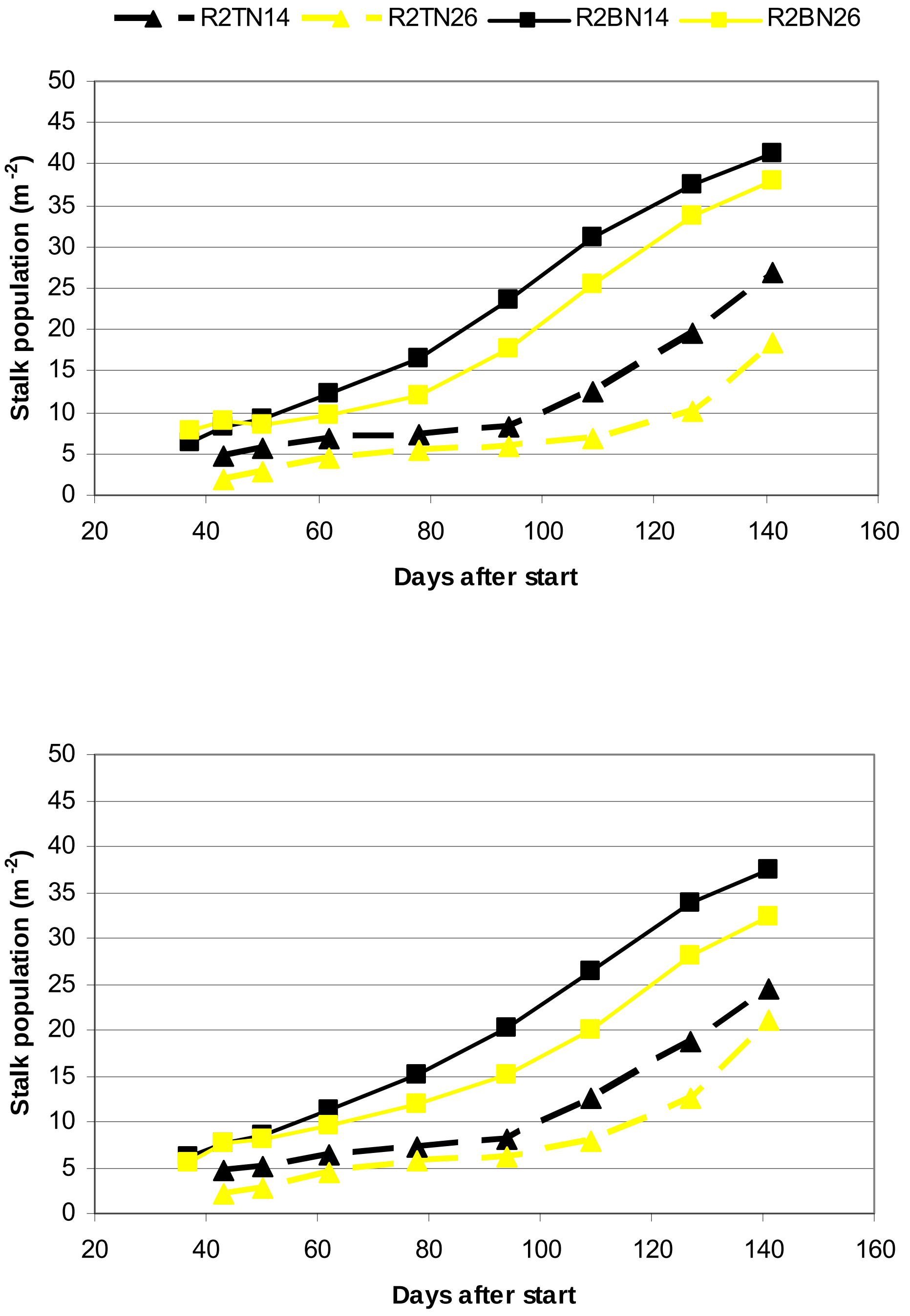

Figure 3.4: Stalk population of bare (B) and mulch (T) plots in a double row (R2) spacing arrangement, (a) Standard and (b) Saving treatments for the cultivars N14 and N26.

Table 3.1: Row spacing X mulch treatment X variety interaction effects on stalk population of planted sugarcane under standard and saving irrigation treatments

Irrigation treatment

Number of stalks (m^2)

DAS	37	43	50	62	78	94	109	127	141
Saving irrigation									
R1BN14	4.80bc	5.66b	6.22b	7.02b	9.74cb	13.32b	17.60b	25.92b	29.26bc
R1BN26	4.14c	4.34cb	4.94cb	6.26cb	8.52c	13.14b	16.94cb	22.62b	26.74bcd
R1TN14	0.00d	3.00cd	3.60cd	4.54cd	4.86ed	6.34dc	7.54e	13.86ed	17.86fe
R1TN26	0.00d	1.36e	1.60e	2.94d	3.48e	3.80d	4.48e	7.58f	12.74f
R2BN14	6.22a	7.70a	8.46a	11.26a	15.06a	20.16a	26.30a	33.78a	37.44a
R2BN26	5.60ba	7.60a	8.12a	9.64a	11.84b	15.10b	19.94b	28.06b	32.34ba
R2TN14	0.00d	4.72b	5.06cb	6.34b	7.18cd	8.14c	12.50cd	18.78cd	24.50cd
R2TN26	0.00d	2.22ed	2.66ed	4.54cd	5.66ed	6.12dc	7.78ed	12.54ef	21.12ed
LSD	1.3151	1.4671	1.5200	1.7936	2.7272	3.7535	4.757	5.5431	6.2975
CV%	39.11	24.75	23.08	21.07	25.38	26.91	25.97	20.98	19.25

Table 3.1 (continued): Row spacing X mulch treatment X variety interaction effects on stalk population of planted sugarcane under standard and saving irrigation treatments

Irrigation treatment

	Number of stalks (m^2)								
DAS	37	43	50	62	78	94	109	127	141
Standard irrigation									
R1BN14	4.34c	5.14b	5.68b	7.42c	10.46cb	14.40cb	21.02cb	24.94b	29.04b
R1BN26	3.88c	4.26b	4.54cb	5.66dc	7.80cd	11.52cd	16.32cd	21.68b	25.40b
R1TN14	0.00d	2.54c	2.94cd	4.18de	5.24ed	5.66ef	7.86ef	10.42c	15.40dc
R1TN26	0.00d	0.96d	1.60d	2.66e	3.20e	3.62f	4.04f	6.12c	10.82d
R2BN14	6.28b	8.16a	9.10a	12.16a	16.60a	23.58a	31.16a	37.52a	41.18a
R2BN26	7.68a	8.90a	8.50a	9.66b	12.12b	17.78b	25.50b	33.68a	37.96a
R2TN14	0.00d	4.82b	5.76b	6.96c	7.22cd	8.28ed	12.56ed	19.56b	26.78b
R2TN26	0.00d	1.94dc	2.72d	4.40de	5.38ed	6.02ef	6.86f	10.20c	18.34c
LSD	1.0124	1.1755	1.7570	2.139	3.2472	3.6486	4.8772	5.6498	5.0971
CV%	28.18	19.76	26.56	24.87	29.47	24.79	24.03	21.25	15.35

Note: Values followed by the same letter in a column are not significantly different at P = 0.5 or less.

3.8. Effect of mulch on canopy development

The amount of solar radiation intercepted by the canopy is a good measure of the size and rate of canopy development. Interception of radiation (FI) by the crop canopy is shown in Figure 3.5 for single row and Figure 3.6 for double row spacing arrangements. In both cases canopy development was initially slow, but form 90 days after start there was a rapid increase in development. The cultivar N14 intercepted more radiation compared to N26. N26 is known as a slow growing cultivar; and was therefore chosen deliberately to compare the effect of mulch on varieties with different growing patterns and characteristics. Fractional interception was considerably reduced by mulch for both varieties and row spacing arrangements. According to Table 3.2 both variety and row spacing arrangement had significant effects on final stalk population at 155 DAS. Although N26 showed signs of slow canopy development, application of trash exacerbated the conditions.

The suppressing effect of mulch was evident from 90 days after starting onwards. Hence, canopy cover of bare treatments increased more rapidly than mulched plots. As already mentioned, N26 is a slow growing cultivar and suffered most from poor canopy development under mulch treatments. The reason for high FI values under double or tram row spacing, compared to single rows, is the higher population of stalks per m^2 planted for tram rows. Generally, varietal differences in canopy development were also evident in double row spacing arrangements. Sugarcane canopy development, according to Inman-Bamber (1994), depends mainly on the rate of tillering, leaf appearance and leaf extension as well as the size of each leaf. In this study, the rate of tillering was mostly reduced for cultivar N26 due to mulch. Generally, the light interception of mulched treatments was lower at the end of the five months growing period, compared to bare treatments. However, this gap could be closed later in the crop growth cycle due to diminishing effects of mulch on stalk growth.

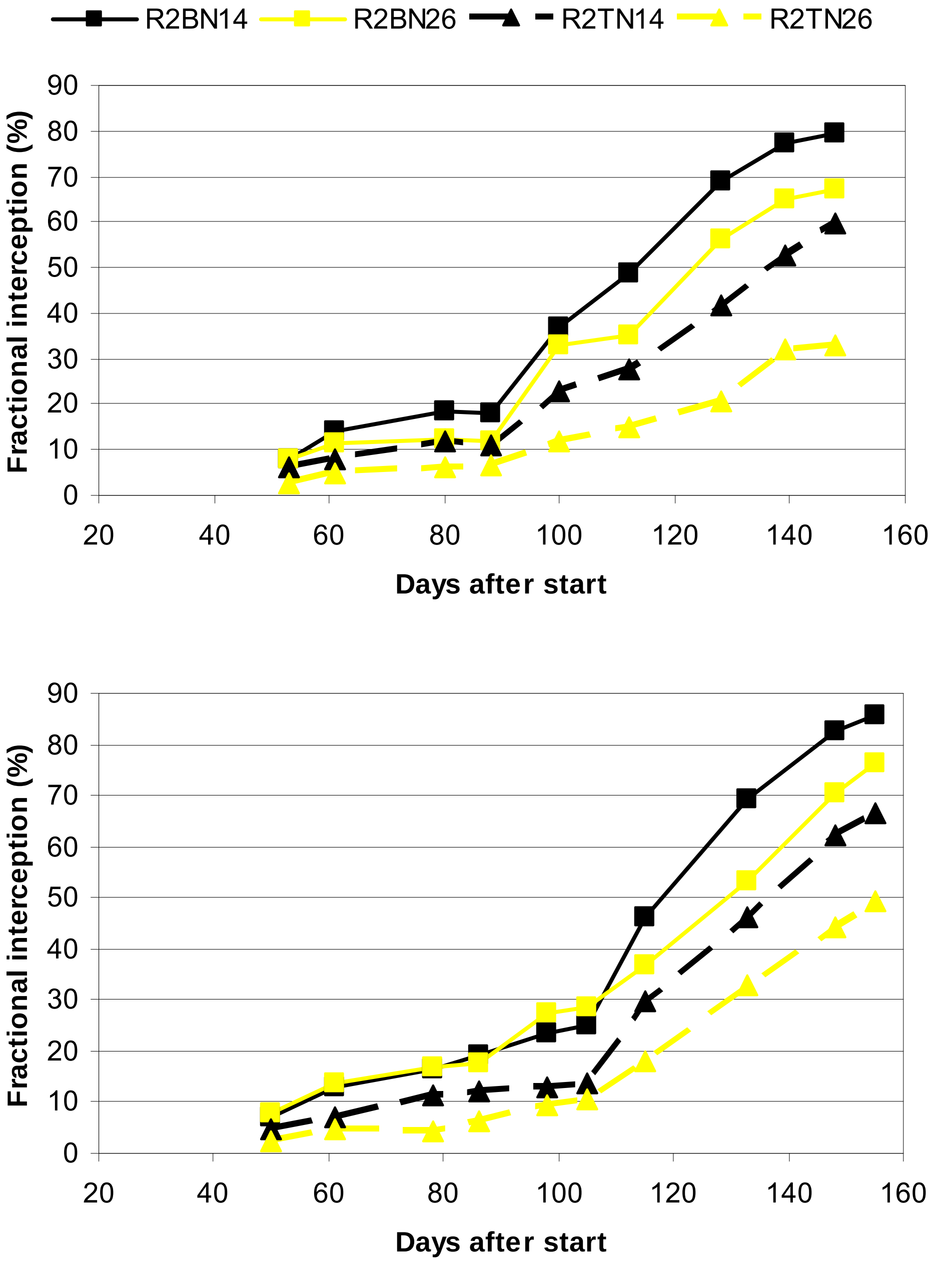

Figure 3.5: Fractional interception of bare (A) and mulch (T) plots in a single row (R1) (a) Standard and (b) Saving treatments for cultivars N14 and N26 spacing arrangement.

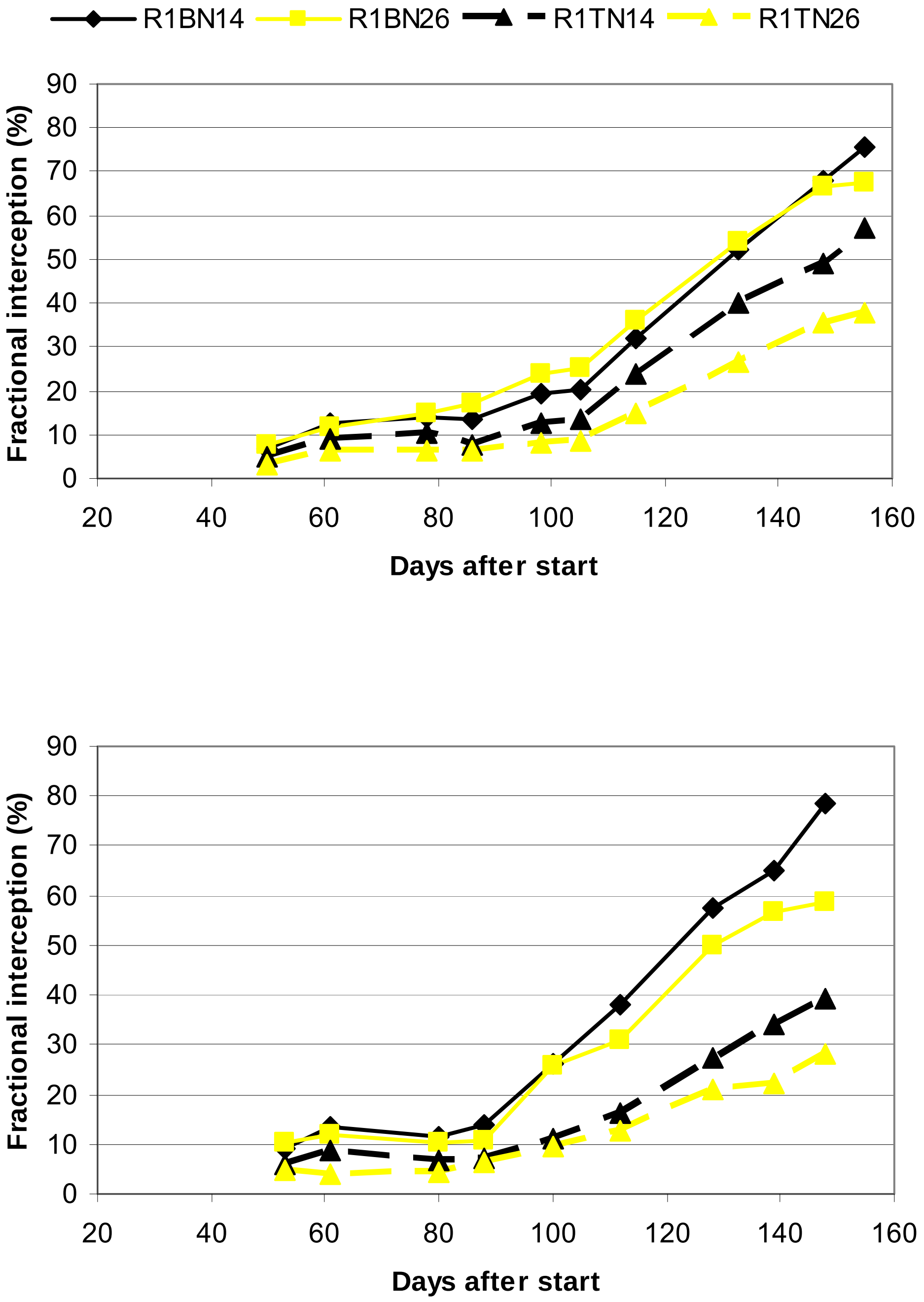

Figure 3.6: Fractional interception of bare (B) and mulch (T) plots in a double row (R2) spacing arrangement, (a) Standard and (b) Saving treatments for cultivars N14 and N26.

Table 3.2: Row spacing X mulch treatments X variety interactions effects on fractional interception of planted sugarcane under standard and saving irrigation treatments

Irrigation Treatment

					FI					
DAS	50	61	78	86	98	105	115	133	148	155
Saving Irrigation										
R1BN14	6.64bac	12.63ba	14.06ba	13.56bc	19.34b	20.24bc	31.92cb	52.26b	67.98b	75.66b
R1BN26	7.74ba	1.93ba	14.78ba	16.96bc	23.98ba	25.16ba	36.00b	54.14b	66.74b	74.77cb
R1TN14	5.16bdc	8.96bc	10.38bc	7.66d	12.48c	13.30dc	23.90d	39.88cd	49.04c	57.18d
R1TN26	3.34ed	6.26c	6.20dc	6.32d	8.06c	8.46d	14.82e	26.42e	35.70d	37.60e
R2BN14	6.98bac	12.86ba	16.62a	19.32a	23.58ba	24.96ba	46.00a	69.22a	82.42a	85.60a
R2BN26	7.94a	13.76a	16.74a	17.68a	27.28a	28.46a	36.94b	53.32b	70.50b	76.44b
R2TN14	4.86edc	7.20c	11.38b	12.16c	12.96c	13.80dc	29.76c	46.22cb	62.02b	66.68c
R2TN26	2.48e	4.83c	4.36d	6.28d	9.54c	10.62d	18.06e	32.82ed	44.18dc	49.22d
CV%	36.39	26.41	32.24	24.75	26.03	31.75	14.39	15.14	11.58	9.66
LSD	2.6606	4.5368	4.9359	4.0061	5.7843	7.4576	5.5335	9.177	8.9791	8.2985

Table 3.2 (continued): Row spacing X mulch treatments X variety interactions effects on fractional interception of planted sugarcane under standard and saving irrigation treatments

	FI								
DAS*	53	61	80	88	100	112	128	139	148
Saving Irrigation									
R1BaN14	9.30ba	13.46a	11.64cb	14.04ba	26.20b	38.00b	57.44b	65.18b	78.48a
R1BaN26	10.22a	11.80ba	10.44cbd	10.64bc	25.80b	31.00cb	49.78cb	56.58cb	58.80b
R1TN14	6.00bdc	8.60bc	6.56ced	7.00c	11.16c	1 6.08d	27.20d	34.04d	39.30c
R1TN26	4.72dc	3.96c	4.52e	6.50c	9.52c	12.88d	20.82d	22.32e	27.98d
R2BN14	8.06bac	14.03a	18.44a	18.06a	36.82a	48.68a	68.80a	77.38a	79.36a
R2BN26	8.08bac	11.63ba	12.44b	12.02bc	33.00a	34.92cb	56.14b	64.82b	67.06b
R2TN14	5.96bdc	7.96bc	12.00b	10.98bc	22.72b	27.60c	41.86c	52.86c	59.70b
R2TN26	2.56d	5.03c	6.24ed	6.74c	11.78c	14.78d	20.68d	32.18ed	32.84dc
CV%	39.88	27.90	38.27	42.67	22.49	22.02	16.69	16.27	15.46
LSD	3.5458	4.6722	5.1002	5.9419	6.4482	7.9886	9.2646	10.684	11.105

Note: Values followed by the same letter in a column are not significantly different at P = 0.5 or less.

* The days after start for saving irrigation differ from standard irrigation due to late canopy development under mulched treatments.

3.9. Effect of mulch on stalk height

Sugar yield depends directly on the number of stalks per unit area and the average length or height of stalks at harvest. In single rows, stalks of N26 in mulched plots were always shorter than the bare plots (Figures 3.7 and 3.8). Stalk height in double rows were not affected by mulch treatment. Stalk or final height, mostly for cultivar N14, under double rows was generally taller compared to stalk height under single rows. In addition, stalks of N14 tended to be taller than that of N26 (varietal difference). Generally, stalk height of both cultivars were often shorter under single row spacing than double rows (Table 3.3). Venkataramana *et al*., (1984) evaluated various sugarcane cultivars, and correlated such varietal differences to environmental parameters, in particular air temperature and soil temperature were critical factors. The differences between the heights of mulched and unmulched treatments were mostly insignificant. Differences in stalk height could mainly be attributed to varietal effects. The cultivar N14 always had taller stalks than N26. According to Venkataramana *et al*., (1984) single row spacing performed better than double spacing due to less competition between plants. Accordingly, single row spacing yielded taller stalks than double rows in their study. However, it is clear that other factors such as cultivar may have an effect on stalk height and should therefore be considered.

Sugarcane has several growth stages, namely, germination and emergence, tillering and canopy development, grand growth, and maturity or ripening (Gascho, 1985). According to Gascho (1985) the germination and emergence stage of sugarcane last for one month, whereas tillering and canopy development, and maturity last for about two months each. The longest growing stage of sugarcane is the grand growth stage, which lasts for about seven months. Stalk elongation starts during the tillering stage and reaches its peak in the grand growth stage (Gascho, 1985). According to the present study stalk elongation was not significantly affected by mulches at the end of the monitoring period (140 DAS). It could, therefore, be expected that by harvesting time, there will also be no significant stalk height differences between mulched and unmulched plots.

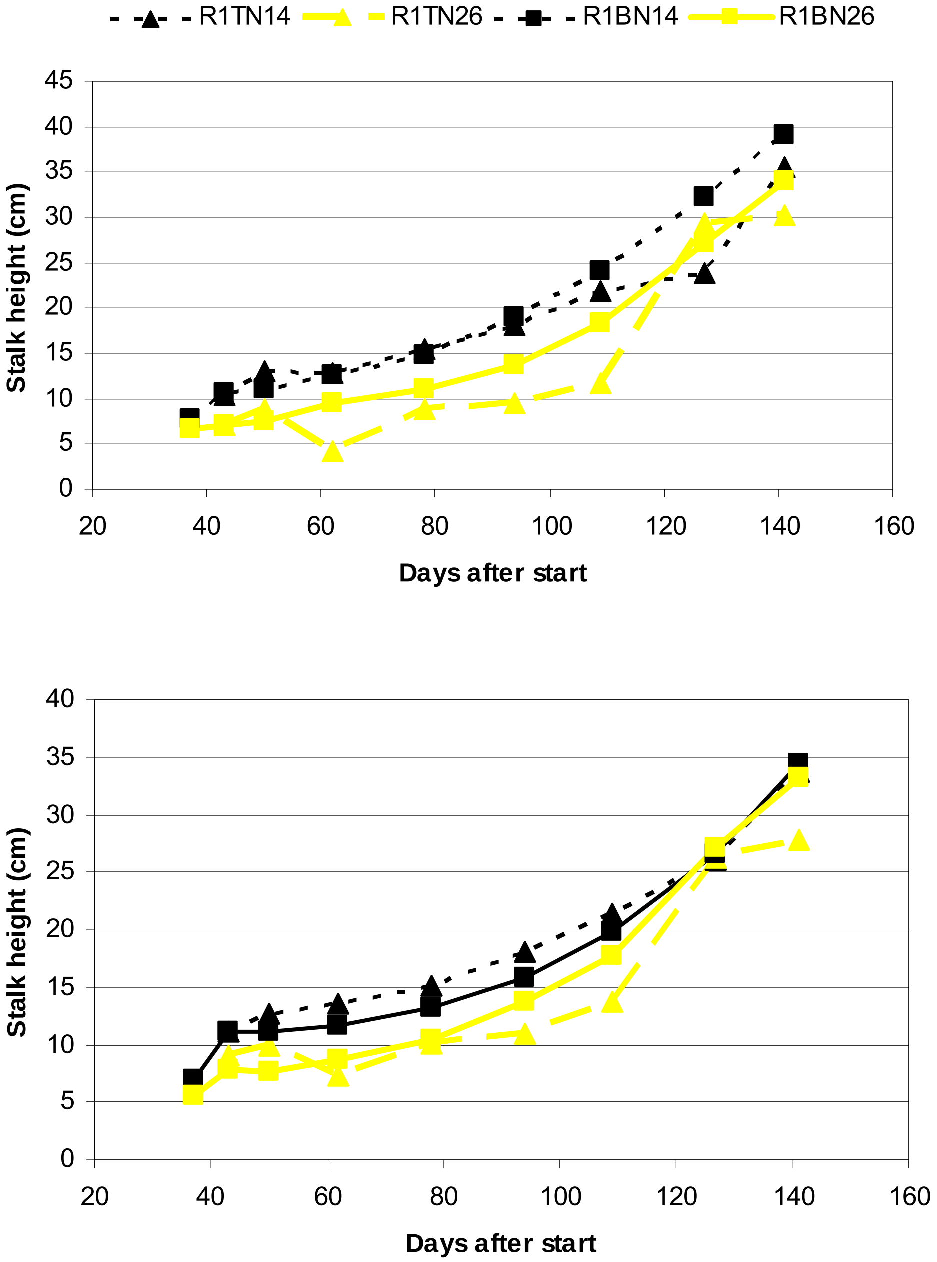

Figure 3.7: Stalk height of bare (B) and mulch (T) plots in single row (R1) spacing arrangement, (a) Standard and (b) Saving treatments for cultivars N14 and N26.

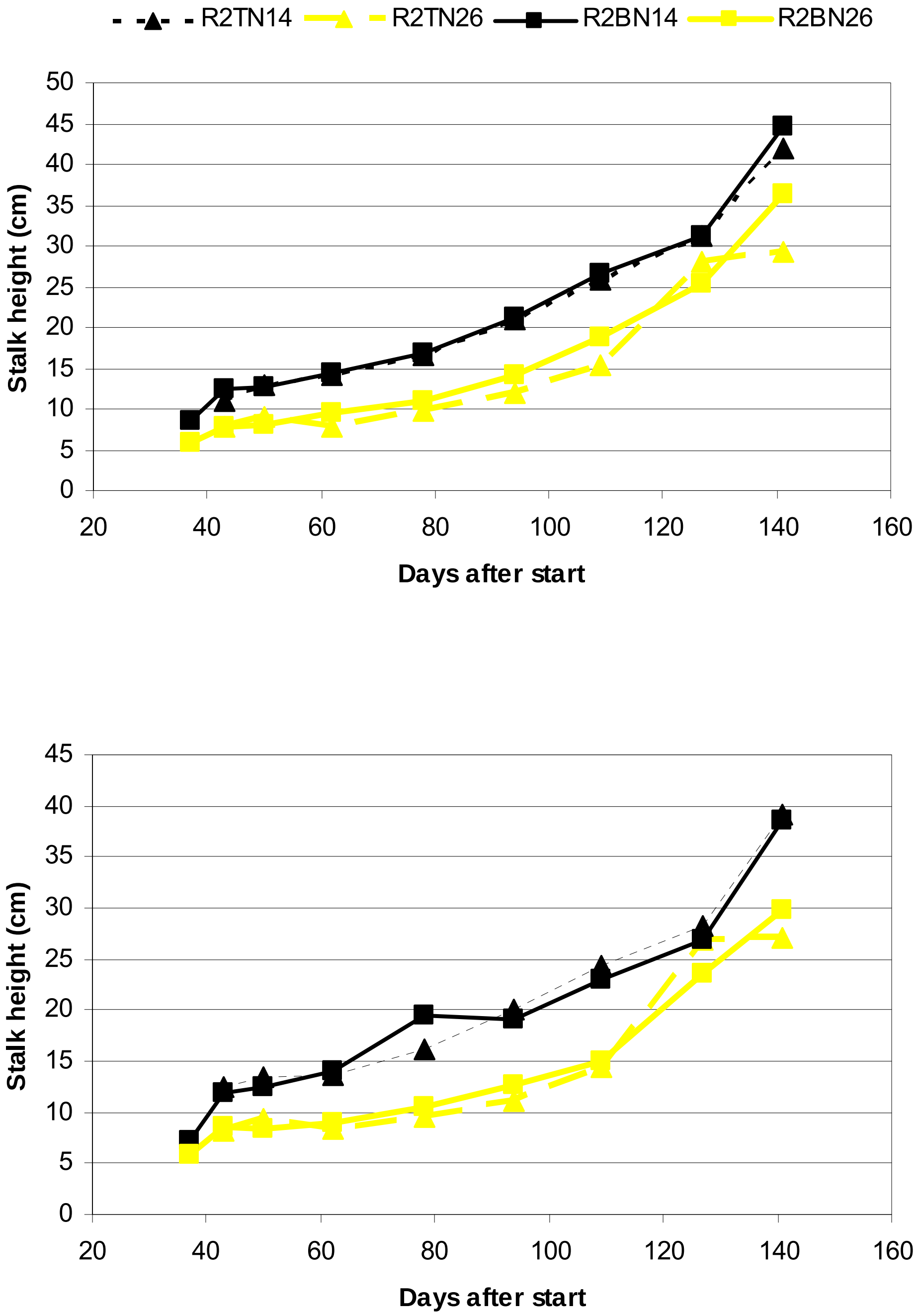

Figure 3.8: Stalk height of bare (B) and mulch (T) plots in double row (R2) spacing arrangement, (a) Standard and (b) Saving treatments for cultivars N15 and N26.

Table 3.3: Row spacing X mulch treatments X variety interaction effects on stalk height of planted sugarcane under standard and saving irrigation treatments

Irrigation treatment

	Stalk height (cm)							
DAS	43	50	62	78	94	109	127	141
Saving irrigation								
R1BN14	11.10a	11.20bc	11.66b	13.14b	15.84bc	19.76bc	26.58a	34.50bc
R1BN26	7.78b	7.60f	8.66c	10.40c	13.74dc	17.68dc	27.18a	33.20dc
R1TN14	11.08a	12.64ba	13.50ba	15.16a	18.06ba	21.38ba	26.08a	33.80dc
R1TN26	9.08b	9.94dc	7.22c	10.08c	10.94e	13.80e	26.26a	24.90f
R2BN14	11.98a	12.44ba	14.12a	15.00ba	19.10a	23.04a	26.98a	38.48ba
R2BN26	8.48b	8.34fe	9.02c	10.48c	12.60de	14.96de	23.50a	29.82de
R2TN14	12.42a	13.42a	13.72ba	16.26a	20.16a	24.32a	28.22a	39.20a
R2TN26	8.10b	9.26de	8.44c	9.48c	11.06e	14.44e	26.94a	26.12fe
CV%	10.72	10.72	16.60	11.52	12.50	12.17	19.54	9.53
LSD	1.39	1.47	2.32	1.88	2.46	2.94	6.70	4.01

Table 3.3 (continued): Row spacing X mulch treatments X variety interaction effects on stalk height of planted sugarcane under standard and saving irrigation treatments

Irrigation treatment

	Stalk height (cm)							
DAS	43	50	62	78	94	109	127	141
Standard irrigation								
R1BN14	10.66b	11.08b	12.50b	14.84b	19.08b	24.00bc	32.20a	38.94bc
R1BN26	7.14c	7.50c	9.40c	11.02c	13.72c	18.38d	27.04bac	34.04d
R1TN14	10.46b	13.00a	12.70ba	15.40ba	18.06b	21.92c	23.86c	35.54d
R1TN26	7.16c	8.55c	4.24d	8.74d	9.52e	11.62f	29.44bac	21.76f
R2BN14	12.54a	12.78a	14.40a	16.84a	21.24a	26.50a	31.24ba	44.58a
R2BN26	7.78c	8.14c	9.42c	10.94c	14.20c	18.84d	25.42bc	36.40dc
R2TN14	11.0ba	12.86a	14.16ba	16.62a	20.88a	25.90ba	31.12ba	41.84ba
R2TN26	7.80c	8.96c	7.84c	9.76dc	11.94d	15.40e	27.96bac	27.54e
CV%	13.93	12.16	12.70	9.03	7.98	8.29	17.83	6.99
LSD	1.7851	1.6396	1.7415	1.5244	1.664	2.1836	6.6025	3.181

Note: Values followed by the same letter in a column are not significantly different at P = 0.5 or less.

3.10. Effect of mulch on soil water content

There were only minor differences in measured soil water content between the mulched and unmulched treatments (Figure 3.9). However, in order to keep the soil water content above the allowable deficit, bare treatments had to be irrigated more frequently than mulched treatments as to keep up with evaporative demand. (Figure 3.10). Due to this frequent application of irrigation water, unmulched treatments appeared wetter than mulched treatments at the 0.25 m depth.

The effect of a trash mulch on reducing soil water evaporation was witnessed by less irrigation water used under trash treatments than under bare treatments from 20 DAS onwards. As a result, the final accumulative irrigation amount for the mulched treatment was 31% (175mm) less, compared to unmulched treatments (554mm) (Figure 3.10). Similar results were reported by Sauer *et al*. (1996). Mulching was therefore effective in minimizing soil water evaporation during the early stages of sugarcane growth. Hence, less water was applied to the bare treatments compared to mulched treatments during that stage.

A ‘diminishing effect’ of crop residue was apparent towards the end of study, similar to the findings of Bond & Willies (1970). As the plant canopy grew bigger, a larger fraction of the soil surface was shaded, until a point when the soil was fully shaded and acted as a “mulching material”. As a result, the differences between mulched and unmulched plots disappeared towards 120 DAS. From then onwards until the end of the study (between 120 and 160 DAS), both treatments were irrigated more or less the same amounts (Figure 3.10). Unger & Parker (1976) reported the same results under dryland cropping of maize. In their study, the effect crop residues in reducing soil water evaporation lasted only 15 days. In the present study, as shown in Figure 3.10, effectiveness of the trash mulching lasted longer than 30 days (between 51 and 86 DAS).

Both treatments were frequently irrigated from July 2005 onwards (from 100 DAS). That is probably related to higher evapotranspiration rates due to increased air temperatures, (higher evaporative demand) and a larger developed plant canopy just after winter. Atmospheric demand is mainly intensified by high temperatures and wind speed (Wind, 1961). Since air temperature according to Figure 3.1 was still as high as 35^{o}C during the early stage of crop development, mulched plots could save more water during that period, compared to bare plots.

According to Tolk *et al*., (1999) there are three factors which determine the effectiveness of mulch residue, namely, evaporative demand, frequency of water application and mass or thickness of mulch materials. Previous work (Chung & Horton, 1987; Bussiere & Celliers, 1994) had suggested that mulching with organic material result in insulating soil and reduce occurrence of heat and vapour transfer. Hence sugarcane mulch probably changed the energy balance and thereby reduced soil evaporation (Unger, 1978; Movahedi-Naeni & Cook, 2000).

According to Figure 3.1 the soil surface of bare treatments was exposed to more heat and vapour transfer for a period of 50 days before complete crop canopy shading. Thus, a large portion of the total evapotranspiration can be attributed to soil evaporation during the early crop growth stages. It was therefore expected for bare treatments to lose more soil water compared to mulched plots. Transpiration or water uptake increased later during the growing season due to a deeper developed root system and established canopy. According to research conducted long ago by Adams *et al*., (1976) the rate of evaporation from the soil surface during the early stage depends mainly on row spacing, leaf area index and soil shading. These results confirmed that mulching can conserve soil water by reducing soil water evaporation, mainly during the early stage of crop development.

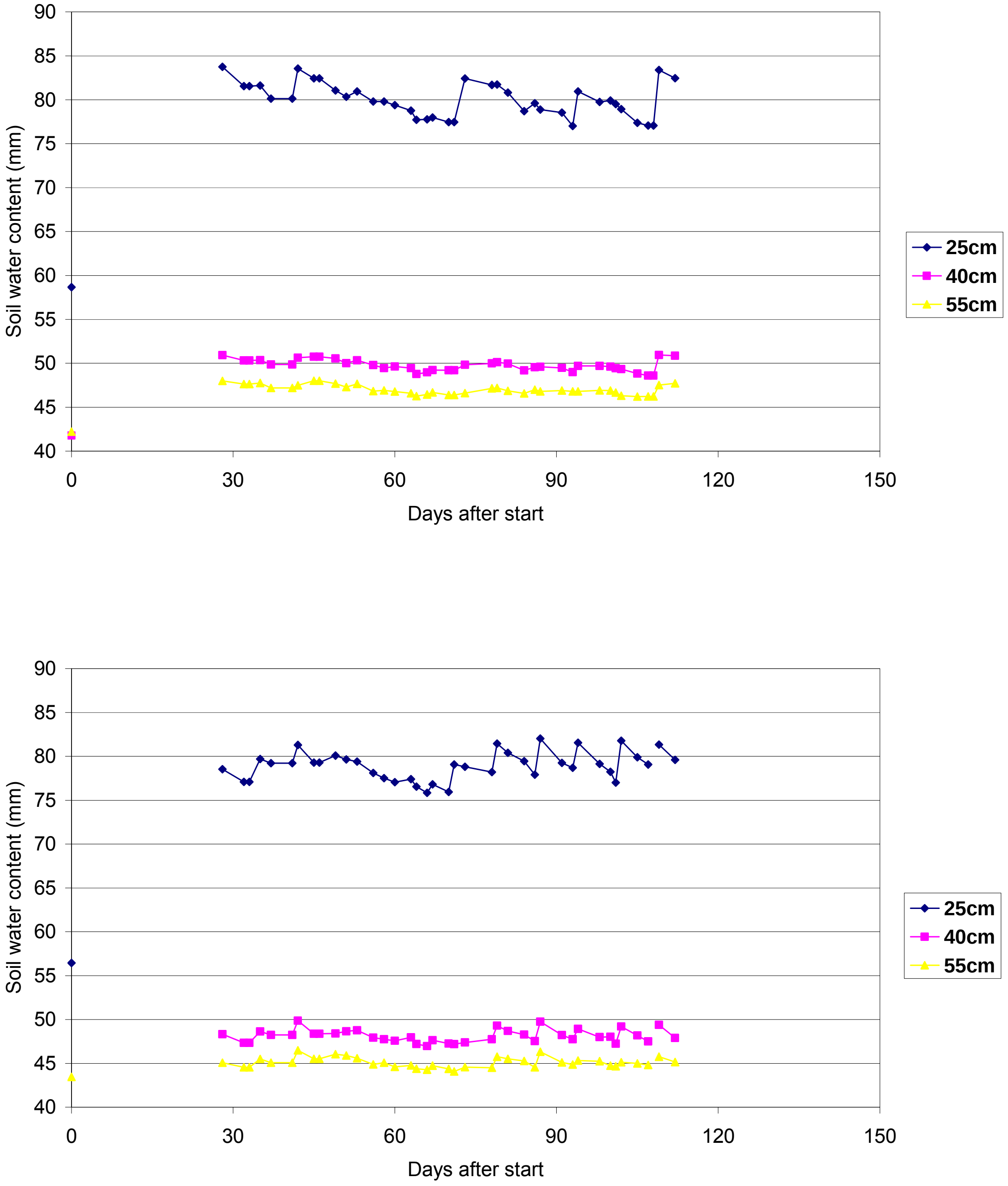

Figure 3.9: Soil water content per depth for (a) bare and (b) mulched treatments

Figure 3.10: cumulative irrigation as well as individual irrigation and rainfall events for the period April 2005 to August 2005.

In addition to changes in the energy balance, the effect of a crop residue on evaporation reduction, as defined by Army *et al*., (1961), can also be attributed due to increased thickness of non-turbulent air above the soil surface. In this study, the thickness of sugarcane mulch decreased gradually throughout the growing period (Figure 3.2). The 'diminishing effect' of mulching materials could be related to a gradual decrease in thickness of the mulch (Figure 3.2). The same was found by Steiner (1989), who believed that the volume or thicknesses of mulch materials are more critical for reducing evaporation than just the mass of crop residue per unit area. Therefore, the contribution by mulch to evaporation reduction was more evident during the early stages when the crop canopy was not yet fully developed to shade the soil surface. Nevertheless, the results of the present study agree well with other research (Tominaga *et al*., 2002), confirming that mulch can conserve soil water by reducing soil water evaporation. All factors such as soil type, mulch rates, and atmospheric demand should be considered when making conclusions on the effectiveness of mulches (Wind, 1961).

CHAPTER 4: CONCLUSIONS

The planting date for sugarcane concurred with the winter season which was characterized by both low air and soil temperatures. In particular, cultivar N26 was severely affected by low soil temperature under mulched treatments. It is therefore advisable to plan accordingly if trashing is considered to be an option. Planting date and cultivar choice are important factors to be considered when trashing. If planting date was carried forward towards the end of August 2005 when air temperatures started to rise, poor tillering and canopy development due to low soil temperature could have been avoided. Although it was not shown in this data, the negative effects of trashing on growth parameters (stalk height and population) tended to disappear towards the first harvest.

The irrigation of both treatments (mulched and unmulched plots) were irrigated back to field capacity once total soil water content reached a deficit of 30 mm per 0.55 m depth. In fact, the objective of irrigation treatments was to compare water saving of both treatments since the irrigation water amount was recommended from neutron probe measurements. Saving of water by mulched treatments was significant during the early stage of sugarcane development. The benefits of trashing diminish when the canopy is fully developed to shade soil surface. This can be a different case where interrow spacing is too wide to be covered by plant canopy. Generally, the effect of trashing in reducing soil evaporation diminishes with increasing leaf area index or canopy development. However, the benefits of trashing were mainly to save soil water from evaporation during the early crop growth stages. Although no data is provided, trashing also proved to be a good way of controlling weeds.

Most of the reasons for not trashing are economically related, namely, better labour productivity, improved haulage payloads, Eldana stalk borer control and super milling performance. However, if incentives are provided to cane cutters to maintain productivity and quality, the conditions favouring trashing are economically justifiable over areas of the coastal and hinterland regions of the sugarcane industry. Nevertheless, there is growing pressure from environmentalists to encourage sustainable farming that protects natural resources and promote sustainable farming. Burning of sugarcane trash continues to be a serious issue that needs urgent attention. In recent years, Environmental specialists from the Department of Environmental affairs and Tourism have already approached the sugarcane industry, warning to ban the practice of burning.

The practice of trashing is not recommended for areas with waterlogging problems or where frost may occur. The results from this work also acknowledge that trashing can delay emergence of planted cane in winter and early summer due to low soil temperature at high altitudes and the KZN Midlands. However, other hotter areas of sugarcane production should be suited for trashing. Accordingly, the results of this trial displayed the effect of trash mulching on growth and development, and possibility of reducing soil evaporation, compared to the traditional way of burning. If trashing is accepted, this could be seen as a huge step towards eradicating the practice of sugarcane burning.

SUMMARY

The burning of sugarcane before harvesting is a conventional practice in South Africa. It is mainly aimed at improving harvesting, handling and milling of sugarcane. However, most farmers agree that scarcity of labour, lack of time, timely land preparation for ratooning, lack of knowledge on trash decomposition, and eradication of pests and diseases are main reasons for burning.

A number of disadvantages related to burning of sugarcane trash such as poorer soil water conservation and low soil carbon content were documented. The practice of sugarcane burning is seen by many environmentalists as a draw back to the sustainable use of land. The practice of burning further contributes directly to “the greenhouse effect” that worsens global warming.

The main benefits of retaining a mulch blanket include soil water conservation, reduced erosion, increased soil fertility, increased soil organic matter levels, improved soil structure, better weed control and increased yield. All mentioned advantages could adequately sustain growth of sugarcane over longer periods. However, little is documented on the effect of trash mulch on the water use, growth and development of sugarcane.

To study the effect of a trash mulch on growth and development of sugarcane, an experiment was conducted at the South African Sugarcane Research Institute Experiment Station based in Komatipoort (25° 33’S; 31° 57’E, 187 m.a.s.l.). The trial layout consisted of primary and secondary treatments. Primary treatments consisted of two row spacings, namely single spacing (1.5 m) and double or tram row spacing (1.2 x 0.6 m). Further, plots were either mulched or kept unmulched with sugarcane trash. Two different varieties, namely N14 (fast canopy growing cultivar) and N26 (slower canopy growing cultivar) were used. The trial was replicated five times to give a total of 40 plots. To apply secondary treatments, the 40 plots were duplicated to give a total of 80 plots. The irrigation schedule of the first 40 plots was based on neutron probe readings taken fortnightly from mulched

plots (water saving irrigation treatment) and the other 40 plots were irrigated according to the neutron probe measurements taken in the unmulched plots (standard irrigation treatment).

Mulch reduced soil temperature considerably, which resulted in slow root growth and canopy development of the planted cane. In general, low air temperature during winter (between May and July 2005) was the main reason for low soil temperature. However, fluctuation of soil temperature was reduced under mulched treatments compared to unmulched treatments. To avoid the negative effects of too low soil temperatures under mulching, it is therefore recommended to plant sugarcane long before the winter season, probably around December and January.

The negative effect of mulch on canopy development was especially evident for cultivar N26, a slow growing cultivar. The amount of solar radiation intercepted by the canopy is a good measure of the size and rate of canopy development. The effect of mulch on canopy cover was evident from 90 days after starting the study. Canopy cover of bare treatments increased more rapidly than mulched plots. Accordingly, N26, the slow growing cultivar, as a result, suffered poor canopy development under mulch treatments. It is therefore not recommended to plant N26 in cold seasons or localities if mulching is considered. The high canopy fractional interception (FI) values that were observed under double or tram row spacing, compared to single rows, can be ascribed to the higher population of stalks per m^2. In another words, more stalks were planted per area than under the single row treatment. Generally, varietal differences in canopy development were more evident in double row spacing arrangements.

The effect of mulch in reducing soil evaporation was significant during the early stages of growth. As a result, approximately 30% of irrigation water was saved compared to unmulched plots. However, trashing should not be practiced at higher altitudes, frost prone areas and in soils that are frequently waterlogged. These results have proven that the effect of trashing on water use, growth and development of sugarcane depend on climatic conditions, cultivar, and location.

The practice of trashing could eliminate the burning of sugarcane, which is overwhelmingly criticized by environmentalists.

REFERENCES

ADAMS, J. E., ARKIN G. F. & RITCHIE, J. T., 1976. Influence of Row Spacing and Straw Mulch on First Stage Drying. *Soil Sci. Soc. Am. J*. 40,436-442.

AMATO, M., LADD, J.N., ELLINGTON, A., FORD, G., MAHONEY, J.E., TAYLOR A.C. & WALSGOTT, D., 1987. Decomposition of plant material in Australian soils. IV. Decomposition in situ of 14C- and 15N-labelled legume and wheat materials in a range of southern Australian soils. *Aust. J. of Soil Res*. 25, 95-105.

ARMY, T.J., WIESE, A.F. & HANKS, R.J., 1961. Effect of tillage and chemical control practices on soil moisture losses during the fallow period. *Soil Sci. Soc. Am. Proc*. 25, 410-413.

BASANTA, M.V., DOURADO-NETO, D., REICHARDT, K., BACCHI, O.O.S., OLIVEIRA, J.C.M., TRIVELIN, P.C.O., TIMM, L.C., TOMINAGA, T.T., CORRECHEL, V., CÁSSARO, F.A.M., PIRES, L.F. & DE MACEDO, J.R., 2003. Management effects on nitrogen recovery in a sugarcane crop grown in Brazil. *Geoderma* 116, 235-248.

BIERDERBECK, V, COMPBELL C.A., BOWREN, K.E., SCHNITZER, N. & MCIVER R.N., 1980. Effect of burning cereal straw on soil properties and grain yields in Saskatchewan. *Soil Sci. Soc. Am*. 44, 103-111.

BLAIR, N., 2000. Impact of cultivation and sugarcane green trash management on carbon fractions and aggregate stability for a chlromic Luvisol in Queensland, Australia. *Soil & Tillage Res*. 55, 183 -191.

BOND, J.J., & WILLIS, W.O., 1969. Soil water evaporation: surface residue rate and placement effects. Soil Sci. Soc. Am. Proc. 33, 445-448.

BONDE, A.T., SCHNIIRER, J. & ROSSWAL, T., 1988. Microbial biomass as a fraction of potentially mineralizable N in soil from long-term field experiments. *Soil Bio. & Biochem*. 20, 447-452.

BOTTNER, P.,1985. Response of microbial biomass to alternate moist and dry conditions in soil incubated with ^{14}C and ^{15}N-labeled plant material. *Soil Bio. & Bioch*. 17, 29-37.

BRISTOW, K. L., CAMPBELL, G. S., PAPENDICK, R. I. & ELLIOTT, L. F., 1986. Simulation of heat and moisture transfer through a surface residue-soil system. *Agric. For. Meteorol*. 36, 193-214.

BUSSIÈRE, F. & CELLIER, P., 1994. Modification of the soil temperature and water content regimes by a crop residue mulch: experiment and modelling. *Agric. For. Meteorol*. 68, 1-28.

CAMPBELL, G.S. & NORMAN, J.M., 1998. *An introduction to environmental biophysics*. 2nd end, Edwards Brothers Inc., Ann Arbor, MI.

CARTER, M. R., 1986. Microbial biomass as an index for tillage-induced changes in soil biological properties. *Soil & Tillage Res*. 7, 29–40.

CHUNG, S. & HORTON, R., 1987. Soil heat and water flow with a partial surface mulch. *Water Resources Res*. 23, 2175–2186

DEIBERT, E.J., FRENCH, E. & HOAG, B., 1986. Water storage and use by spring wheat under conventional tillage and no-till in continuous and alternate crop-fallow systems in the northern Great Plains. *J. Soil Water Conserv*. 41:53–58.

DEKKER, L.W. & RITSEMA, C.J., 1997. Effect of maize canopy and water repellency on moisture patterns in a Dutch black plaggen soil. *Plant Soil* 195, 339-350.

DEWIT, C.T., 1958. *Transpiration and crop yields*. Versl. Landouwk. Onderz. 64.6. Inst. of Biol. and Chem. Res. on Field Crops and Herbage, Wageningen, The Netherlands.

DORING, T.F., BRANDT, M., HEB, J., FINCKH, M. R. & SAUKE, H., 2005. Effects of straw mulch on soil nitrate dynamics, weeds, yield and soil erosion, in organically grown potatoes. *Field Crops Res*. 94, 238-249.

DWIVEDI, S.V., SINGH, S.S. & SINGH, S.P., 1999. Weed control in pointed gourd (*Trichosanthes dioica* Roxb). *Vegetable Sci*. 26(2), 133-136.

ELLIS, R.D., WILSON, J.H. & SPIES, P.M., 1985. Development of a irrigation policy to optimise sugar production during seasons of water shortage. *Proc. S. Afr. Sug. Technol Ass.,* 59,142-147.

FABRIZZI, K. P., GARCÍA, . F. O., COSTA, J. L. & PICONE, L. I., 2005. Soil water dynamics, physical properties and corn and wheat responses to minimum and no-tillage systems in the southern Pampas of Argentina. *Soil & Tillage Res*. 81 (1), 57-69.

GASCHO, G. J., 1985. Water-sugarcane relationships. *Sugar J*. 48(6), 11-17.

GIRIJESH, G. K. & CHANDRASEKHAR, C. P., 2001. Pattern of on farm sugarcane management in GLBC area of Karnataka. *Karnataka J. of Agric. Sci*. 14(2), 465-467.

GRAHAM, M. H. & HAYNES, R. J., 2005a. Organic matter status and the size, activity and metabolic diversity of the soil microbial community in the row and inter-row of sugarcane under burning and trash retention. *Soil Bio. & Biochem*. 37, 1–11.

GRAHAM, M. H. & HAYNES, R. J., 2005b. Catabolic diversity of soil microbial communities under sugarcane and other land uses estimated by Biologic and substrate-induced respiration methods. *Applied Soil Eco*. 29(2), 155-164.

GRAHAM, M. H., 2002. Soil organic matter content and quality: effects of fertilizer application, burning and trash retention on a long term sugarcane experiment in South Africa. *Soil Bio. & Biochem*. 34, 93-102.

GREB, B.W., 1966. Effect of surface-applied wheat straw on soil water losses by solar distillation. *Soil Sci. Soc. Am. Proc*. 30, 786-788.

GUPTA, S. C., RADKE, J. K. & LARSON, W. E., 1981. Predicting temperatures of bare and residue covered soils with and without a corn crop. *Soil Sci. Soc. Am. J*. 45, 405-12.

GUPTA, V.V.S.R. & GERMIDA, J.J., 1988. Distribution of microbial biomass and its activity in different soil aggregate size classes as affected by cultivation. *Soil Biol. & Biochem.* 20 (6), 777-786.

HAM, J.M., KLUITENBERG, G.J. & LAMONT, W.J., 1993. Optical properties of plastic mulches affect the field temperature regime. *J. Amer. Soc. Hort. Sci*. 118, 188-193.

HORTON, R., BRISTOW, K.L., KLUITENBERG, G.J. & SAUER, T.J., 1996. Crop residue effects on surface radiation and energy balance—review. *Theor. Appl. Climat*. 54, 27-37

HURLEY, K., 2002. Burning – what should you be doing? *The Link* 11(2),12.

INMAN-BAMBER, N. G. & SMITH, D. M., 2005. Water relations in sugarcane and response to water deficits. *Field crops Res*. 92, 185-202.

INMAN-BAMBER, N. G., 1994. Temperature and seasonal effects on canopy development and light interception of sugarcane. *Field Crop Res*. 36, 41-51.

JALOTA, S.K. & PRIHAR, S.S., 1990. Effect of straw mulch on evaporation reduction in relation to rates of mulching and evaporativity. *J. Ind. Soc. Soil Sci*. 38, 728-730.

JAMUNA, P., SWAMY, K. R., NAIDU, N. V. & SUBRAHMANYAM, K., 2003. Effect of mulching and integrated nutrient management in rainfed sugarcane. Proceedings of the 65th Annual Convention of the Sugar Technologists' Association of India. *Sugar Technol. Ass. India*, A18-A30.

LEFROY, R.D.B., CHAITEP, W. & BLAIR, G.J., 1994. Release of sulfur from rice residues under flooded and non-flooded soil conditions. *Aust. J. Agric. Resour*. 45, 657– 667.

LEI, Y., TAKAHASHI, H. & LI, W., 2004. Effect of concrete mulch on soil thermal and moisture regimes. *J. Agric Meteorol*. 60(1), 17-23.

LUO, J.J., 1992. A study on effects of radiation, temperature and soil water of corn planted outside plastic film cover. *Gansu Agric. Sci. Technol*. 2, 6–9.

MA, L. W. & SELIM, H. M., 2005. Predicting pesticide transport in mulch-amended soils: a two-compartment model. *Soil Sci. Soc. of Am. J*. 69(2), 318-327.

MAHENDER-SINGH, SRIVASTAVA, S.N.L. & SUBHASH-CHANDER., 2002. Effect of weed control methods and nitrogen levels on yield attributes and yield of sugarcane. *Ann. Agric. Res.* 23(2), 322-324.

MEYER, E., NORRIS, C.P., JACQUIN, E., RICHARD, C. & SCANDALIARIS, J., 2005. Burnt versus green cane harvesting: Agricultural engineering challenges. *Proc Int. Soc Sugar Cane Technol*. 25, 294-302.

MOVAHEDI-NAENI, S.A.R.& COOK, H.F., 2000. Influence of compost amendment on soil water and evaporation. Commun. *Soil Sci. Plant Anal.* 31 (19/20), 3147-3161.

NOVAK, M.D., CHEN, W. & HARES, M.A., 2000. Simulating the radiation distribution within a barley-straw mulch. *Agric. & For. Meteorol*. 102, 173-186.

OLASANTAN, F.O., 1999. Effect of time of mulching on soil temperature and moisture regime and emergence, growth and yield of white yam in western Nigeria. *Soil & Tillage Res. 50, 215-221.*

OLIVEIRA, J.C.M., TIMM, L.C., TOMINAGA, T.T., CÁSSARO, F. A. M., REICHARDT, K., BACCHI, O. O.S., DOURADO-NETO, D. & CÁMARA, G.M., 2000. Soil temperature in a sugarcane crop as function of the management system. *Plant Soil*. 230, 61-66.

OLSEN, J.K. & GOUNDER, R.K., 2001. Alternatives to polyethylene mulch film — a field assessment of transported materials in capsicum (Capsicum annuum L.). *Aust. J. Exp. Agric.* 41, 93-103.

OSSOM, E.M., PACE, P.F., RHYKERD, R.L. & RHYKERD, C.L., 2001. Effect of mulch on weed infestation, soil temperature, nutrient concentration, and tuber yield in *Ipomoea batatus* (L.) Lam. In Papua New Guinea. *Trop. Agric. (Trinidad)* 78, 144–151.

PRIHAR, S.S., SINGH, B., SINGH, N. & SANDHU, K.S., 1968. Influence of soil and environment on evaporation losses from mulched or unmulched pots. *J. Res., Punjab Agriculture University, Ludhiana, India* 5,320-328.

RANA, N. S., SAINI, S. K., SANJAY, K. & GURUSHARAN, P., 2002. Trash management practices in sugarcane based cropping systems to enhance sugarcane yield and sustain soil productivity. *Indian J. of Sugarcane Tech*. 17(2), 32-34.

RITA-DAHIYA., MALIK, R. S. & JHORAR, B. S. 2003. Effect of sugarcane trash and enriched sugarcane trash mulches on ratoon cane yield and soil properties. *J. of the Ind. Soc. of Soil Sci*. 51(4): 504-508.

ROBERTSON, F., 2003. *Sugarcane Trash Management: Consequences for Soil C and N*. p. 39. In: CRC for Sustainable Sugar Production, Townsville.

ROSS P.J., WILLIAMS, J. & MCCOWN, R.L., 1985. Soil temperature and the energy balance of vegetative mulch in the semi-arid tropics: II. Dynamic analysis of the total energy balance. *Aust. J. Soil Res*. 23, 515-532.

SANDHU, B.S., PRIHAR, S.S. AND KHERA, K.L., 1980. Sugarcane response to irrigation andstraw mulch in a subtropical region. *Agric. Water Manag*., 3, 35-44.

SAS INSTITUTE., 2005. SAS Users Guide: Statistics. Version 9.1 Edition. SAS Institute, Cary, North Carolina.

SAUER, T.J., HATFIELD, J.L. & PRUEGER, J.H., 1996. Corn residue age and placement effects on evaporation and soil thermal regime. *Soil Sci. Soc. Am. J*. 60:1558-1564.

SHEN, Y. & TANNER, C.B., 1990. Radiative and conductive transportof heat through flail-chopped corn residue. *Soil Sci. Soc. Am. J*. 54, 653-658.

SINGH, T. & SINGH, P.N., 2002. Effect of integrated nutrient management on soil fertility status and productivity of sugarcane grown under sugarcane based cropping sequence. *Indian J. of Sugarcane Tech*. 17(2), 53-55.

SOUTH AFRICAN SUGAR ASSOCIATION., 2005. Sugarcane production areas of South Africa. http://www.sasa.org.za/HomePage1.aspx (Accessed 25/10/2005).

SPAIN, A.V. & HODGEN, M.J., 1994. Changes in the composition of sugar cane harvest residues during decomposition as a surface mulch. *Biol. Fert. Soils* 17: 225-231.

SRIVASTAVA, A. C. & SIGH, R. D., 1987. Sugarcane trash management in India. Agric. *Mech. Asia Africa & Latin Amer*. 18, 72-82.

STEINER, J.L., 1989. Tillage and surface residue effects on evaporation from soils. *Soil Sci. Soc. Am. J.* 53, 911-916.

STEEL, R.G.D., TORRIE, J.H. & DICKEY, D.A., 1997. principles and procedure of statistics: a biometrical approach. 3rd ed. McGraw-Hill Companies, Inc. New York.

STEWART, B.A. & POWER, J.F., 1983. Soil Management for Efficient Water Use: Soil Fertility. p. 461–470. In: H.M. Taylor *et al*. (ed.) *Limitations to efficient water use in crop production*. ASA, Madison, WI.

STOTT, D.E., ELLIOT, L.F. & PAPENDICK, R.I. & CAMPBELL, G.S., 1986. Low temperature or low water potential effects on the microbial decomposition of wheat residue. *Soil Biol. & Biochem*. 18, 577-582.

STRANACK, R.A., 1998. The benefits of trashing. *The Link* 7(3),1

TANNER, C.B. & SINCLAIR, T.R., 1983. Efficient water use in crop production: research or research? p. 1-27. In: H.M. Taylor, W.R. Jordan & T.R. Sinclair (eds.). *Limitations to Efficient Water Use in Crop Production*. ASA, Madison, Wisconsin.

TOLK, J.A. HOWELL, T.A. & EVETT, S.R., 1999. Effect of mulch, irrigation, and soil type on water use and yield of maize. *Soil & Tillage Res*. 50, 137-147

TOMINAGA , T.T., CÁSSARO, F. A. M., BACCHI, O. O.S., REICHARDT, K., OLIVEIRA, J.CM. & TIMM, L.C., 2002. Variability of soil water content and bulk density in a sugarcane field. *Ast. J. Soil Res*. 40, 605-614.

TUCKER, T., 1995. Atmospheric pollution - a burning issue. *The Link* 4(1), 11.

TUCKER, T., 1998. Complaints about careless burning. *The Link* 7(4), 2.

UNGER, P.W., 1978. Straw-mulch effects on soil temperature and sorghum germination and growth*. Agronomy J*. 70, 858-864.

UNGER, P.W. & JONES, O.R., 1981. Effect of soil water content and a growing season straw mulch on grain sorghum. *Soil Sci. Soc. Am. J*. 45, 129-134.

UNGER, P.W. & PARKER, J.J., 1976. Evaporation reduction from soil with wheat, sorghum, and cotton residues. *Soil Sci. Soc. Am. J*. 40, 938-942.

VALLIES, I., PARTON, W.J., KEATING, B.A. & WOOD, A.W., 1996. Simulation of the effects of trash and N fertilizer management on soil organic matter levels and yields of sugarcane. *Soil & Tillage Res*. 38, 115-132.

VENKATARAMANA, S. SHUNMAUGASUNDARAM, S. & NAIDU, K.M., 1984. Growth behaviour of field grown sugarcane varieties in relation to environmental parameters and soil moisture stress. *Agric. For. Meteorol*. 31, 251-260.

WHITMAN, P.C., BUL, T.A. & GLASZIOU, K.T., 1963. The physiology of sugarcane; VI: Effects of temperature, light, and water on set germination and early growth (Saccharum spp*). Aust. J. Biological Sci*. 15(2), 415–428.

WICK, B., KÜHNE, R.F. & VLEK, P.L.G., 1998. Soil microbiological parameters as indicators of soil quality under improved fallow management systems in southwestern *Nigeria. Plant and Soil*, 202, 97–107.

WIND, G.P.,1961. *Capillary rise and some implications of the theory of moisture in unsaturated soil*. Institute of Land and Water Management Research Technical Bulletin 22. Wageningon, the Netherlands.

WOOD, A.W., 1991. Management of crop residues following green harvesting of sugarcane in north Queensland. *Soil & Tillage Res*. 22: 69-85.

YADAV, R. L., PRASAD, S. R., SINGH, R. & SRIVASTAVA, V. K., 1994. Recycling sugarcane trash to conserve soil organic carbon for sustaining yields of successive ratoon crop in sugarcane. *Biores. Technol*., 49 (3), 321-5.

YADAV, D. V., SINGH, T. & SRIVASTAVA, A. K., 1987. Recycling of nutrients in trash with N for higher cane yields. *Biol. Wastes*, 20, 133-41.

YANG, Y., LIU, X., LI, W., & LI, C., 2006. Effect of different mulch materials on winter wheat production in desalinized soil in Heilongjiang region of North China. *J. Zhejiang Univ. Science* B, 7(11), 858-867.

ZHAI, R., KACHANOSKI, R.G. & VORONEY, R.P., 1990. Tillage effects on the spatial and temporal variations of soil water. *Soil Sci. Soc. Am. J*. 54:186-192.

ZHANG, C. E., LIU G. B. & CHEN, X. L., 1999. Micro-organism, enzyme activities and biomass in soils in hillside fields under varied patterns of land use. *Chinese J. of Soil Sci.* 30 (3), 101-103.

APPENDIX

APPENDIX A: Air temperature measured at the height of 1.5 m, soil temperature below bare and mulched soil at the depth of 0.15 m, and temperature between the trash and soil surface.

Days after start	Days of the year	Year	Air temperature °C	Between °C	Bare °C	Trash °C
1	119	2005	25.0	22.1	23.3	21.7
2	120	2005	19.2	17.7	22.3	21.0
3	121	2005	21.0	19.9	22.3	20.7
4	122	2005	22.6	21.1	23.3	21.0
5	123	2005	21.2	19.2	20.7	21.4
6	124	2005	22.2	20.6	14.1	21.3
7	125	2005	23.2	21.7	21.0	21.2
8	126	2005	25.7	23.8	22.8	21.3
9	127	2005	22.7	21.5	23.0	21.6
10	128	2005	24.8	23.5	23.6	21.9
11	129	2005	24.8	23.7	24.4	22.5
12	130	2005	23.6	22.3	24.4	22.4
13	131	2005	19.1	17.1	22.8	21.5
14	132	2005	22.2	19.9	22.1	21.1
15	133	2005	22.1	20.6	21.6	20.8
16	134	2005	21.9	20.5	21.6	20.6
17	135	2005	22.1	21.2	22.8	21.2
18	136	2005	23.0	21.5	22.6	20.7
19	137	2005	23.8	22.5	23.4	21.1
20	138	2005	22.6	20.9	23.4	21.0
21	139	2005	21.4	19.8	22.6	20.2
22	140	2005	19.0	18.6	21.9	20.4
23	141	2005	21.1	19.2	21.5	20.5
24	142	2005	22.2	20.0	21.9	20.5
25	143	2005	20.0	18.7	21.4	20.1
26	144	2005	18.4	17.6	20.7	19.6
27	145	2005	18.1	16.3	20.5	19.1
28	146	2005	18.7	16.3	20.2	18.5
29	147	2005	18.2	15.3	20.3	18.5
30	148	2005	19.9	17.7	20.2	18.1
31	149	2005	21.7	19.3	21.5	19.0
32	150	2005	21.9	19.1	21.6	19.2
33	151	2005	21.6	19.3	22.0	19.2
34	152	2005	21.5	18.6	22.0	19.3
35	153	2005	21.6	18.1	21.9	19.2

36	154	2005	21.5	18.4	21.9	19.1
37	155	2005	19.9	17.7	21.8	19.2
38	156	2005	17.3	15.3	20.6	18.9
39	157	2005	17.2	14.5	19.1	18.3
40	158	2005	19.6	16.4	18.9	18.0
41	159	2005	21.5	18.2	19.2	18.0
42	160	2005	21.0	18.9	20.1	18.3
43	161	2005	17.7	17.2	20.0	18.6
44	162	2005	20.6	18.6	20.0	18.5
45	163	2005	19.1	16.8	20.1	18.5
46	164	2005	21.1	18.3	20.0	18.2
47	165	2005	20.7	17.6	20.8	18.4
48	166	2005	17.6	16.6	19.8	18.3
49	167	2005	9.8	18.5	10.2	18.0
50	168	2005	21.3	18.8	20.3	18.4
51	169	2005	19.4	17.0	19.5	18.1
52	170	2005	19.4	18.1	20.0	18.4
53	171	2005	18.5	17.0	19.6	18.3
54	172	2005	19.0	17.4	19.6	18.1
55	173	2005	18.9	18.2	19.9	18.4
56	174	2005	20.1	19.3	20.3	18.7
57	175	2005	19.7	18.3	20.4	19.0
58	176	2005	19.2	18.3	20.4	19.0
59	177	2005	19.0	16.6	20.4	19.0
60	178	2005	18.0	15.3	19.9	18.5
61	179	2005	19.8	17.8	19.8	18.1
62	180	2005	18.9	18.0	20.1	18.3
63	181	2005	18.7	17.4	20.1	18.3
64	182	2005	17.3	15.5	19.8	18.1
65	183	2005	18.5	17.7	19.4	17.9
66	184	2005	17.8	16.0	19.7	17.9
67	185	2005	14.1	14.1	18.7	17.5
68	186	2005	14.2	13.1	18.0	17.1
69	187	2005	16.7	13.7	17.8	17.2
70	188	2005	17.2	15.8	17.7	17.3
71	189	2005	14.5	14.4	17.6	17.4
72	190	2005	16.7	14.9	16.9	17.1
73	191	2005	17.3	16.1	17.5	17.3
74	192	2005	16.5	14.5	17.2	17.2
75	193	2005	16.5	14.8	17.5	17.0
76	194	2005	17.6	15.6	18.6	17.3
77	195	2005	17.8	15.8	18.1	17.6
78	196	2005	20.2	18.4	18.6	18.0
79	197	2005	19.8	18.3	18.7	18.1
80	198	2005	18.9	17.7	19.0	18.0
81	199	2005	15.9	15.7	18.1	17.3
82	200	2005	18.6	16.9	18.5	17.4
83	201	2005	19.5	18.1	20.0	18.0

84	202	2005	15.8	13.3	18.7	17.7
85	203	2005	17.8	14.9	17.5	17.3
86	204	2005	19.2	17.7	17.9	17.5
87	205	2005	19.2	17.9	18.8	17.7
88	206	2005	19.0	17.6	18.8	17.6
89	207	2005	18.9	17.5	19.3	17.7
90	208	2005	18.6	17.3	19.1	17.4
91	209	2005	18.5	17.3	19.6	17.8
92	210	2005	20.5	17.4	19.4	18.4
93	211	2005	19.9	17.9	19.3	18.4
94	212	2005	20.0	17.7	18.9	18.2
95	213	2005	20.2	17.7	19.3	18.1
96	214	2005	21.6	18.9	20.6	18.6
97	215	2005	18.9	16.6	20.2	18.4
98	216	2005	19.5	18.6	20.0	17.9
99	217	2005	19.2	17.2	20.6	18.4
100	218	2005	19.1	15.2	19.6	18.7
101	219	2005	20.3	17.3	19.0	18.4
102	220	2005	20.7	17.3	19.6	18.4
103	221	2005	20.9	17.7	19.9	18.3
104	222	2005	21.9	19.9	20.8	18.6
105	223	2005	20.7	17.3	19.6	18.4
106	224	2005	20.9	17.7	19.9	18.3
107	225	2005	21.9	19.9	20.8	18.6
108	226	2005	18.5	17.9	20.6	19.0
109	227	2005	20.9	19.0	20.5	19.1
110	228	2005	21.1	18.4	20.6	19.6
111	229	2005	22.4	19.4	20.8	19.8
112	230	2005	22.2	19.4	20.7	19.7
113	231	2005	22.6	19.2	20.9	19.5
114	232	2005	18.6	17.9	20.4	19.1
115	233	2005	19.5	18.3	19.9	18.9
116	234	2005	23.0	20.0	20.5	19.1
117	235	2005	23.0	20.0	20.5	19.1
118	236	2005	19.1	17.6	20.6	19.2
119	237	2005	23.0	18.8	20.4	19.4
120	238	2005	21.3	19.3	20.2	19.5
121	239	2005	23.0	20.1	21.0	19.7
122	240	2005	23.0	20.2	21.3	19.7
123	241	2005	20.3	18.6	21.1	19.8
124	242	2005	21.1	19.6	21.2	19.9
125	243	2005	26.4	21.4	22.1	20.9
126	244	2005	22.9	20.4	21.7	20.8
127	245	2005	17.1	17.7	20.1	19.9
128	246	2005	21.7	20.0	20.5	19.7
129	247	2005	24.1	20.2	21.7	20.2
130	248	2005	22.8	20.8	22.4	20.5
131	249	2005	18.7	17.7	21.3	20.1

132	250	2005	23.8	20.0	21.5	20.5
133	251	2005	24.5	20.6	21.9	21.0
134	252	2005	25.7	21.1	22.0	20.9
135	253	2005	21.4	20.5	22.1	20.8
136	254	2005	20.5	19.4	21.5	21.1
137	255	2005	21.7	20.1	21.3	20.8
138	256	2005	21.2	20.5	21.9	21.3
139	257	2005	21.7	19.3	21.4	21.7
140	258	2005	22.8	20.2	21.3	21.5
141	259	2005	24.7	22.5	22.3	21.9
142	260	2005	21.4	20.5	22.1	20.8
143	261	2005	20.5	19.4	21.5	21.1
144	262	2005	21.7	20.1	21.3	20.8
145	263	2005	21.2	20.5	21.9	21.3
146	264	2005	21.7	19.3	21.4	21.7
147	265	2005	22.8	20.2	21.3	21.5
148	266	2005	24.7	22.5	22.3	21.9
149	267	2005	24.4	21.9	23.0	22.1
150	268	2005	18.8	18.8	21.9	21.4
151	269	2005	19.0	18.8	21.0	21.0
152	270	2005	20.8	18.5	20.5	20.8
153	271	2005	21.4	19.1	20.5	20.7
154	272	2005	23.3	20.1	21.0	20.8
155	273	2005	23.7	21.6	22.1	21.2
156	274	2005	20.9	20.7	22.4	21.7
157	275	2005	25.0	20.7	22.2	22.0
158	276	2005	20.0	19.6	21.6	21.7
159	277	2005	25.2	21.8	22.2	22.2
160	278	2005	26.5	24.3	23.0	22.8
161	279	2005	27.9	24.8	23.7	23.3
162	280	2005	29.5	25.2	23.9	23.3
163	281	2005	23.8	23.0	24.1	23.5
164	282	2005	22.5	22.2	23.5	23.5
165	283	2005	18.3	17.3	22.4	23.4

Appendix B: Row spacing X mulch treatments X variety interaction effects generated by general Linear Model (GML) showing treatments means of all variables measured (stalk population, stalk height or length and Fractional Interception) and separated using Fisher's least significance test (LSD) at P<0.05.

```
---------------------------------- Irri=Sav DAS=37 --------------------------

                              The GLM Procedure

                        t Tests (LSD) for Population

       NOTE: This test controls the Type I comparisonwise error rate, not the
                              experimentwise error rate.


                         Alpha                              0.05
                         Error Degrees of Freedom             28
                         Error Mean Square              1.030393
                         Critical Value of t             2.04841
                         Least Significant Difference     1.3151


             Means with the same letter are not significantly different.


                    t Grouping          Mean      N     RxTxV

                             A        6.2200      5     R2BN14
                             A
                        B    A        5.6000      5     R2BN26
                        B
                        B    C        4.8000      5     R1BN14
                             C
                             C        4.1400      5     R1BN26

                             D        0.0000      5     R1TN14
                             D
```

```
                D         0.0000      5     R1TN26
                D
                D         0.0000      5     R2TN14
                D
                D         0.0000      5     R2TN26


 ---------------------------------- Irri=Sav DAS=43 ------------------

                              The GLM Procedure

                          t Tests (LSD) for Length

     NOTE: This test controls the Type I comparisonwise error rate, not the
                         experimentwise error rate.
                    Alpha                               0.05
                    Error Degrees of Freedom              28
                    Error Mean Square               1.151411
                    Critical Value of t              2.04841
                    Least Significant Difference      1.3901

           Means with the same letter are not significantly different.


             t Grouping          Mean      N     RxTxV

                      A       12.4200      5     R2TN14
                      A
                      A       11.9800      5     R2BN14
                      A
                      A       11.1000      5     R1BN14
                      A
                      A       11.0800      5     R1TN14

                      B        9.0800      5     R1TN26
                      B
                      B        8.4800      5     R2BN26
                      B
```

```
                  B          8.1000       5     R2TN26
                  B
                  B          7.7800       5     R1BN26

                      t Tests (LSD) for Population

   NOTE: This test controls the Type I comparisonwise error rate, not the
                      experimentwise error rate.
                Alpha                              0.05
                Error Degrees of Freedom             28
                Error Mean Square              1.282482
                Critical Value of t             2.04841
                Least Significant Difference     1.4671

         Means with the same letter are not significantly different.

            t Grouping          Mean       N     RxTxV

                     A        7.7000       5     R2BN14
                     A
                     A        7.6000       5     R2BN26

                     B        5.6600       5     R1BN14
                     B
                     B        4.7200       5     R2TN14
                     B
                C    B        4.3400       5     R1BN26
                C
                C    D        3.0000       5     R1TN14
                     D
                E    D        2.2200       5     R2TN26
                E
                E             1.3600       5     R1TN26


---------------------------------- Irri=Sav DAS=50 --------------------------
```

```
                           The GLM Procedure

                       t Tests (LSD) for Length

NOTE: This test controls the Type I comparisonwise error rate, not the
                      experimentwise error rate.
                 Alpha                            0.05
                 Error Degrees of Freedom           28
                 Error Mean Square            1.294339
                 Critical Value of t           2.04841
                 Least Significant Difference   1.4739

      Means with the same letter are not significantly different.

             t Grouping          Mean      N    RxTxV

                      A       13.4200      5    R2TN14
                      A
                 B    A       12.6400      5    R1TN14
                 B    A
                 B    A       12.4400      5    R2BN14
                 B
                 B    C       11.2000      5    R1BN14
                      C
                 D    C        9.9400      5    R1TN26
                 D
                 D    E        9.2600      5    R2TN26
                      E
                 F    E        8.3400      5    R2BN26
                 F
                 F             7.6000      5    R1BN26

                     t Tests (LSD) for Population

NOTE: This test controls the Type I comparisonwise error rate, not the
                      experimentwise error rate.
                 Alpha                            0.05
                 Error Degrees of Freedom           28
                 Error Mean Square            1.376518
```

```
                 Critical Value of t           2.04841
                 Least Significant Difference     1.52

           Means with the same letter are not significantly different.

               t Grouping          Mean      N    RxTxV

                        A        8.4600      5    R2BN14
                        A
                        A        8.1200      5    R2BN26

                        B        6.2200      5    R1BN14
                        B
                   C    B        5.0600      5    R2TN14
                   C    B
                   C    B        4.9400      5    R1BN26
                   C
                   C    D        3.6000      5    R1TN14
                        D
                   E    D        2.6600      5    R2TN26
                   E
                   E             1.6000      5    R1TN26

---------------------------------- Irri=Sav DAS=62 -------------------------

                              The GLM Procedure

                          t Tests (LSD) for Length

      NOTE: This test controls the Type I comparisonwise error rate, not the
                            experimentwise error rate.
                 Alpha                                0.05
                 Error Degrees of Freedom               28
                 Error Mean Square                3.213357
                 Critical Value of t               2.04841
                 Least Significant Difference       2.3223

           Means with the same letter are not significantly different.
```

```
             t Grouping          Mean       N     RxTxV

                      A        14.120       5     R2BN14
                      A
                 B    A        13.720       5     R2TN14
                 B    A
                 B    A        13.500       5     R1TN14
                 B
                 B             11.660       5     R1BN14

                      C         9.020       5     R2BN26
                      C
                      C         8.660       5     R1BN26
                      C
                      C         8.440       5     R2TN26
                      C
                      C         7.220       5     R1TN26

                        t Tests (LSD) for Population

NOTE: This test controls the Type I comparisonwise error rate, not the
                        experimentwise error rate.
                 Alpha                              0.05
                 Error Degrees of Freedom             28
                 Error Mean Square              1.916625
                 Critical Value of t             2.04841
                 Least Significant Difference     1.7936

      Means with the same letter are not significantly different.

             t Grouping          Mean       N     RxTxV

                      A       11.2600       5     R2BN14
                      A
                      A        9.6400       5     R2BN26

                      B        7.0200       5     R1BN14
                      B
                      B        6.3400       5     R2TN14
```

```
                             B
                        C    B         6.2600      5     R1BN26
                        C
                        C    D         4.5400      5     R1TN14
                        C    D
                        C    D         4.5400      5     R2TN26
                             D
                             D         2.9400      5     R1TN26


---------------------------------- Irri=Sav DAS=78 --------------------------

                                  The GLM Procedure



                              t Tests (LSD) for Length

       NOTE: This test controls the Type I comparisonwise error rate, not the
                             experimentwise error rate.
                        Alpha                                0.05
                        Error Degrees of Freedom               27
                        Error Mean Square                2.053525
                        Critical Value of t               2.05183
                        Least Significant Difference       1.8884
                        Harmonic Mean of Cell Sizes      4.848485

                           NOTE: Cell sizes are not equal.


             Means with the same letter are not significantly different.


                    t Grouping          Mean      N     RxTxV

                             A       16.2600      5     R2TN14
                             A
                             A       15.1600      5     R1TN14
                             A
```

```
                 B    A       15.0000      4    R2BN14
                 B
                 B            13.1400      5    R1BN14

                      C       10.4800      5    R2BN26
                      C
                      C       10.4000      5    R1BN26
                      C
                      C       10.0800      5    R1TN26
                      C
                      C        9.4800      5    R2TN26



                     t Tests (LSD) for Population

NOTE: This test controls the Type I comparisonwise error rate, not the
                      experimentwise error rate.
                 Alpha                            0.05
                 Error Degrees of Freedom           28
                 Error Mean Square            4.431518
                 Critical Value of t           2.04841
                 Least Significant Difference   2.7272

      Means with the same letter are not significantly different.

             t Grouping          Mean      N    RxTxV

                      A        15.060      5    R2BN14

                      B        11.840      5    R2BN26
                      B
                 C    B         9.740      5    R1BN14
                 C
                 C              8.520      5    R1BN26
                 C
                 C    D         7.180      5    R2TN14
                      D
                 E    D         5.660      5    R2TN26
```

```
                E    D
                E    D          4.860      5     R1TN14
                E
                E               3.480      5     R1TN26


---------------------------------- Irri=Sav DAS=94 --------------------------

                          The GLM Procedure

                      t Tests (LSD) for Length

       NOTE: This test controls the Type I comparisonwise error rate, not the
                        experimentwise error rate.
                Alpha                            0.05
                Error Degrees of Freedom           28
                Error Mean Square            3.606679
                Critical Value of t           2.04841
                Least Significant Difference   2.4604
             Means with the same letter are not significantly different.

            t Grouping          Mean      N     RxTxV


                     A        20.160      5     R2TN14
                     A
                     A        19.100      5     R2BN14
                     A
                B    A        18.060      5     R1TN14
                B
                B    C        15.840      5     R1BN14
                     C
                D    C        13.740      5     R1BN26
                D
                D    E        12.600      5     R2BN26
                     E
                     E        11.060      5     R2TN26
                     E
                     E        10.940      5     R1TN26
```

```
                       t Tests (LSD) for Population

NOTE: This test controls the Type I comparisonwise error rate, not the
                      experimentwise error rate.
                 Alpha                              0.05
                 Error Degrees of Freedom             28
                 Error Mean Square              8.394214
                 Critical Value of t             2.04841
                 Least Significant Difference     3.7535

      Means with the same letter are not significantly different.

               t Grouping          Mean       N    RxTxV

                        A        20.160       5    R2BN14

                        B        15.100       5    R2BN26
                        B
                        B        13.320       5    R1BN14
                        B
                        B        13.140       5    R1BN26

                        C         8.140       5    R2TN14
                        C
                   D    C         6.340       5    R1TN14
                   D    C
                   D    C         6.120       5    R2TN26
                   D
                   D              3.800       5    R1TN26

-------------------------------- Irri=Sav DAS=109 -------------------------

                             The GLM Procedure

                         t Tests (LSD) for Length

NOTE: This test controls the Type I comparisonwise error rate, not the
                      experimentwise error rate.
                 Alpha                              0.05
```

```
                 Error Degrees of Freedom           28
                 Error Mean Square            5.164946
                 Critical Value of t           2.04841
                 Least Significant Difference   2.9443

      Means with the same letter are not significantly different.

             t Grouping          Mean      N    RxTxV

                      A        24.320      5    R2TN14
                      A
                      A        23.040      5    R2BN14
                      A
                 B    A        21.380      5    R1TN14
                 B
                 B    C        19.760      5    R1BN14
                      C
                 D    C        17.680      5    R1BN26
                 D
                 D    E        14.960      5    R2BN26
                      E
                      E        14.440      5    R2TN26
                      E
                      E        13.800      5    R1TN26

                     t Tests (LSD) for Population

NOTE: This test controls the Type I comparisonwise error rate, not the
                      experimentwise error rate.
                 Alpha                            0.05
                 Error Degrees of Freedom           28
                 Error Mean Square             13.4828
                 Critical Value of t           2.04841
                 Least Significant Difference    4.757

      Means with the same letter are not significantly different.

             t Grouping          Mean      N    RxTxV
```

```
                 A         26.300      5    R2BN14


                 B         19.940      5    R2BN26
                 B
                 B         17.600      5    R1BN14
                 B
            C    B         16.940      5    R1BN26
            C
            C    D         12.500      5    R2TN14
                 D
            E    D          7.780      5    R2TN26
            E
            E               7.540      5    R1TN14
            E
            E               4.480      5    R1TN26

---------------------------- Irri=Sav DAS=127 --------------------------

                            The GLM Procedure

                        t Tests (LSD) for Length

  NOTE: This test controls the Type I comparisonwise error rate, not the
                      experimentwise error rate.
            Alpha                                0.05
            Error Degrees of Freedom               28
            Error Mean Square                26.75821
            Critical Value of t               2.04841
            Least Significant Difference       6.7015

        Means with the same letter are not significantly different.

      t Grouping          Mean       N    RxTxV

              A         28.220      5    R2TN14
              A
              A         27.180      5    R1BN26
              A
              A         26.980      5    R2BN14
```

```
                   A
                   A        26.940      5    R2TN26
                   A
                   A        26.580      5    R1BN14
                   A
                   A        26.260      5    R1TN26
                   A
                   A        26.080      5    R1TN14
                   A
                   A        23.500      5    R2BN26

                     t Tests (LSD) for Population

NOTE: This test controls the Type I comparisonwise error rate, not the
                      experimentwise error rate.
                 Alpha                            0.05
                 Error Degrees of Freedom           28
                 Error Mean Square            18.30695
                 Critical Value of t           2.04841
                 Least Significant Difference   5.5431

      Means with the same letter are not significantly different.

             t Grouping          Mean       N    RxTxV

                      A        33.780       5    R2BN14

                      B        28.060       5    R2BN26
                      B
                      B        25.920       5    R1BN14
                      B
                 C    B        22.620       5    R1BN26
                 C
                 C    D        18.780       5    R2TN14
                      D
                 E    D        13.860       5    R1TN14
                 E
                 E    F        12.540       5    R2TN26
                      F
```

```
                             F         7.580      5    R1TN26



--------------------------------- Irri=Sav DAS=141 ----------------------------

                                  The GLM Procedure

                              t Tests (LSD) for Length

       NOTE: This test controls the Type I comparisonwise error rate, not the
                             experimentwise error rate.
                        Alpha                            0.05
                        Error Degrees of Freedom           28
                        Error Mean Square             9.60225
                        Critical Value of t           2.04841
                        Least Significant Difference   4.0145

             Means with the same letter are not significantly different.

                    t Grouping          Mean      N    RxTxV

                             A        39.200      5    R2TN14
                             A
                        B    A        38.480      5    R2BN14
                        B
                        B    C        34.500      5    R1BN14
                             C
                        D    C        33.800      5    R1TN14
                        D    C
                        D    C        33.200      5    R1BN26
                        D
                        D    E        29.820      5    R2BN26
                             E
                        F    E        26.120      5    R2TN26
                        F
                        F             24.900      5    R1TN26

                            t Tests (LSD) for Population
```

```
NOTE: This test controls the Type I comparisonwise error rate, not the
                      experimentwise error rate.
                 Alpha                              0.05
                 Error Degrees of Freedom             28
                 Error Mean Square              23.62857
                 Critical Value of t             2.04841
                 Least Significant Difference     6.2975

      Means with the same letter are not significantly different.

              t Grouping           Mean      N     RxTxV

                   A             37.440      5     R2BN14
                   A
              B    A             32.340      5     R2BN26
              B
              B    C             29.260      5     R1BN14
              B    C
              B    C    D        26.740      5     R1BN26
                   C    D
                   C    D        24.500      5     R2TN14
                        D
                   E    D        21.120      5     R2TN26
                   E
              F    E             17.860      5     R1TN14
              F
              F                  12.740      5     R1TN26


---------------------------------- Irri=Std DAS=37 --------------------------

                            The GLM Procedure

                     t Tests (LSD) for Population

NOTE: This test controls the Type I comparisonwise error rate, not the
                      experimentwise error rate.
```

```
                Alpha                              0.05
                Error Degrees of Freedom             28
                Error Mean Square              0.610625
                Critical Value of t             2.04841
                Least Significant Difference    1.0124


          Means with the same letter are not significantly different.


            t Grouping          Mean       N     RxTxV


                     A        7.6800       5     R2BN26


                     B        6.2800       5     R2BN14


                     C        4.3400       5     R1BN14
                     C
                     C        3.8800       5     R1BN26


                     D        0.0000       5     R1TN14
                     D
                     D        0.0000       5     R1TN26
                     D
                     D        0.0000       5     R2TN14
                     D
                     D        0.0000       5     R2TN26

---------------------------------- Irri=Std DAS=43 --------------------------

                                The GLM Procedure

                            t Tests (LSD) for Length

      NOTE: This test controls the Type I comparisonwise error rate, not the
                           experimentwise error rate.
                Alpha                              0.05
                Error Degrees of Freedom             28
                Error Mean Square              1.898536
```

```
                 Critical Value of t           2.04841
                 Least Significant Difference   1.7851

      Means with the same letter are not significantly different.

             t Grouping          Mean      N    RxTxV

                      A       12.5400      5    R2BN14
                      A
                 B    A       11.0000      5    R2TN14
                 B
                 B            10.6600      5    R1BN14
                 B
                 B            10.4600      5    R1TN14

                      C        7.8000      5    R2TN26
                      C
                      C        7.7800      5    R2BN26
                      C
                      C        7.1600      5    R1TN26
                      C
                      C        7.1400      5    R1BN26

                        t Tests (LSD) for Population

NOTE: This test controls the Type I comparisonwise error rate, not the
                      experimentwise error rate.
                 Alpha                                 0.05
                 Error Degrees of Freedom                28
                 Error Mean Square                 0.823268
                 Critical Value of t                2.04841
                 Least Significant Difference        1.1755

      Means with the same letter are not significantly different.

             t Grouping          Mean      N    RxTxV

                      A        8.9000      5    R2BN26
                      A
```

```
          A         8.1600      5     R2BN14

          B         5.1400      5     R1BN14
          B
          B         4.8200      5     R2TN14
          B
          B         4.2600      5     R1BN26

          C         2.5400      5     R1TN14
          C
     D    C         1.9400      5     R2TN26
     D
     D              0.9600      5     R1TN26



---------------------------------- Irri=Std DAS=50 --------------------------

                           The GLM Procedure

                       t Tests (LSD) for Length

       NOTE: This test controls the Type I comparisonwise error rate, not the
                       experimentwise error rate.
                  Alpha                            0.05
                  Error Degrees of Freedom           28
                  Error Mean Square            1.601696
                  Critical Value of t           2.04841
                  Least Significant Difference   1.6396

             Means with the same letter are not significantly different.

           t Grouping          Mean       N     RxTxV

                   A        13.0000       5     R1TN14
                   A
                   A        12.8600       5     R2TN14
                   A
                   A        12.7800       5     R2BN14
```

```
                   B       11.0800      5    R1BN14

                   C        8.9600      5    R2TN26
                   C
                   C        8.8800      5    R1TN26
                   C
                   C        8.1400      5    R2BN26
                   C
                   C        7.5000      5    R1BN26

                     t Tests (LSD) for Population

NOTE: This test controls the Type I comparisonwise error rate, not the
                      experimentwise error rate.
                 Alpha                             0.05
                 Error Degrees of Freedom            28
                 Error Mean Square             1.839304
                 Critical Value of t            2.04841
                 Least Significant Difference     1.757

      Means with the same letter are not significantly different.

             t Grouping          Mean      N    RxTxV

                      A        9.1000      5    R2BN14
                      A
                      A        8.5000      5    R2BN26

                      B        5.7600      5    R2TN14
                      B
                      B        5.6800      5    R1BN14
                      B
                 C    B        4.5400      5    R1BN26
                 C
                 C    D        2.9400      5    R1TN14
                      D
                      D        2.7200      5    R2TN26
                      D
```

```
                             D        1.6000      5    R1TN26



---------------------------------- Irri=Std DAS=62 --------------------------

                                  The GLM Procedure

                              t Tests (LSD) for Length

       NOTE: This test controls the Type I comparisonwise error rate, not the
                             experimentwise error rate.
                        Alpha                             0.05
                        Error Degrees of Freedom            28
                        Error Mean Square             1.807054
                        Critical Value of t            2.04841
                        Least Significant Difference    1.7415

             Means with the same letter are not significantly different.

                    t Grouping          Mean      N    RxTxV

                             A       14.4000      5    R2BN14
                             A
                        B    A       14.1600      5    R2TN14
                        B    A
                        B    A       12.7000      5    R1TN14
                        B
                        B            12.5000      5    R1BN14

                             C        9.4200      5    R2BN26
                             C
                             C        9.4000      5    R1BN26
                             C
                             C        7.8400      5    R2TN26

                             D        4.2400      5    R1TN26

                            t Tests (LSD) for Population
```

```
NOTE: This test controls the Type I comparisonwise error rate, not the
                      experimentwise error rate.
                 Alpha                              0.05
                 Error Degrees of Freedom             28
                 Error Mean Square              2.726018
                 Critical Value of t             2.04841
                 Least Significant Difference      2.139

      Means with the same letter are not significantly different.

             t Grouping          Mean       N    RxTxV

                      A        12.160       5    R2BN14

                      B         9.660       5    R2BN26

                      C         7.420       5    R1BN14
                      C
                      C         6.960       5    R2TN14
                      C
                 D    C         5.660       5    R1BN26
                 D
                 D    E         4.400       5    R2TN26
                 D    E
                 D    E         4.180       5    R1TN14
                      E
                      E         2.660       5    R1TN26
```

```
--------------------------------- Irri=Std DAS=78 -------------------------

                                  The GLM Procedure

                              t Tests (LSD) for Length

       NOTE: This test controls the Type I comparisonwise error rate, not the
                              experimentwise error rate.
                         Alpha                            0.05
                         Error Degrees of Freedom           28
                         Error Mean Square            1.384625
                         Critical Value of t           2.04841
                         Least Significant Difference   1.5244

             Means with the same letter are not significantly different.

                    t Grouping          Mean       N     RxTxV

                              A       16.8400      5     R2BN14
                              A
                              A       16.6200      5     R2TN14
                              A
                         B    A       15.4000      5     R1TN14
                         B
                         B            14.8400      5     R1BN14

                              C       11.0200      5     R1BN26
                              C
                              C       10.9400      5     R2BN26
                              C
                         D    C        9.7600      5     R2TN26
                         D
                         D             8.7400      5     R1TN26

                            t Tests (LSD) for Population

       NOTE: This test controls the Type I comparisonwise error rate, not the
                              experimentwise error rate.
                         Alpha                            0.05
```

```
                        Error Degrees of Freedom            28
                        Error Mean Square             6.282304
                        Critical Value of t            2.04841
                        Least Significant Difference    3.2472


            Means with the same letter are not significantly different.


                    t Grouping          Mean       N     RxTxV


                             A        16.600       5     R2BN14


                             B        12.120       5     R2BN26
                             B
                        C    B        10.460       5     R1BN14
                        C
                        C    D         7.800       5     R1BN26
                        C    D
                        C    D         7.220       5     R2TN14
                             D
                        E    D         5.380       5     R2TN26
                        E    D
                        E    D         5.240       5     R1TN14
                        E
                        E              3.200       5     R1TN26
```

```
---------------------------------- Irri=Std DAS=94 --------------------------

                                 The GLM Procedure

                             t Tests (LSD) for Length

       NOTE: This test controls the Type I comparisonwise error rate, not the
                           experimentwise error rate.
                      Alpha                              0.05
                      Error Degrees of Freedom             28
                      Error Mean Square              1.649696
                      Critical Value of t             2.04841
                      Least Significant Difference     1.664

             Means with the same letter are not significantly different.

                 t Grouping          Mean       N     RxTxV

                          A       21.2400       5     R2BN14
                          A
                          A       20.8800       5     R2TN14

                          B       19.0800       5     R1BN14
                          B
                          B       18.0600       5     R1TN14

                          C       14.2000       5     R2BN26
                          C
                          C       13.7200       5     R1BN26

                          D       11.9400       5     R2TN26

                          E        9.5200       5     R1TN26

                           t Tests (LSD) for Population

       NOTE: This test controls the Type I comparisonwise error rate, not the
                           experimentwise error rate.
                      Alpha                              0.05
```

```
Error Degrees of Freedom            28
Error Mean Square             7.931464
Critical Value of t            2.04841
Least Significant Difference    3.6486


Means with the same letter are not significantly different.


t Grouping          Mean      N    RxTxV


         A        23.580      5    R2BN14


         B        17.780      5    R2BN26
         B
    C    B        14.400      5    R1BN14
    C
    C    D        11.520      5    R1BN26
         D
    E    D         8.280      5    R2TN14
    E
    E    F         6.020      5    R2TN26
    E    F
    E    F         5.660      5    R1TN14
         F
         F         3.620      5    R1TN26
```

```
-------------------------------- Irri=Std DAS=109 -------------------------

                                 The GLM Procedure

                             t Tests (LSD) for Length

      NOTE: This test controls the Type I comparisonwise error rate, not the
                              experimentwise error rate.
                         Alpha                            0.05
                         Error Degrees of Freedom           28
                         Error Mean Square            2.840875
                         Critical Value of t           2.04841
                         Least Significant Difference   2.1836

            Means with the same letter are not significantly different.

                   t Grouping          Mean       N     RxTxV


                            A        26.500       5     R2BN14
                            A
                       B    A        25.900       5     R2TN14
                       B
                       B    C        24.000       5     R1BN14
                            C
                            C        21.920       5     R1TN14

                            D        18.840       5     R2BN26
                            D
                            D        18.380       5     R1BN26

                            E        15.400       5     R2TN26

                            F        11.620       5     R1TN26

                           t Tests (LSD) for Population

      NOTE: This test controls the Type I comparisonwise error rate, not the
                              experimentwise error rate.
                         Alpha                            0.05
```

```
           Error Degrees of Freedom           28
           Error Mean Square            14.17232
           Critical Value of t           2.04841
           Least Significant Difference   4.8772

Means with the same letter are not significantly different.

       t Grouping          Mean      N    RxTxV

                A        31.160      5    R2BN14

                B        25.500      5    R2BN26
                B
           C    B        21.020      5    R1BN14
           C
           C    D        16.320      5    R1BN26
                D
           E    D        12.560      5    R2TN14
           E
           E    F         7.860      5    R1TN14
                F
                F         6.860      5    R2TN26
                F
                F         4.040      5    R1TN26
```

```
--------------------------------- Irri=Std DAS=127 --------------------------

                              The GLM Procedure

                          t Tests (LSD) for Length

      NOTE: This test controls the Type I comparisonwise error rate, not the
                          experimentwise error rate.
                     Alpha                             0.05
                     Error Degrees of Freedom            28
                     Error Mean Square             25.97321
                     Critical Value of t            2.04841
                     Least Significant Difference    6.6025

            Means with the same letter are not significantly different.

                  t Grouping            Mean      N     RxTxV

                       A              32.200      5     R1BN14
                       A
                  B    A              31.240      5     R2BN14
                  B    A
                  B    A              31.120      5     R2TN14
                  B    A
                  B    A    C         29.440      5     R1TN26
                  B    A    C
                  B    A    C         27.960      5     R2TN26
                  B    A    C
                  B    A    C         27.040      5     R1BN26
                  B         C
                  B         C         25.420      5     R2BN26
                            C
                            C         23.860      5     R1TN14

                        t Tests (LSD) for Population

      NOTE: This test controls the Type I comparisonwise error rate, not the
                          experimentwise error rate.
                     Alpha                             0.05
```

```
                  Error Degrees of Freedom           28
                  Error Mean Square            19.01841
                  Critical Value of t           2.04841
                  Least Significant Difference   5.6498

       Means with the same letter are not significantly different.

           t Grouping           Mean       N     RxTxV

                    A         37.520       5     R2BN14
                    A
                    A         33.680       5     R2BN26

                    B         24.940       5     R1BN14
                    B
                    B         21.680       5     R1BN26
                    B
                    B         19.560       5     R2TN14

                    C         10.420       5     R1TN14
                    C
                    C         10.200       5     R2TN26
                    C
                    C          6.120       5     R1TN26
```

```
--------------------------------- Irri=Std DAS=141 --------------------------

                              The GLM Procedure

                          t Tests (LSD) for Length

       NOTE: This test controls the Type I comparisonwise error rate, not the
                         experimentwise error rate.
                    Alpha                                0.05
                    Error Degrees of Freedom               28
                    Error Mean Square                6.028875
                    Critical Value of t               2.04841
                    Least Significant Difference        3.181

             Means with the same letter are not significantly different.

                t Grouping          Mean       N    RxTxV

                         A        44.580       5    R2BN14
                         A
                    B    A        41.840       5    R2TN14
                    B
                    B    C        38.940       5    R1BN14
                         C
                    D    C        36.400       5    R2BN26
                    D
                    D             35.540       5    R1TN14
                    D
                    D             34.040       5    R1BN26

                         E        27.540       5    R2TN26

                         F        21.760       5    R1TN26

                        t Tests (LSD) for Population

       NOTE: This test controls the Type I comparisonwise error rate, not the
                         experimentwise error rate.
                    Alpha                                0.05
```

```
          Error Degrees of Freedom            28
          Error Mean Square             15.47916
          Critical Value of t            2.04841
          Least Significant Difference    5.0971

Means with the same letter are not significantly different.

       t Grouping          Mean      N    RxTxV


                A        41.180      5    R2BN14
                A
                A        37.960      5    R2BN26

                B        29.040      5    R1BN14
                B
                B        26.780      5    R2TN14
                B
                B        25.400      5    R1BN26

                C        18.340      5    R2TN26
                C
           D    C        15.400      5    R1TN14
           D
           D             10.820      5    R1TN26

   P-values for the Shapiro-Wilk test for Normality

       Obs     Irri     DAS     NLength     NPopulation


         1     Sav       37     0.49033       0.12364
         2     Sav       43     0.74376       0.99296
         3     Sav       50     0.65079       0.72404
         4     Sav       62     0.11769       0.81764
         5     Sav       78     0.21486       0.18492
         6     Sav       94     0.54515       0.00534
         7     Sav      109     0.06566       0.00654
         8     Sav      127     0.47872       0.25186
         9     Sav      141     0.04759       0.18742
        10     Std       37     0.65211       0.04542
```

```
11     Std       43    0.44951      0.19420
12     Std       50    0.09665      0.06774
13     Std       62    0.06136      0.93865
14     Std       78    0.47826      0.52489
15     Std       94    0.81049      0.63072
16     Std      109    0.93342      0.55579
17     Std      127    0.69238      0.91967
18     Std      141    0.36879      0.10274
```

Means

```
Obs RxTxV  _NAME_       _37   _43   _50   _62   _78    _94   _109  _127  _141

  1 R1BN14 Length       7.37 10.88 11.14 12.08 13.99 17.46 21.88 29.39 36.72
  2 R1BN26 Length       6.08  7.46  7.55  9.03 10.71 13.73 18.03 27.11 33.62
  3 R1TN14 Length        .   10.77 12.82 13.10 15.28 18.06 21.65 24.97 34.67
  4 R1TN26 Length        .    8.12  9.41  5.73  9.41 10.23 12.71 27.85 23.33
  5 R2BN14 Length       7.91 12.26 12.61 14.26 16.02 20.17 24.77 29.11 41.53
  6 R2BN26 Length       5.88  8.13  8.24  9.22 10.71 13.40 16.90 24.46 33.11
  7 R2TN14 Length        .   11.71 13.14 13.94 16.44 20.52 25.11 29.67 40.52
  8 R2TN26 Length        .    7.95  9.11  8.14  9.62 11.50 14.92 27.45 26.83
  9 R1BN14 Population   4.57  5.40  5.95  7.22 10.10 13.86 19.31 25.43 29.15
 10 R1BN26 Population   4.01  4.30  4.74  5.96  8.16 12.33 16.63 22.15 26.07
 11 R1TN14 Population   0.00  2.77  3.27  4.36  5.05  6.00  7.70 12.14 16.63
 12 R1TN26 Population   0.00  1.16  1.60  2.80  3.34  3.71  4.26  6.85 11.78
 13 R2BN14 Population   6.25  7.93  8.78 11.71 15.83 21.87 28.73 35.65 39.31
 14 R2BN26 Population   6.64  8.25  8.31  9.65 11.98 16.44 22.72 30.87 35.15
 15 R2TN14 Population   0.00  4.77  5.41  6.65  7.20  8.21 12.53 19.17 25.64
 16 R2TN26 Population   0.00  2.08  2.69  4.47  5.52  6.07  7.32 11.37 19.73
```

```
---------------------------------- Irri=Sav DAS=50 --------------------------

                                 The GLM Procedure

                               t Tests (LSD) for FI

       NOTE: This test controls the Type I comparisonwise error rate, not the
                             experimentwise error rate.


                      Alpha                               0.05
                      Error Degrees of Freedom              28
                      Error Mean Square               4.217732
                      Critical Value of t              2.04841
                      Least Significant Difference    2.6606


             Means with the same letter are not significantly different.


                    t Grouping          Mean      N    RxTxV

                         A             7.940      5    R2BaN26
                         A
                    B    A             7.740      5    R1BaN26
                    B    A
                    B    A    C        6.980      5    R2BaN14
                    B    A    C
                    B    A    C        6.640      5    R1BaN14
                    B         C
                    B    D    C        5.160      5    R1TrN14
                         D    C
                    E    D    C        4.860      5    R2TrN14
                    E    D
                    E    D             3.340      5    R1TrN26
                    E
                    E                  2.480      5    R2TrN26
```

```
---------------------------------- Irri=Sav DAS=61 --------------------------

                             The GLM Procedure

                           t Tests (LSD) for FI

      NOTE: This test controls the Type I comparisonwise error rate, not the
                           experimentwise error rate.


                   Alpha                               0.05
                   Error Degrees of Freedom              14
                   Error Mean Square               6.711667
                   Critical Value of t              2.14479
                   Least Significant Difference      4.5368


            Means with the same letter are not significantly different.


                  t Grouping          Mean       N    RxTxV

                           A        13.767       3    R2BaN26
                           A
                      B    A        12.867       3    R2BaN14
                      B    A
                      B    A        12.633       3    R1BaN14
                      B    A
                      B    A        11.933       3    R1BaN26
                      B
                      B    C         8.967       3    R1TrN14
                           C
                           C         7.200       3    R2TrN14
                           C
                           C         6.267       3    R1TrN26
                           C
                           C         4.833       3    R2TrN26
```

```
--------------------------------- Irri=Sav DAS=78 -------------------------

                           The GLM Procedure

                         t Tests (LSD) for FI

       NOTE: This test controls the Type I comparisonwise error rate, not the
                        experimentwise error rate.


                 Alpha                                  0.05
                 Error Degrees of Freedom                 28
                 Error Mean Square                  14.51552
                 Critical Value of t                 2.04841
                 Least Significant Difference         4.9359


             Means with the same letter are not significantly different.


                t Grouping          Mean        N     RxTxV

                         A        16.740        5     R2BaN26
                         A
                         A        16.620        5     R2BaN14
                         A
                    B    A        14.780        5     R1BaN26
                    B    A
                    B    A        14.060        5     R1BaN14
                    B
                    B             11.380        5     R2TrN14
                    B
                    B    C        10.380        5     R1TrN14
                         C
                    D    C         6.200        5     R1TrN26
                    D
                    D              4.360        5     R2TrN26
```

```
---------------------------------- Irri=Sav DAS=86 --------------------------

                                  The GLM Procedure

                                t Tests (LSD) for FI

      NOTE: This test controls the Type I comparisonwise error rate, not the
                           experimentwise error rate.


                      Alpha                              0.05
                      Error Degrees of Freedom             28
                      Error Mean Square              9.562268
                      Critical Value of t             2.04841
                      Least Significant Difference     4.0061


            Means with the same letter are not significantly different.


                t Grouping          Mean       N     RxTxV

                         A        19.320       5     R2BaN14
                         A
                         A        17.680       5     R2BaN26
                         A
                    B    A        16.960       5     R1BaN26
                    B
                    B    C        13.560       5     R1BaN14
                         C
                         C        12.160       5     R2TrN14

                         D         7.660       5     R1TrN14
```

```
                         D
                         D          6.320      5    R1TrN26
                         D
                         D          6.280      5    R2TrN26




---------------------------------- Irri=Sav DAS=98 --------------------------

                                 The GLM Procedure

                               t Tests (LSD) for FI

       NOTE: This test controls the Type I comparisonwise error rate, not the
                             experimentwise error rate.


                     Alpha                                0.05
                     Error Degrees of Freedom               28
                     Error Mean Square                19.93488
                     Critical Value of t               2.04841
                     Least Significant Difference       5.7843


             Means with the same letter are not significantly different.


                t Grouping          Mean       N    RxTxV

                         A         27.280      5    R2BaN26
                         A
                    B    A         23.980      5    R1BaN26
                    B    A
                    B    A         23.580      5    R2BaN14
                    B
                    B              19.340      5    R1BaN14
```

```
                      C         12.960      5    R2TrN14
                      C
                      C         12.480      5    R1TrN14
                      C
                      C          9.540      5    R2TrN26
                      C
                      C          8.060      5    R1TrN26


--------------------------------- Irri=Sav DAS=105 --------------------------

                                The GLM Procedure

                              t Tests (LSD) for FI

       NOTE: This test controls the Type I comparisonwise error rate, not the
                            experimentwise error rate.


                  Alpha                                0.05
                  Error Degrees of Freedom               28
                  Error Mean Square                33.13636
                  Critical Value of t               2.04841
                  Least Significant Difference       7.4576


             Means with the same letter are not significantly different.


              t Grouping          Mean       N    RxTxV


                      A         28.460      5    R2BaN26
                      A
                 B    A         25.160      5    R1BaN26
                 B    A
                 B    A         24.960      5    R2BaN14
                 B
                 B    C         20.240      5    R1BaN14
                      C
```

```
          D     C         13.800       5     R2TrN14
          D     C
          D     C         13.300       5     R1TrN14
          D
          D               10.620       5     R2TrN26
          D
          D                8.460       5     R1TrN26
```

```
--------------------------------- Irri=Sav DAS=115 --------------------------

                                  The GLM Procedure

                                t Tests (LSD) for FI

       NOTE: This test controls the Type I comparisonwise error rate, not the
                             experimentwise error rate.


                 Alpha                               0.05
                 Error Degrees of Freedom              28
                 Error Mean Square               18.24364
                 Critical Value of t              2.04841
                 Least Significant Difference      5.5335


             Means with the same letter are not significantly different.


          t Grouping          Mean       N     RxTxV

                   A        46.000       5     R2BaN14
```

```
                B        36.940      5     R2BaN26
                B
                B        36.000      5     R1BaN26
                B
           C    B        31.920      5     R1BaN14
           C
           C             29.760      5     R2TrN14

                D        23.900      5     R1TrN14

                E        18.060      5     R2TrN26
                E
                E        14.820      5     R1TrN26


--------------------------------- Irri=Sav DAS=133 --------------------------

                                 The GLM Procedure

                               t Tests (LSD) for FI

       NOTE: This test controls the Type I comparisonwise error rate, not the
                             experimentwise error rate.


                    Alpha                                0.05
                    Error Degrees of Freedom               28
                    Error Mean Square                50.17754
                    Critical Value of t               2.04841
                    Least Significant Difference        9.177


             Means with the same letter are not significantly different.


              t Grouping          Mean      N     RxTxV


                A        69.220      5     R2BaN14
```

```
            B          54.140       5     R1BaN26
            B
            B          53.320       5     R2BaN26
            B
            B          52.260       5     R1BaN14
            B
       C    B          46.220       5     R2TrN14
       C
       C    D          39.880       5     R1TrN14
            D
       E    D          32.820       5     R2TrN26
       E
       E               26.420       5     R1TrN26



--------------------------------- Irri=Sav DAS=148 --------------------------

                                  The GLM Procedure

                                t Tests (LSD) for FI

       NOTE: This test controls the Type I comparisonwise error rate, not the
                           experimentwise error rate.


                    Alpha                               0.05
                    Error Degrees of Freedom              28
                    Error Mean Square               48.03634
                    Critical Value of t              2.04841
                    Least Significant Difference      8.9791


             Means with the same letter are not significantly different.


         t Grouping          Mean        N     RxTxV

            A          82.420       5     R2BaN14
```

```
                B        70.500      5    R2BaN26
                B
                B        67.980      5    R1BaN14
                B
                B        66.740      5    R1BaN26
                B
                B        62.020      5    R2TrN14

                C        49.040      5    R1TrN14
                C
           D    C        44.180      5    R2TrN26
           D
           D             35.700      5    R1TrN26



--------------------------------- Irri=Sav DAS=155 --------------------------

                                  The GLM Procedure

                                t Tests (LSD) for FI

       NOTE: This test controls the Type I comparisonwise error rate, not the
                              experimentwise error rate.


                  Alpha                                0.05
                  Error Degrees of Freedom               27
                  Error Mean Square                39.65456
                  Critical Value of t               2.05183
                  Least Significant Difference       8.2985
                  Harmonic Mean of Cell Sizes      4.848485

                     NOTE: Cell sizes are not equal.


             Means with the same letter are not significantly different.
```

```
         t Grouping          Mean       N     RxTxV


                  A        85.600       5     R2BaN14


                  B        76.440       5     R2BaN26
                  B
                  B        75.660       5     R1BaN14
                  B
             C    B        74.775       4     R1BaN26
             C
             C             66.680       5     R2TrN14


                  D        57.180       5     R1TrN14
                  D
                  D        49.220       5     R2TrN26


                  E        37.600       5     R1TrN26



---------------------------------- Irri=Std DAS=53 --------------------------

                          The GLM Procedure

                        t Tests (LSD) for FI

      NOTE: This test controls the Type I comparisonwise error rate, not the
                           experimentwise error rate.



             Alpha                                   0.05
             Error Degrees of Freedom                  28
             Error Mean Square                   7.490893
             Critical Value of t                  2.04841
             Least Significant Difference          3.5458


            Means with the same letter are not significantly different.
```

```
t Grouping          Mean      N    RxTxV

     A            10.220      5    R1BaN26
     A
B    A             9.300      5    R1BaN14
B    A
B    A    C        8.080      5    R2BaN26
B    A    C
B    A    C        8.060      5    R2BaN14
B         C
B    D    C        6.000      5    R1TrN14
B    D    C
B    D    C        5.960      5    R2TrN14
     D    C
     D    C        4.720      5    R1TrN26
     D
     D             2.560      5    R2TrN26


---------------------------------- Irri=Std DAS=61 --------------------------

                         The GLM Procedure

                       t Tests (LSD) for FI

       NOTE: This test controls the Type I comparisonwise error rate, not the
                      experimentwise error rate.


            Alpha                              0.05
            Error Degrees of Freedom             14
            Error Mean Square              7.118036
            Critical Value of t             2.14479
            Least Significant Difference     4.6722


        Means with the same letter are not significantly different.
```

```
          t Grouping          Mean      N    RxTxV


                   A        14.033      3    R2BaN14
                   A
                   A        13.467      3    R1BaN14
                   A
              B    A        11.800      3    R1BaN26
              B    A
              B    A        11.633      3    R2BaN26
              B
              B    C         8.600      3    R1TrN14
              B    C
              B    C         7.967      3    R2TrN14
                   C
                   C         5.033      3    R2TrN26
                   C
                   C         3.967      3    R1TrN26
```

```
---------------------------------- Irri=Std DAS=80 --------------------------

                               The GLM Procedure

                             t Tests (LSD) for FI

       NOTE: This test controls the Type I comparisonwise error rate, not the
                          experimentwise error rate.


                     Alpha                             0.05
                     Error Degrees of Freedom            28
                     Error Mean Square               15.498
                     Critical Value of t            2.04841
                     Least Significant Difference    5.1002
```

```
        Means with the same letter are not significantly different.


                t Grouping           Mean      N     RxTxV

                     A             18.440      5     R2BaN14

                     B             12.440      5     R2BaN26
                     B
                     B             12.000      5     R2TrN14
                     B
                C    B             11.640      5     R1BaN14
                C    B
                C    B    D        10.440      5     R1BaN26
                C         D
                C    E    D         6.560      5     R1TrN14
                     E    D
                     E    D         6.240      5     R2TrN26
                     E
                     E              4.520      5     R1TrN26



---------------------------------- Irri=Std DAS=88 --------------------------

                              The GLM Procedure

                             t Tests (LSD) for FI

      NOTE: This test controls the Type I comparisonwise error rate, not the
                           experimentwise error rate.


                   Alpha                            0.05
                   Error Degrees of Freedom           28
```

```
                Error Mean Square            21.03573
                Critical Value of t           2.04841
                Least Significant Difference   5.9419


      Means with the same letter are not significantly different.


            t Grouping          Mean       N     RxTxV

                     A        18.060       5     R2BaN14
                     A
                B    A        14.040       5     R1BaN14
                B
                B    C        12.020       5     R2BaN26
                B    C
                B    C        10.980       5     R2TrN14
                B    C
                B    C        10.640       5     R1BaN26
                     C
                     C         7.000       5     R1TrN14
                     C
                     C         6.740       5     R2TrN26
                     C
                     C         6.500       5     R1TrN26



--------------------------------- Irri=Std DAS=100 --------------------------

                          The GLM Procedure

                        t Tests (LSD) for FI

      NOTE: This test controls the Type I comparisonwise error rate, not the
                      experimentwise error rate.


                Alpha                              0.05
```

```
                      Error Degrees of Freedom            28
                      Error Mean Square               24.773
                      Critical Value of t            2.04841
                      Least Significant Difference    6.4482


           Means with the same letter are not significantly different.


               t Grouping          Mean      N    RxTxV

                        A        36.820      5    R2BaN14
                        A
                        A        33.000      5    R2BaN26

                        B        26.200      5    R1BaN14
                        B
                        B        25.800      5    R1BaN26
                        B
                        B        22.720      5    R2TrN14

                        C        11.780      5    R2TrN26
                        C
                        C        11.160      5    R1TrN14
                        C
                        C         9.520      5    R1TrN26




 --------------------------------- Irri=Std DAS=112 --------------------------

                                  The GLM Procedure

                                t Tests (LSD) for FI

       NOTE: This test controls the Type I comparisonwise error rate, not the
                               experimentwise error rate.
```

```
                        Alpha                            0.05
                        Error Degrees of Freedom           28
                        Error Mean Square            38.02298
                        Critical Value of t           2.04841
                        Least Significant Difference   7.9886


             Means with the same letter are not significantly different.


                   t Grouping          Mean      N    RxTxV


                            A        48.680      5    R2BaN14


                            B        38.000      5    R1BaN14
                            B
                       C    B        34.920      5    R2BaN26
                       C    B
                       C    B        31.000      5    R1BaN26
                       C
                       C             27.600      5    R2TrN14


                            D        16.080      5    R1TrN14
                            D
                            D        14.780      5    R2TrN26
                            D
                            D        12.880      5    R1TrN26




--------------------------------- Irri=Std DAS=128 --------------------------

                                  The GLM Procedure

                                t Tests (LSD) for FI
```

```
NOTE: This test controls the Type I comparisonwise error rate, not the
                   experimentwise error rate.


                  Alpha                              0.05
                  Error Degrees of Freedom             28
                  Error Mean Square              51.13996
                  Critical Value of t             2.04841
                  Least Significant Difference     9.2646


        Means with the same letter are not significantly different.


           t Grouping          Mean       N     RxTxV

                    A        68.800       5     R2BaN14

                    B        57.440       5     R1BaN14
                    B
                    B        56.140       5     R2BaN26
                    B
               C    B        49.780       5     R1BaN26
               C
               C             41.860       5     R2TrN14

                    D        27.200       5     R1TrN14
                    D
                    D        20.820       5     R1TrN26
                    D
                    D        20.680       5     R2TrN26


--------------------------------- Irri=Std DAS=139 --------------------------

                             The GLM Procedure

                           t Tests (LSD) for FI
```

```
       NOTE: This test controls the Type I comparisonwise error rate, not the
                             experimentwise error rate.


                        Alpha                            0.05
                        Error Degrees of Freedom           28
                        Error Mean Square            68.00939
                        Critical Value of t           2.04841
                        Least Significant Difference   10.684


             Means with the same letter are not significantly different.


                   t Grouping          Mean      N    RxTxV

                            A        77.380      5    R2BaN14

                            B        65.180      5    R1BaN14
                            B
                            B        64.820      5    R2BaN26
                            B
                       C    B        56.580      5    R1BaN26
                       C
                       C             52.860      5    R2TrN14

                            D        34.040      5    R1TrN14
                            D
                       E    D        32.180      5    R2TrN26
                       E
                       E             22.320      5    R1TrN26




--------------------------------- Irri=Std DAS=148 --------------------------

                                  The GLM Procedure
```

```
                       t Tests (LSD) for FI

  NOTE: This test controls the Type I comparisonwise error rate, not the
                      experimentwise error rate.


            Alpha                              0.05
            Error Degrees of Freedom             28
            Error Mean Square              73.47941
            Critical Value of t             2.04841
            Least Significant Difference     11.105


      Means with the same letter are not significantly different.


      t Grouping          Mean      N    RxTxV

               A        79.360      5    R2BaN14
               A
               A        78.480      5    R1BaN14

               B        67.060      5    R2BaN26
               B
               B        59.700      5    R2TrN14
               B
               B        58.800      5    R1BaN26

               C        39.300      5    R1TrN14
               C
          D    C        32.840      5    R2TrN26
          D
          D             27.980      5    R1TrN26
```

Means

Sav

```
 Obs   RxTxV   _NAME_  _50    _61     _78    _86    _98    _105   _115   _133   _148   _155

 1  R1BaN14    FI    6.64 12.6333 14.06 13.56 19.34 20.24 31.92 52.26 67.98 75.660
 2  R1BaN26    FI    7.74 11.9333 14.78 16.96 23.98 25.16 36.00 54.14 66.74 74.775
 3  R1TrN14    FI    5.16  8.9667 10.38  7.66 12.48 13.30 23.90 39.88 49.04 57.180
 4  R1TrN26    FI    3.34  6.2667  6.20  6.32  8.06  8.46 14.82 26.42 35.70 37.600
 5  R2BaN14    FI    6.98 12.8667 16.62 19.32 23.58 24.96 46.00 69.22 82.42 85.600
 6  R2BaN26    FI    7.94 13.7667 16.74 17.68 27.28 28.46 36.94 53.32 70.50 76.440
 7  R2TrN14    FI    4.86  7.2000 11.38 12.16 12.96 13.80 29.76 46.22 62.02 66.680
 8  R2TrN26    FI    2.48  4.8333  4.36  6.28  9.54 10.62 18.06 32.82 44.18 49.220



Std
Obs RxTxV    _NAME_    _53      _61      _80     _88     _100    _112    _128    _139    _148

 1    R1BaN14     FI      9.30   13.4667   11.64   14.04   26.20   38.00   57.44   65.18   78.48
 2    R1BaN26     FI     10.22   11.8000   10.44   10.64   25.80   31.00   49.78   56.58   58.80
 3    R1TrN14     FI      6.00    8.6000    6.56    7.00   11.16   16.08   27.20   34.04   39.30
 4    R1TrN26     FI      4.72    3.9667    4.52    6.50    9.52   12.88   20.82   22.32   27.98
 5    R2BaN14     FI      8.06   14.0333   18.44   18.06   36.82   48.68   68.80   77.38   79.36
 6    R2BaN26     FI      8.08   11.6333   12.44   12.02   33.00   34.92   56.14   64.82   67.06
 7    R2TrN14     FI      5.96    7.9667   12.00   10.98   22.72   27.60   41.86   52.86   59.70
 8    R2TrN26     FI      2.56    5.0333    6.24    6.74   11.78   14.78   20.68   32.18   32.84
```