

Growth and yield responses of commercial sugarcane cultivars to residue mulching in different environments

by

Braveman Nkosinathi Gcugcwa Nxumalo

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**In the Department of Plant Production and Soil Science,
Faculty of Natural and Agricultural Sciences,
University of Pretoria**

Supervisor: Prof. J.M. Steyn

Co-supervisor: Dr. S. Ramburan

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DECLARATION

I, Braveman Nkosinathi Gcugwa Nxumalo, declare that this dissertation, which I hereby submit for the degree M.Sc. Agric (Agronomy) at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at any other tertiary institution.

Signed:

Date:

Braveman Nkosinathi Gcugwa Nxumalo

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ABSTRACT

Mulching in sugarcane agriculture involves retaining leaf residue on the ground after harvesting. Many sugarcane industries across the world support this agronomic practice because of its benefits as opposed to burning sugarcane at harvest. In the South African industry, however, there have been isolated reports of negative responses of certain cultivars to mulching. The objective of this study was to evaluate the cane yield and quality responses, population dynamics, and mulch yields of popular sugarcane cultivars to mulching in three major agronomic regions of South Africa. A field trial was established in each of the three major South African sugarcane production regions (Coastal rainfed, Northern irrigated, Midlands) in 2008. Each trial comprised eight of the most popular cultivars for the respective regions. Trials were planted as 2 x 8 factorial strip-plots with four replicates. Burning and mulching were the main plots (strips) and cultivar was sub-plot. In the coastal rainfed and the irrigated region cultivar responses to mulching were evaluated over a period of three summer crops (1st, 2nd, and 3rd ratoon) and one winter crop (5th ratoon), while the Midlands trial was harvested for one summer crop (1st ratoon). The impact on stalk population, heights and soil water was evaluated during each growing season. Cane yields (TCANE), estimated recoverable crystal percentage (ERC) and ERC yields (TERC), as well as mulch yields were determined at each harvest.

Mulching significantly ($p < 0.05$) improved cane and ERC yields of all cultivars across all four ratoons in the coastal rainfed region. Cane yield improvements ranged from as high as 85% (N45) in the winter ratoon to as low as 7% (N41) in the summer ratoon. Cultivar N47 had the highest improvement (up to 74%) in TERC for the drier summer ratoons, while cultivar N39 had the greatest improvements (up to 92%) in the winter ratoon. In the irrigated region cane and ERC yields were not significantly affected by mulching across cultivars and ratoons. However, the mean cane yields for all cultivars in the first, third and fifth ratoon were slightly reduced. The reductions ranged from 2% in the first ratoon to 7% in the fifth winter ratoon. Mean ERC yields ranged from an improvement of 1% in the second ratoon to a reduction of 10% in the fifth ratoon. Cultivar N25 in the fifth ratoon was the only cultivar with a significant reduction in ERC yield (22%). In the Midlands, cane and ERC yields were reduced by mulching for seven out of eight cultivars. However, only cultivars 94H004 (20%), N16 (22%), N37 (24%) and N48 (20%) had significant reductions in cane yield, while only cultivars 94H004 (22%), N37 (24%) and N48 (19%) had significant reductions in ERC yields. The observed improvements in the rainfed region were attributed to improved soil water content

under the mulch blanket. Under irrigated conditions and in the cold Midlands region, yield reductions were caused by lower soil temperatures and reduced stalk population. In the coastal rainfed region, there were no significant differences in stalk population between burn and mulch treatments in the summer ratoons, however, most cultivars had significantly improved stalk populations when mulched in the winter ratoon. Stalk heights and mass on the other hand were generally improved by mulching across all cultivars and ratoons in the coastal rainfed and irrigated regions. In the Midlands region, most cultivars had reduced stalk heights, but stalk mass was not affected by mulching. All cultivars across sites and ratoons showed delayed emergence due to lower soil temperatures under the mulch blanket. This was attributed to lower soil temperatures measured under the mulch blanket at the beginning of the growing season. The highest mulch yielding cultivars at the coastal rainfed region were cultivars N47 and N42, with 15 and 13 t ha⁻¹, and in the irrigated region cultivars N40 and N43, both having 13 t ha⁻¹ of mulch. In the Midlands, cultivars N12 (25 t ha⁻¹), N37 (21 t ha⁻¹), N48 (21 t ha⁻¹) and N50 (22 t ha⁻¹) were found to be the highest mulch yielding cultivars and can be potentially used for co-generation of energy. The coastal rainfed region had the highest mulch yield/cane yield ratio of 33% for cultivar N47, followed by the irrigated region where cultivar N41 had the highest mulch yield/cane yield ratio of 21%. In the Midlands region the highest mulch yield/cane yield ratio of 18% was calculated for cultivar N37. Only the third and fifth ratoon at Empangeni had positive and moderate correlations ($R^2 = 0.65$ and $R^2 = 0.78$ respectively) between mulch yield and cane yield. In both the Midlands and irrigated region no strong correlations between mulch yield and cane yield were observed.

Recommendations regarding mulching in the South African sugar industry are dependent on the agronomic region. Under low rainfall in the coastal rainfed region mulching can have substantial yield benefits, regardless of the cultivar or ratoon. Under irrigated conditions and in the Midlands yield reduction in response to mulching can be expected. Economic analysis on mulching has to be done to verify if this agronomic practice would be economically feasible but current yield responses from the coastal rainfed region are promising.

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CHAPTER 1

GENERAL INTRODUCTION

Sugarcane is one of the most important sugar crops in the world, accounting for approximately 75% of the world's sucrose production (da Silva and Bressian 2005). Besides the production of raw sugar, of which sugarcane is mainly produced for, sugarcane also represents an important source of renewable energy which has recently gained attention because of ethanol production. Over 90 countries around the world grow sugarcane, which occupies about 23 million hectares of land (Mnisi and Dlamini 2012). In South Africa, an average of 2.2 million tons of sugar per season has been estimated to be produced by the industry, of which 70% is marketed locally. Sugarcane in South Africa is grown under a wide range of agro-climatic conditions. Approximately 70% of the total sugarcane production occurs under rainfed conditions and the rest of the production occurs under irrigation (Van Antwerpen et al. 2006).

Generally, the two methods of harvesting sugarcane are manual or mechanical harvesting. The South African sugar industry has, since 1848, been dominated by manual harvesting due to a relatively cheap, abundant labour force and primarily because a large portion of cane is planted on steep terrain (>20% slope) where mechanised harvesting is not possible (Meyer 2005). With manual harvesting comes the necessity to burn the standing sugarcane crop because the residue material significantly slows down cane cutters and reduces their efficiency. Burning in the sugarcane industry can be defined as a controlled application of fire in predetermined sugarcane fields prior to harvest. However, in many counties the government is putting pressure on industries to regulate burning (Meyer et al. 2011). The alternate system of harvesting sugarcane without burning is referred to as mulching. Mulching is the physical removal and spreading of green and dead leaf material from the previous crop over the next ratoon crop as a mulch layer (Oliver and Singels 2006).

The decision to continue burning or changing to mulching has been debated for many years (Wynne and van Antwerpen 2004; van Antwerpen et al. 2006; van Antwerpen et al. 2008; Lecler et al. 2009). Approximately 90% of all South African cane fields are burned at harvest, and the remaining 10% are harvested without burning (Anonymous 2005). It is estimated that nearly 100% of irrigated areas are burned whereas coastal rain-fed areas of KwaZulu-Natal near Empangeni have an estimated sugarcane field burning rate of less than 70% (van Antwerpen et al. 2006). However, it is well known that the majority of cane growers burn

before harvesting. Reasons for the lack of uptake of mulching as routine practice include increased costs, reduction in harvest efficiency of cane cutters, increased transport and maintenance required by machinery, and increased accident risks for manual sugarcane cutters.

Sugarcane residue mulch material is increasingly regarded as an asset rather than extraneous matter to be eliminated (De Beer et al. 1996). The value of mulch residue has been enhanced by advances in technology addressing ethanol production from lignocelluloses (Donaldson et al. 2008). Studies have shown that having a mulch blanket on the field can change the local production environment; this includes soil water relations and temperature, radiation interception and weed competition (Wynne and van Antwerpen 2005). However most of these studies were specific to certain cultivars and only conducted in a single sugarcane production region. Although mulching is a recommended practice, some growers have reported that certain cultivars show negative responses to mulching. There has been no comprehensive work done to investigate the possible interactions between commercially grown cultivars and mulching in terms of growth and yield responses.

Sugarcane growth is affected by the interaction of the crop with environmental factors, and any factor that alters such environmental conditions will affect growth and productivity. The current study was aimed at investigating how popular cultivars respond to mulching in their commercial production environments. The study was also aimed at quantifying the amount of mulch material produced by these cultivars since very little information is currently known about this aspect. The information gathered from this study could be used by farmers to make informed decisions about their cultivar choice if they choose to adopt mulching instead of burning.

The objectives of this study were to:

- ❖ Compare popular commercial cultivars under mulch vs. burnt (tops raked out) conditions with respect to their growth and population dynamics at their common production environment (coastal rainfed, cold Midlands and Northern irrigated regions).
- ❖ Quantify effects of mulch vs. burnt conditions on yield (cane and ERC yields) and yield components of popular commercial cultivars.

- ❖ Evaluate the influence of mulching on the local production environment in terms of soil water, soil temperature and canopy radiation interception in order to explain some of the yield responses.

- ❖ Quantify the amount of mulch material produced by the different commercial cultivars.

CHAPTER 2

LITERATURE REVIEW

2.1 General background on sugarcane production

Sugarcane (*Saccharum* spp.) belongs to the family Poaceae, which are large tropical or subtropical grasses that are grown widely within the zone of 30° on either side of the equator (Ming et al. 2006). The most generally recognised within this genus, *Saccharum*, are *S. officinarum*, *S. barberi*, *S. sinence* and *S. spontaneum*, which are used in modern breeding programmes for commercial sugarcane hybrid development (Ngomane 2005). The high sucrose containing *S. officinarum* is one of the most important cash crops in the world with its distinctive feature of partitioning carbon into sucrose in the stem.

Sugarcane is cultivated in more than 90 countries around the world and occupies about 23 million hectares of land (Mnisi and Dlamini 2012). Approximately 75% of world's sucrose production is from sugarcane (da Silva and Bressian 2005). Besides the production of raw sugar, of which sugarcane is mainly produced for, sugarcane also represents an important source of renewable energy which has recently gained attention because of ethanol production. Brazil is the largest producer of sugarcane in the world with more than half of its production channelled into ethanol (Meyer et al. 2011).

2.2 Sugarcane production in South Africa

In South Africa the area under sugarcane cultivation is subdivided into 14 mill supply areas (MSAs), which extend from Northern Pondoland in the Eastern Cape, through the coastal belt and Midlands of KwaZulu-Natal (KZN), and into the lowveld of Mpumalanga (Figure 1.1). There are approximately 29130 registered sugarcane growers of whom 27580 are small scale growers. The remainder are large scale growers who produce 84.69% and milling companies with sugar estates that produce 6.72% of the crop (Anonymous 2011).

An average of 2.2 million tons of sugar per season has been estimated to be produced by the industry of which 70% is marketed locally in the Southern African Customs Union (SACU). The rest is exported to markets in Africa, Asia and the Middle East (Mnisi and Dlamini 2012). The contribution that the South African sugar industry makes is imperative to the national

economy. Anonymous (2011) reported that the industry is responsible for generating an annual average direct income of R8 billion, with an estimated R5.1 billion foreign earnings for the country and the balance is contributed by milling companies. The sugarcane industry also plays a huge role in the country’s employment rate. Approximately 79000 jobs are contributed directly and an extra 350 000 are estimated to be contributed indirectly by the sugarcane industry.

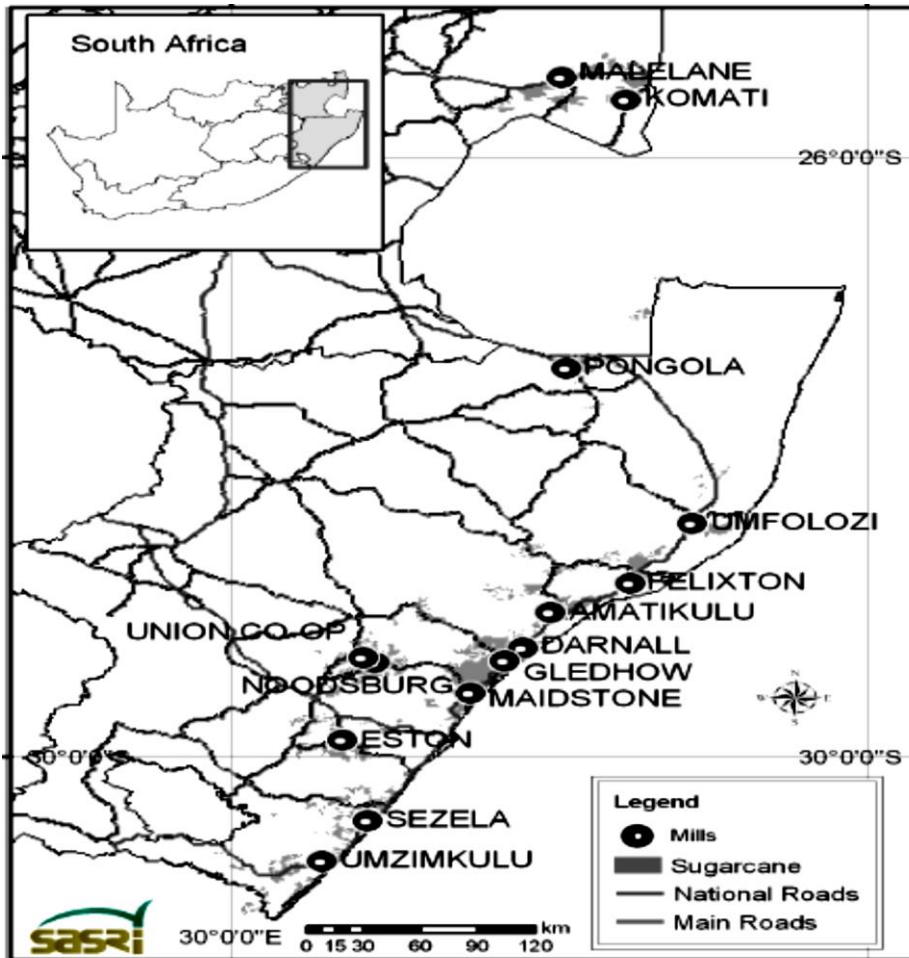


Figure 2.1 Sugarcane producing areas and mills of South Africa. Source: (SASRI)

2.3 Sugarcane growth and development

Sugarcane produces multiple tillers which consist of a series of nodes separated by internodes. Although sugarcane produces seeds under artificial condition, commercially, sugarcane is propagated vegetatively. Seed propagation in sugarcane produces genotypes that differ from the parent whereas vegetative propagation breeds “true to type” which is important for uniformity. Either the whole stem or stem cuttings (known as setts) are used as planting

material. Sugarcane grows perennially; when cane is reaped or harvested there is still a portion of the stem left underground, and it is this portion which gives rise to the succeeding growth of cane known as the ratoons (Barnes 1974). The auxiliary buds from remaining stems after harvest sprout and emerge faster than those of stem cuttings used for planting (Moore and Botha 2014). Consequently, ratoon crops produce a leaf canopy much faster than the plant cane and also accumulate dry matter at a faster rate (Thompson 1988). The quicker biomass accumulation of a ratoon crop over a plant crop is also associated with greater fraction of incident radiation intercepted initially (Robertson et al. 1996). Low soil temperatures, lack of soil water, or misapplication of growth inhibitors generally reduces the ability of the ratoon bud to sprout (Moore and Botha 2014).

The growth of sugarcane can be separated into four distinct phases: germination, tillering stage, stem elongation and sucrose accumulation (maturation and ripening stage).

2.3.1 Germination

Germination for sugarcane grown by vegetative propagation refers to the initiation of growth from buds present in the planted setts or stems of the stools that remain in the soil after harvest of the previous crop (Willcox et al. 2000). The temperature required for germination usually differs with cultivars. Generally, varieties have a low germination capacity when the temperature is below 18 °C but germination will increase rapidly up to 35 °C. Good germination is also induced by growing seed cane under favourable conditions i.e. adequate soil water and aeration, and good soil nutrition. However, germination can also be affected by internal factors that include bud health, sett moisture, and nutrient status (Barners 1974).

2.3.2 Tillering stage

“Tillering is the process of side shoots emerging from auxiliary buds of an existing culm to form additional culms” (Moore and Botha 2014). The tillering stage starts around 40 days after planting and may last up to 120 days (Binbol et al. 2006). This process of underground branching or tillering results in a number of cane stalks, forming a stool. The extent of tillering and survival of the tillers to maturity is to some extent a genetic character, but is influenced by climatic (light. Temperature soil moisture), soil and nutrient conditions (Barnes 1974). This process continues until peak tiller population.

2.3.3 Stem elongation, maturation and ripening

Stem elongation occurs when the intercalary meristem produces cells that subsequently expand (Moore and Botha 2014). Stalk elongation rates of about 2 cm/day can be logged under tropical conditions, provided the cane has favourable conditions of 25 °C day time temperatures and night time temperatures above 15 °C, adequate soil water and sufficient radiation levels (Soopramanien 2000). In the maturation and ripening stage the growth rate slows down and sucrose content increases. During stem growth, each internode acts as an independent unit. While it has a green leaf attached, the internodes complete cell elongation and cell wall thickening and fill with sucrose. The lower internodes are essentially ripe while the upper part of the stem is still growing. The stored sugar is, however, still available for translocation to support further tillering or growth when conditions are not favourable for photosynthesis (Bull 2000).

2.4 Sugarcane harvesting

Generally, the two methods of harvesting sugarcane are manual or mechanical harvesting. Mechanised harvesting refers to use of mechanical harvesters to cut sugarcane at ground level. Internationally, sugarcane is usually harvested using mechanical harvesters. However, the South African sugar industry has, since 1848, been dominated by manual harvesting due to a relatively cheap, abundant labour force and primarily because a large portion of cane is planted on steep terrain (>20% slope) which is not suitable for mechanised harvesting (Meyer 2005). More than 90% of South African sugarcane is harvested manually (Langton et al. 2007). With manually harvested cane it becomes necessary to burn cane while it is still standing since the mulch material significantly slows down cane cutters. The reduction in performance of the cutters can be as much as 30% if harvested with mulch material (Meyer and Fenwick 2003).

Burning in the sugarcane industry can be defined as a controlled application of fire in predetermined sugarcane fields prior to harvest whereas mulching, also referred to as green cane harvest and mulch blanket system (GCHMB), is the physical removal of leaf material from the previous crop and spreading it over the next ratoon crop (Oliver and Singels 2006). The total potential mulch is the total leaf material that can be removed from cane stalks during harvesting, including entire shoots that have died during the growing season. In practice some leaf material clings to the stalks and therefore not all the mulch material remains in the field. Green foliage is composed of all green leaves and partially necrotic leaves. Dead mulch

includes all leaves and shoots that have died during the development of the crop (Donaldson et al. 2008).

Even though the main reason for burning is to maximize productivity from each cutter, many countries' governments are putting pressure on industries to regulate burning (Meyer et al. 2011). In South Africa the local grower community responded to public pressures by establishing Local Environment Committees (LECs) for the various extension areas. These areas include Noodsberg, Darnall and Umvoti LECs, which have introduced the concept of environmental auditing to their growers. The LECs compiled a long list of aspects of sugarcane growing which can potentially impact the environment and the welfare of workers, including cane burning and harvesting (Maher 2000).

The decision to continue burning or change into mulching has been debated for many years (Wynne and van Antwerpen 2004; van Antwerpen et al. 2006; van Antwerpen et al. 2008; Lecler et al. 2009). Approximately 90% of the fields in South Africa under sugarcane cultivation are burnt at harvest, and the remaining 10% are mulched (van Antwerpen et al. 2006). It is estimated that nearly 100% of irrigated areas are burned whereas coastal rain-fed areas of KwaZulu-Natal near Empangeni has an estimated sugarcane field burning rate of less than 70% (van Antwerpen et al. 2006).

Studies have shown that having a mulch blanket on the field can change the local production environment; this includes soil water and temperature, radiation interception and weed competition (Wynne and van Antwerpen 2005). Sugarcane growth occurs through the interaction of the crop with environmental factors, and any factor that alters such environmental conditions will affect growth and productivity.

2.5 Effects of mulching on sugarcane production

2.5.1 Effects of mulching on soil nutrient status and soil organic matter

Sugarcane residues contain a considerable amount of nutrients. When sugarcane is burned, about 70-90% of N and dry matter is lost from the field (Mitchell et al. 2000). Ramakrishnarao and Ramalingaswamy (1982) reported that approximately 75% of nutrients such as Ca, P, Mg, Na, K and Zn are lost during burning. This loss of nutrients may not actually be as large as expected, since a large mineral constituent remains in the ash left in the field after burning

(Thompson 1966). However, when mulch is retained, most nutrients and organic matter remain in the field (Digonzelli et al. 2011). This means that retaining the mulch blanket after harvesting has certain nutritional advantages. Thompson (1966) reported that the green components of the mulch blanket, which include actively growing leaves and tops that are left in the field, may still have a considerable amount of N held at the apical meristem at high concentrations. However, the crop uptake of such N from the mulch blanket in the season following mulch blanketing is negligible since N is mainly immobilised in the soil organic matter (Ng Kee Kwong et al. 1987, Thorburn et al. 1999).

Although many authors report on the effect of mulching on soil nutrient status, not all the nutrients that result from mulch decomposition are instantly available to the plant. Most of them are used by soil microorganisms and it's only when they die that a proportion of it becomes available to the plant (van Antwerpen et al. 2001). For this reason, it is usually believed that the analysis of leaf nutrients can give a better indication of nutrients that can be made available to the plant compared to analysing soil samples (van Antwerpen and Meyer 2002). Van Antwerpen and Meyer (2002) measured leaf nutrient status for cultivar N16 in various treatments, including burnt versus mulching. In their experiment they found that mulching mainly increased leaf N, P, K and Mn, whereas the burnt treatment improved leaf Mg and Fe. Similar results were reported by van Antwerpen et al. (2001) for leaf N, P, and K, however, the treatment differences never reached a significant level.

Generally there are two major components of soil organic matter, decomposable (labile) carbon and inert (non-labile) carbon. The non-labile component is influenced by long-term climatic factors and soil type, whereas labile carbon is largely influenced by management strategies (Eustice et al. 2009). Harvesting practices (burning or mulching) have a marked effect on the labile component of organic matter. Many authors have reported reduced soil organic matter content in burned sugarcane fields (van Antwerpen et al. 2001; Mendoza et al. 2001; Eustice et al. 2009). This decline in soil organic matter under sugarcane monoculture is considered the most serious aspect of soil degradation (Graham et al. 2001). A decrease in soil organic matter content leads to a decrease in the quality of the soil in terms of its chemical, physical and biological properties (van Antwerpen et al. 2001). Furthermore, soil acidification and salinization have been associated with the reduction of organic matter in the soil (Schroeder et al. 1994; van Antwerpen and Meyer 1996). In contrast, mulching has been reported to have beneficial effects on soil organic matter quality in terms of increased labile organic matter content in short-term (<5 years) experiments (Blair 2000).

2.5.2 Effects of mulching on soil temperature

Soil temperature serves as one of the most important abiotic variables in most sugarcane growth and development phases. Since green cane harvesting and mulch blanketing covers the soil with organic residues, soil temperature will be severely affected (Oliveira et al. 2010). Soil temperature has often been reported as being lower under mulched conditions as compared to bare conditions (Horton et al. 1996). Mulch blanketing especially reduces soil temperature in the first few centimetres of the profile, which can impair sugarcane emergence, initial growth and tillering (Beater and Maud 1962; Woods 1991; Morandini et al. 2005; Digonzelli et al., 2009). Soil temperatures under a mulch blanket can be between 4°C and 6°C lower than under bare soil surfaces (Thompson 1966; Hardman et al. 1985). Digonzelli et al. (2011) also measured lower soil temperatures under mulched conditions. In the plant crop of their experiment, the mulched cane had an average of 0.3 °C lower soil temperature whereas in the second cycle the average difference between treatments increased to 1.6 °C. The lower average soil temperature difference between burnt and mulched cane in the plant crop was attributed to an abundance of rainfall in that growing cycle. Similarly, Chapman et al. (2001) found that soil temperature under a mulch blanket at 15 cm depth was 3.8 °C lower than the unmulched treatment. They also reported that irrigation or rainfall reduced soil temperature differences between the treatments. Another study by Morandini et al. (2005) further reported that temperatures under mulch ranged from 0.6 to 3.6 °C (average difference of 1.5 °C) lower as compared to the burnt plots.

A review of mulch management by Ridge and Dick (1989) mentioned that in cooler environments there are concerns of poor ratooning ability on mulched cane harvested early in the season when soil temperatures are low. However, growth differences between burnt and mulched cane harvested early in the season diminishes after 100 days (Chapman et al. 2001). These findings were later confirmed under local conditions by Olivier and Singels (2012).

Mulching affects the radiation balance due to modification in thermal conductivities and reflection coefficients and, as a consequence, all other energy balance components are also affected. A simplified equation of the energy balance of the soil was described by Olivier et al. (2010) as follows:

$$R_n - G = LE + H \quad 2.1$$

The net irradiance (R_n) less soil heat flux (G) is the energy available at the soil surface to drive

various physical and physiological processes (Olivier et al. 2010). LE and H are the latent heat flux and sensible heat flux, respectively. Net irradiance is defined as the balance between incoming and reflected solar irradiance and outgoing and returned infrared irradiance. This heat flux is primarily used to heat the soil (soil heat flux, G), for evaporation of water (latent energy flux, LE) and heating of the atmosphere above the soil (sensible heat flux, H).

Despite the many reports that mulching reduces soil temperatures, the relationship between mulch blanketing and soil temperature may actually be variable, at times causing conditions to be cooler than in a bare soil, and at times causing conditions to be warmer (Thompson 1966). For example, the reflection coefficient of mulching material 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 R_n reaching the soil surface. A denser and less reflective material will increase the soil temperature by inhibiting evaporation (Rabothata 2009). Furthermore, Gilbert et al. (2010) reported a buffering effect due to mulch. In their experiment mulching led to a higher minimum soil temperature during cool periods early in the growing season. As the air temperature increased later in the season, mulched plots showed lower maximum soil temperatures. This buffering effect on soil temperature was reported on both a diurnal and seasonal basis. A buffering effect by the mulch blanket was also reported by Oliviera et al. (2010). Similarly, a study conducted by Viator (2005) in Louisiana found an insulating effect caused by the mulch blanket during winter months. In winter, soil temperatures under a mulch blanket were 0.8 °C warmer than those without mulch. However, in spring the soil temperature of the mulched plots was 1.3 °C cooler than the burnt plots. The actual effects of mulch on soil temperature are variable as indicated by literature and is highly dependent on environmental conditions. In general, most authors (Page et al. 1986; Woods 1991; Chapman et al. 2001; Digonzelli et al. 2011) agree that the differences in soil temperature fade away as the canopy develops and shades the soil surface.

2.5.3 Effects of mulching on sugarcane water conservation and water use efficiency

The South African sugarcane industry is one of the most water scarce sugarcane industries in the world. About 70% of sugarcane is produced under rainfed conditions, with rainfall varying from 800 to 1200 mm per annum (van Antwerpen et al. 2006). Variation in responses to water loss within crop species and between cultivars exists and there are many management practices that can reduce the loss of water by evaporation from the soil surface (Bacon 2004). Mulching has been reported to reduce soil water evaporation (Olivier and Singels 2006) and improve

water infiltration, which then increases the water content in the first few centimetres of the soil profile (Morandini et al. 2005; Sanzano et al. 2009). The combined effect of improved infiltration and reduced soil evaporation also results in more available water for crop uptake (Rabothata 2009). Thompson (1965) conducted an experiment at Mount Edgecombe South Africa in Rydalvale clay loam soil and reported an average reduction of evaporation by full mulch blanketing of 90 mm/annum. Similarly, Van Antwerpen et al. (2002) found a reduction in evaporation from the soil surface under a mulch blanket for selected South African scenarios. They reported that an average 90 mm to 100 mm can be saved per annum by mulching, thus resulting in more water available for the crop. Furthermore, Thompson (1976) established that the value of additional water obtained by mulch blanketing in terms of yield can average 9 tons of cane per 100 mm water lost through transpiration.

Digonzelli et al. (2011) evaluated the effect of mulching versus burning on soil water content at two depths (20 cm and 40 cm). In their experiment they reported that there were no significant differences in soil water content between the treatments (mulch vs burning) for both depths in the first growing cycle. They attributed these results to 68% above normal rate of rainfall during that growing cycle. However, in the following ratoon, the soil water content was higher under the mulch blanket at 20 cm depth, whereas at 40 cm no significant differences were found. The conclusion from their work was that the effect of mulching on soil water content was affected by annual rainfall rates and distributions. Similar conclusions were made by van Antwerpen et al. (2006). The water conserving properties of mulch have been reported by most authors as being most visible at periods of partial canopy cover. The differences in soil water between mulched versus burnt treatment tend to diminish after canopy closure (Torres and Villegas 1995; Digonzelli et al. 2011; Olivier and Singels 2012).

Water use efficiency (WUE) is defined as “cane yield per unit of crop water use (evapotranspiration)”. It can be described by a simple equation:

$$\text{WUE} = Y/ET \quad 2.2$$

Where Y is the yield of the crop (Total harvestable biomass or marketed yield), and ET is the evapotranspiration from the soil, and through stomata (transpiration). Generally, WUE is a measure of the effectiveness of water received either from rainfall, irrigation or both for crop production. Another generally used term which relates to WUE is Irrigation Water Use Efficiency (IWUE) and can be defined as “the cane yield response per unit of irrigation water applied” (Olivier and Singels 2003). More efficient water-conserving agronomic practices such

as mulching are potential means to increase water use efficiency. Many researchers have supported mulching as a means to increase the effectiveness of irrigation by reducing evaporative losses of water (Yadav et al. 2009). Nunez and Spaans (2007) reported a decline in daily evapotranspiration rate of up to 39% under the mulch blanket, thus resulting in a reduced irrigation frequency. Furthermore, Murombo et al. (1997) found a 288 mm irrigation water saving with mulching. This was later confirmed by Morandini et al. (2005), who reported that the burnt cane had higher water requirements whereas mulching reduced irrigation by two cycles.

2.5.4 Effects of mulching on intercepted solar radiation

Solar radiation intercepted by the crop is one of the most important factors that influence plant development. The productivity of the crop depends on the ability of the plant cover to intercept incident radiation, which is a function of leaf area available, the architecture of the vegetation cover and conversion efficiency of the energy captured by the plant into biomass (Campillo et al. 2012). However, only a proportion of the solar radiation intercepted by the plant canopy is used to carry out photosynthesis, namely photosynthetic active radiation (PAR) (Varlet-Grancher et al. 1993).

Where other factors are not limiting (e.g. water and nutrients), production strategies are directed towards maximizing the interception of solar radiation. This implies promoting agricultural practices that facilitate obtaining complete canopy cover as soon as possible (Campillo et al. 2012). Inman-Bamber (1994) reported that sugarcane canopy development depends mainly on the rate of leaf appearance, tillering and leaf extension as well as the size of each leaf. In literature, many authors have reported a reduced rate of tillering and a lower stalk population under mulched compared with bare conditions (Thompson 1965; Olivier and Singels 2006; Rabothata 2009). Olivier and Singels (2006) reported that in their experiment the unmulched treatment reached 80% radiation interception 45 days before the mulched treatment. However, both the treatments intercepted close to 100% of incoming radiation flux towards the end of the growing season. Furthermore, Rabothata (2009) reported that the fractional interception of PAR was considerably reduced by mulching for cultivars N14 and N26. The low fractional interception was also considered to be a cultivar characteristic. Cultivar N26, which is known as a slow growing cultivar, suffered most from poor early canopy development under mulched conditions.

Productivity of cultivars at different locations can be compared on the basis of their efficiency of producing plant biomass in relation to intercepted radiation, known as radiation use efficiency (RUE) (Sinclair & Muchow 1999). Crop species differ in RUE (Sinclair and Muchow 1999). Despite these differences, many species sustain very consistent RUE values throughout the duration of the cropping season (Park et al. 2005). According to Donaldson et al. (2008) values ranging from 1.25 g/MJ to 1.96 g/MJ are quoted in literature for sugarcane. As discussed earlier, mulching has been found to negatively affect tillering rate and stalk population (Thompson 1965; Olivier and Singels 2006; Rabothata 2009). This in turn reduces canopy development and thus radiation capture, which could possibly reduce the RUE of the crop. However, in addition to intercepted radiation, RUE is commonly used to explain limited productivity of the crop (Liu et al. 2012). Sinclair and Muchow (1999) described RUE as the slope of the linear relationship between biomass and intercepted solar radiation. Park et al. (2005) stated that in order to increase commercial sugarcane biomass yield it would be necessary to increase inputs (water, fertilize, etc.) or ensure better use of available resources by the crop. Other studies have also proved that RUE is determined by cultivar, temperature (Andrade et al. 1993; Donaldson et al. 2008), water (Jamieson et al. 1995), and nutrients (Rodriguez et al. 2000; Caviglia et al. 2001).

In earlier parts of this review, mulching has been reported to increase water use efficiency (WUE) or irrigation water use efficiency (IWUE) (Motiwele and Singh 1971) by reducing evaporation from the soil. Furthermore, some studies have confirmed higher leaf nutrient status in sugarcane grown under mulched conditions as compared to burnt cane (Van Antwerpen and Meyer 2002). These studies show that mulching can in fact increase the efficiency of sugarcane in utilising available resources, hence increase the RUE of sugarcane. However, further work may be required to confirm this assumption.

2.6 Effects of mulching on cane yields and Recoverable Value (RV %)

Crop yield is defined as the amount of harvested product per unit land area. In sugarcane, yields are conventionally described in terms of cane yields in tonnes per hectare (Donaldson et al. 2008). Harvest practices (burning vs mulching) have over the years been documented as having a marked effect on sugarcane yield. Mulching can either contribute to higher yields or have detrimental effects by reducing yields (Gilbert et al. 2010). Increased cane yield under mulched conditions have been reported in places like Zimbabwe (Murombo et al. 1997) and South

Africa (Van Antwerpen et al. 2006). In Mexico, Toledo et al. (2005) reported accumulative cane yields across six years of 750.9 t ha⁻¹ where sugarcane was mulched and 534.1 t ha⁻¹ in the burned treatment. However, in contrast to this, other studies have reported a decline in cane yield in the presence of a mulch blanket (Torres and Villegas 1995; Kingston et al., 2002; Kingston et al., 2005). In these studies the decline in cane yield seems to be most severe under cool and wet conditions. On the other hand, yield gains under mulched conditions are mostly observed in exceptionally dry or low rainfall areas (De Beer et al. 1995).

Thompson (1965) reported that the potential conservation of water by mulch blanketing would be more important under local conditions of inadequate rainfall in South Africa. An average cane yield increase of 10 t ha⁻¹ per annum can be obtained under rainfed conditions, but under irrigation the responses to mulch blanketing are reported to be much lower (Thompson 1966). Such yield responses can generally be attributed to better soil water retention (Olivier and Singles, 2006). Van Antwerpen et al. (2001) found differences in yield when comparing two fertilised treatments (mulching versus burnt with no tops) of 6 t ha⁻¹ per annum in the fourth ratoon and 9 t ha⁻¹ per annum in the fifth ratoon (mulched treatment having higher yields). They also pointed out that similar trends were noted in the non-fertilised version of the two treatments. Similarly, Thompson (1990) reported a mean cane yield response of 9 t ha⁻¹ in favour of mulching when compared with burnt cane. Furthermore, Van Antwerpen et al. (2006) reported a 13% increase in yield in dry seasons under mulched conditions for cane harvested in summer. However, the effects of mulching on cane yield are not always beneficial and may vary according to local climatic and other conditions. At the coastal rainfed region of South Africa there was a 15% decrease in yield for mulched cane in high rainfall years when cane was harvested in winter (Van Antwerpen et al. 2006). Conclusions were that rainfall and the season in which the crop is harvested are amongst the important factors that determine sugarcane response to mulching. Similarly Pearson (1959) reported a depression in yield due to the presence of mulch. This was attributed to waterlogged conditions being prevalent under mulched conditions on black dolerite soils of Mount Edgecombe. Furthermore, Woods (1991) also reported that wetter areas with poorly drained clay soil and a mulch blanket can accentuate waterlogging problems by keeping soil moist for a longer period. A study by van Antwerpen et al. (2001) related the effect of mulching versus burning on cane yield to the amount of rainfall. In their experiment they found that the yield response to the mulch treatment decreased with increase in rainfall from as much as 10 to less than 3 t ha⁻¹.

The sucrose component of a cultivar is the most important economic factor to consider as it determines the value of a ton of cane delivered. The payment system for farmers in the South African sugarcane industry has reformed since the 2000/2001 growing season, from remunerating farmers according to the quantity of sucrose in the batch delivered, to a sugarcane payment system based on quality of cane transported to the mill. The Recoverable Value (RV) is a payment system used as a measure of Estimated Recoverable Crystal (ERC). The system takes into account the quality characteristics of sugarcane delivered to the mill. The formula for RV is:

$$RV\% = S - dN - cF \quad 2.3$$

Where

S = sucrose % in sugarcane delivered

N = non-sucrose % in sugarcane delivered

F = fibre % in sugarcane delivered

d = coefficient to account for the loss of sucrose per unit non-sucrose through molasses during processing.

c = coefficient to account for the loss of sucrose in sugar production per unit of fibre.

The coefficients d and c are mill specific and vary slightly from mill to mill but vary considerably from season to season. The c factor is calculated annually based on a three season rolling average. The d factor is calculated monthly and is based on a three season rolling average and current sugar and molasses price estimates. The growers are rewarded based on the total tons RV (cane yield in $t\ ha^{-1}$ X RV %) delivered to the mill per grower (Ramburan 2012). The final expression of yield (cane and sugar) is the result of interactions between the genetic makeup of the cultivar, cultural practice, and environmental factors (Ahmed et al. 2008).

Gosnell (1970) found an interaction of interest between irrigation level and mulching and on sucrose yield ha^{-1} for cultivar NCo376. Mulching treatment produced 4 tons sucrose ha^{-1} more compared with the burnt plots on the lowest irrigation treatment but produced 2 tons sucrose ha^{-1} less on the highest irrigation treatment. The lowest irrigation level in this study can represent a dry land or rainfed scenario where less water is readily available to the plant.

However, the drop in sucrose content with high irrigation, especially for the mulched plots, was attributed to the following factors: (i) more vigorous vegetative growth resulting in lower sucrose accumulation (ii), dilution by higher water content and (iii) the effect of lodging which caused considerable decreases in sucrose content of NCo376. Olivier et al. (2009) reported a 23% sucrose yield reduction in their tops and mulch treatment when compared to the bare plots. However, the differences in these treatments were mainly ascribed to reduced cane yield in the residue (tops and mulch) treatment. Although there have been reports of differences in yield (cane and sugar yields) due to mulching, there have been no formal study to quantify these differences in a range of cultivars in different environments.

2.7 Mulch production by cane cultivars

Previously, sugarcane mulch was regarded as extraneous matter to be eliminated prior to harvest, however, in the current generation it has been increasingly reported to have a greater worth (De Beer et al. 1996). Mulch left in the field has been well documented in literature by many authors as mostly having advantages of improving soil properties (Thompson 1966; Ng Kee Kwong et al. 1987; Graham et al. 1999; Robertson and Thorburn 2000; and van Antwerpen et al. 2001). Alternatively, current development of ethanol production technologies using lignocellulose has enriched the value of sugarcane mulch material (Donaldson et al. 2008). Sugarcane can produce sufficient biomass to provide energy for its processing and still leave a surplus (De Beer et al. 1996). Donaldson et al. (2008) reported that the productivity of sugarcane is conventionally measured in terms of cane yield and sucrose content, and these parameters form the basis of cultivar selection. However, very few researchers have quantified the amount of mulch produced by commercial cultivars in field experiments.

An estimation of sugarcane potential mulch available for use as soil mulch and as biofuel is very important in order to define management strategies that ensure the sustainable development of both agriculture and energy generation (Romero et al. 2009). The quantity of mulch from sugarcane harvesting is highly variable and depends on many factors. Some of the most influential factors are differences in harvesting system (burning vs mulching) and operation efficiency (topping height), crop age, management variability, cane cultivar, cane yield (Romero et al. 2009; Dias Paes and Oliveira 2005; Thompson 1966) and seasonal effects on growth (Donaldson 2009).

Donaldson (2009) reported that a minimum of 10 t/ha of mulch must be produced to justify full mulching as opposed to scattering tops after burning, as below this amount the advantages of full mulching diminish. Quantifying the amount of mulch in the field is dependent on the amount of water it contains. However, the water content of mulch left in the field is variable and cannot be easily predicted (Donaldson 2009). De Beer et al. (1996) reported a water content of about 50% at harvest. This moisture content drops to about 30% in three days and to 15% in two weeks. Because of the large variation in water content according to the period the mulch stays in the field, dry mass is normally used by most authors. Dias Paes and Oliveira (2005) cited many authors that reported data about the ratio between the amount of mulch left in the field and cane yield. The percentage values varied considerably; in Colombia they found 10% to 60%, from 20% to 35% in South Africa and 14% in Cuba. The amount of mulch produced varies according to a range of growing conditions. There have been indications that South African cultivars differ in mulch production, but no studies have quantified mulch production in a range of cultivars in South Africa.

2.8 Previous research on mulch effects on cane cultivars

Cultivars differ in their inherent characteristics and it is these specific varietal characteristics that will determine their response to mulching. A study by Donaldson, (2009) in Pongola found that mulch yields ranged from 13 t ha⁻¹ for cultivar N26 to about 24 t ha⁻¹ for NCo376 in the April ratoon. However, a thicker blanket of mulch can also have a retarding effect on the ratooning ability of some cultivars. Viator et al. (2005) concluded that most currently grown cultivars in Louisiana do not tolerate the environmental conditions created by mulching. As discussed in the previous section on the effects of mulching on soil temperature, there can be a reduction in temperature beneath the mulch blanket. This reduction in soil surface temperature was reported to cause a serious constraining effect on the speed of emergence and tillering of some Australian cultivars (Hardman et al. 1985). Rabothata (2009) reported that early growth was delayed due to mulching for cultivar N26 and N14; however, stalk length was reduced to a greater extent for cultivar N26, which represent a slow canopy developing cultivar. Similar results were reported by Olivier et al. (2009) in both the plant crop and the ratoon crop, but the differences in stalk length disappeared towards harvest. Mulching reduced peak stalk population by 19% for both N26 and N14 but did not cause a delay in the time to reach peak stalk population. However the final stalk population was similar for the burnt and mulched treatments (Olivier et al. 2009). Contrary to their previous findings, Olivier et al. (2010) used

cultivar N46 and found that initial stalk population in the mulch treatment was reduced by 50% compared to the burnt treatment. The peak stalk population however was delayed by 16 days in the mulch treatment. The productivity of cultivars can be enhanced by correctly matching cultivar to the environment and managing them correctly (Singels et al. 2005). There have also been grower reports of possible negative response to mulching for some commercially grown cultivars, yet very little work has been done to investigate the possible interactions between cultivars and mulching. A field-based quantification of responses of commercially available cultivars to mulching under conventional growing conditions in South Africa is therefore required.

2.9 Economic implications of mulching

The section on mulch production by cultivars showed that these days mulch is more regarded as an asset than extraneous matter. In South Africa the situation on mulch changed in 2004 when the idea came up that growers might profit from supplying mulch to the mill for co-generation of energy. Millers are now prepared to purchase and willingly accept mulch arriving at the mill with the cane (van Antwerpen et al. 2008). The economic value of mulching however is not limited to selling the mulch for co-generation in the mills. If the mulch left in the field is adequate it can suppress water loss by evaporation (up to 90 mm/annum; Thompson 1966) from the soil surface, especially in rainfed regions. The additional organic matter can improve soil health (Woods 1991), inhibit weeds and reduce herbicide cost and inter-row cultivation (Murombo et al. 1997; and Mendoza et al. 2001). Such benefits can significantly improve cane yields and profits (Wynne and van Antwerpen 2004).

However, the incorporation of such a harvest method (mulching) in the cultivation of sugarcane has a number of encounters of economic significance. One of these challenges includes the perceived negative impact that mulching has by having additional costs on harvest operations (Lecler et al. 2009). It takes more time to physically remove the mulch from the cane sticks for both manual and mechanical harvesting (de Beer et al. 1995). Since mulched cane takes up more volume, the transportation costs are higher than for burnt cane and this further decrease profitability of mulching (Wynne and van Antwerpen 2004). Furthermore, mulching is not advised in wet, low lying areas and cooler areas since it increases the risk of stool rotting and inhibits ratooning (Murombo et al. 1997), which can result in lower yields.

Van Antwerpen et al. (2008) compiled a model to verify the performance of the decision support programme (DSP) developed by Wynne and van Antwerpen (2004) when estimating real economics on-farm, comparing burn with no burn at harvest. In their model they concluded that there was significant economic response for mulching due to reduced herbicide costs and improved plant available water resulting in higher yields, from the rainfed farm relative to the irrigated farm. However, Lecler et al. (2009) reported that resources like energy, fertilizer, water and herbicides that will be saved directly as a result of mulching are more likely to be counterweighted by the significant increase in the costs of harvesting sustained. Without tangible evidence, it is difficult to argue that the benefits of mulching often outweigh the extra cost of harvesting and the conditions under which this occurs (Meyer et al. 2011). It is therefore important to conduct a formal study to quantify the economic benefits of mulching relative to the cost incurred.

REFERENCES

- Ahmed W, Khan NU, Khalil MR, Parveen A, Aimen U, Saeed M, Samiullah, Shah SA. 2008. Genetic variability and correlation analysis in upland cotton. *Sarhad Journal of Agriculture*. 24: 573-580.
- Andrade FH, Uhart SA, Cirilo A. 1993. Temperature affects radiation use efficiency in maize. *Field Crop Research* 32: 17-25.
- Anon. 2011. A profile of the South African sugar market value chain. *Department of Agriculture and Forestry*, South Africa.
- Bacon MA. 2004. Water use efficiency in plant biology. In: Bacon MA, ed. *Water use efficiency in plant biology*. Oxford: Blackwell Publishing: 1–26.
- Barnes, A.C., 1974. *The sugarcane*. 2nd edition. Leonard Hill, Ltd., London.
- Beater B, Moud R. 1962. The effect of trash on soil temperature in the sugar belt of Natal. *Proceedings of the International Society of Sugar Cane Technologists* 11: 378-380.
- Binbol NL, Adebayo AA, Kwon-Ndung EH. 2006. Influence of climatic factors on the growth and yield of sugar cane at Numan, Nigeria. *Climate Research* 32(3): 247-252.
- Blair, N. 2000. Impact of cultivation and sugarcane green trash management on carbon fractions and aggregate stability for a Chromic Luvisol in Queensland, Australia. *Soil and Tillage Research* 55: 183 - 191.
- Campillo C, Fortes R, Prieto MH. 2012. Solar Radiation Effect on Crop Production, Solar Radiation, Babatunde EB (Ed.), ISBN: 978-953-51-0384-4, InTech, Available from:<http://www.intechopen.com/books/solar-radiation/solar-radiation-effect-on-crop-production>.
- Caviglia OP, Sadras VO. 2001. Effect of nitrogen supply on crop conductance, water- and radiation-use efficiency of wheat. *Field Crop Research* 69: 259-266.
- Chapman LS, Larsen PL, Jackson J. 2001. Trash conservation cane yield in the Mackay district. *Proceedings of the Australian Society Sugar Cane Technologists* 23: 176- 184.
- Da Silva JA, Bressiani JA. 2005. Sucrose synthase molecular marker associated with sugar content in elite sugarcane progeny. *Genetics and Molecular Biology*, 28 (2): 294-298.

- De Beer AG, Hudson C, Meyer E, Seigmund B. 1996. Green cane harvesting and trash management. *International Society Sugar Cane Technologists (ISSCT)*: 133 - 141.
- Digonzelli P A, Romero E R, Alonso L, de Ullivarri F J, Quinteros HR, Fajre S. 2011. Assessing a sustainable sugarcane production system in Tucumán, Argentina. Part 1: Dynamics of sugarcane harvest residue (trash) decomposition. *Revista Industrial y Agrícola de Tucumán* 88 (1): 1-12.
- Digonzelli PA, Fernández de Ullivarri J, Romero E, Giardina J, Alonso L, Casen S, Tonatto J, Leggio Neme M, Scandaliaris J. 2009. Assessment of two sugarcane management systems: with or without post-green-cane-harvest residue retention. In: *Proceedings of the International Society Sugar Cane Technologists. Agronomy Workshop*, 8, Uberlandia, Brasil. pp. 27-28.
- Digonzelli PA, Tonatto MJ, Romero ER, Sanzano GA, de Ullivarri JF, Giardina JA, Scandaliaris J. 2011 Assessing a Sustainable Sugarcane Production System in Tucumán, Argentina: Part 2: Soil water and thermal regime, stalk population dynamics and sugarcane production. *Revista industrial y agrícola de Tucumán* 88: 01-12.
- Donaldson RA, Redshaw KA, Rhodes R, van Antwerpen R. 2008. Season effect on productivity of some commercial South African sugarcane cultivars, I: biomass and radiation use efficiency. *Proceedings of South African Sugar Technologists' Association* 81: 517-527.
- Donaldson RA. 2009. Season effects on the potential biomass and sucrose accumulation of some commercial cultivars of sugarcane. PhD thesis, University of KwaZulu-Natal, South Africa.
- Eustice T, van Antwerpen R, Weigel A. 2009. Burning, trashing and fertilization: Effects on carbon pool proportions? *Proceedings of the South African Sugar Technologists' Association* 82: 564-569.
- Gilbert RA, Kingston G, Morgan K, Rice RW, Baucum L, Shine JM, Subiros JF. 2010. Effect of harvest method on microclimate and Sugarcane yield in Florida and Costa Rica. *Proceedings of the International Society of Sugar Cane Technologists* 27:1-8.

- Gosnell JM. 1970. Optimum irrigation levels for cane under burnt and trashed conditions. *Proceedings of the South African Sugar Technologists' Association* 44: 121-130.
- Graham M, Haynes RJ, Meyer JH. 1999. Green cane harvesting promotes accumulation of soil organic matter and an improvement in soil health. *Proceedings of the South African Sugar Technologists' Association* 73: 53 – 57.
- Graham MH, Haynes RJ, Meyer JH. 2002. Changes in soil chemistry and aggregate stability induced by fertilizer applications, burning and trash retention on a long-term Illovo mechanical cane cutter. *International Sugar Journal* 109: 118-120.
- Hardman JR, Tilley LGW, Glanville T. 1985. Agronomic and economic aspects of various farming systems for sugarcane in the Bundaberg district. *Proceedings of the Australian Society Sugar Cane Technologist* 7: 47-153.
- Horton R. 1996. Crop residue effects of surface radiation and energy balance: *Review of the Theoretical and Applied Climatology*. 54: 27-37.
- Inman-Bamber NG. 1994. Temperature and seasonal effects on canopy development and light interception of sugarcane. *Field Crops Research* 36: 41–51.
- Jamieson PD, Martin RJ, Francis GS, Wilson DR 1995. Drought effects on biomass production and radiation-use efficiency in barley. *Field Crop Research* 43: 77-86.
- Kingston G, Donzelli JL, Meyer JH, Richard EP, Seeruttun S, Torres J, Van Antwerpen R. 2005. Impact of the green-cane harvest production system on the agronomy of sugarcane. *Proceedings of the South African Sugar Technologists' Association* 15: 521–533.
- Kingston G. 2002. Recognising the impact of climate on CCS of sugarcane across tropical and sub-tropical regions of the Australian sugar industry. *Proceedings of the Australian Society Sugar Cane Technologist* 24: 145-152.
- Langton MI, Smithers JC, Bezuidenhout CN, Lyne PWL. 2007. Evaluation of the Illovo mechanical cane cutter. *International Sugar Journal*, 109(1298): 118-120.
- Lecler N, Olivier F, Jones M. 2009. Economic analysis of harvesting burnt versus green cane under irrigated conditions. *Proceedings of the South African Sugar Technologists' Association* 82: 613-617.

- Lecler NL, Olivier F, Jones M. 2009. Economic analysis of harvesting burnt versus green cane under irrigated conditions. *Proceedings of the South African Sugar Technologist Association* 82: 613-617.
- Liu T, Song F, Liu S, Zhu X. 2012. Light interception and radiation use efficiency response to narrow-wide row planting patterns in maize. *Australian Journal of Crop Science* 6(3): 506-513.
- Maher GW. 2000. Guidelines for Environmental Conservation Management in the South African Sugar Industry (SASA) Experiment Station Report McGuire P. 2005. NSW Sugar Industry Farming Code of Practice. *NSW Sugar Milling Coop., Ballina, NSW* pp.17.
- Mendoza TC, Samson R, Helwig T. 2001. Evaluating the many benefits of sugarcane trash farming systems. *Philippine Journal of Crop Science* 27(1): 43-51.
- Meyer E, Fenwick LJ. 2003. Manual sugarcane cutter performance in the southern African region. *Proceedings of the South African Sugar Technologists' Association* 77: 150-157.
- Meyer E. 2005. Machinery Systems for Sugarcane Production in South Africa. MSc thesis, University of KwaZulu-Natal, Pietermaritzburg. South Africa.
- Meyer JH, Rein P, Turner P, Mathias K, 2011. Good management practices manual for the cane sugar industry. Johannesburg, South Africa.
- Meyer JH, van Antwerpen R, Meyer E. 1996. A review of soil degradation and management research under intensive sugarcane cropping. *Proceedings of the South African Sugar Technologist's Association*. 70: 22-28
- Ming R, Moore PH, Wu KK, D'Hont A, Glaszmann JC, Tew TL, Mirkov TE, da Silva J, Jifon J, Rai M, Schnall RJ, Brumblay SM, Lakshmanan P, Cosmstock JC, Peterson AH, 2006. Sugarcane improvement through breeding and biotechnology. *Plant Breeding Reviews* 27: 2-118.
- Mitchell RDJ, Thorburn PJ, Larson, P. (2000). Quantifying the immediate loss of nutrients when sugarcane residues are burnt. *Proceedings of the Australian Society Sugar Cane Technologist* 22: 206-211.

- Mnisi MS, Dlamini CS. 2012. The concept of sustainable sugarcane production: Global, African and South African perception. *African Journal of Agricultural Research* 31: 4337-4343.
- Moore PH, Botha FC. 2014. Sugarcane: Physiology, Biochemistry, and functional biology. In F.C. Botha & P.H. Moore (Eds.), *Sugarcane Physiology, Biochemistry, and Functional Biology*. Wiley-Blackwell. ISBN: 978-0-8138-2121-4.
- Morandini M, Figueroa R, Pérez Zamora F, Scandalariis J. 2005. The effects of green cane trash blanket on soil temperature, soil moisture and sugarcane growth. In: *Proceedings of the International Society Sugar Cane Technologists Congress*, 25, Guatemala, Guatemala. pp. 231-236.
- Motivale MP, Singh AB. 1971. Effect of trsh mulch in economy of water and fertilizer use in sugarcane. *Annual report IISR, Luckno*, pp.23-24.
- Mourombo M, Takavarasha E, Wiseman J. (1997). Green cane harvesting at Mltwasine Estate, Zimbabwe. *Proceedings of the South African Sugar Technologists' Association* 71: 30-32.
- Ng Kee Kwong KF, Deville J, Cavalot PC, Reviere V. (1987). Value of cane trash in nitrogen nutrition of sugarcane. *Plant Soil* 102: 79-83.
- Ngomane D. 2005. Moderation of growth and sucrose flux in sugarcane by temperature. MSc thesis, University of KwaZulu-Natal, Pietermaritzburg. South Africa.
- Núñez O, Spaans E. 2007. Evaluation of green-cane harvesting and crop management with trash-blanket. In: *Proceedings of the International Society Sugar Cane Technologists Congress*, 26, Durban, Sudáfrica. pp 131-142.
- Olivier F, Singles A. 2003. Water use effeciancy of irrigated sugarcane as affected by row spacing and variety. *Proceedings of the South African Sugar Technologists' Association* 7: 347-351.
- Olivier FC, Lecler NL, Singels A. 2009. Increasing water use efficiency of irrigated sugarcane by means of specific agronomic practices. WRC Report No. 1577/1/09, ISBN 978-1-77005-883-5. *Water Research Commission*, Pretoria, South Africa. pp 127.

- Olivier FC, Singels A, Savage MJ. 2010. The effect of a trash blanket on the energy balance of a sugarcane crop: preliminary results. *Proceedings of the South African Sugar Technologists' Association* 83: 225-229.
- Olivier FC, Singels A. 2006. The effect of plant residue layers on water use and growth of irrigated sugarcane. *Proceedings of the South African Sugar Technologists' Association*. 80 178-181.
- Olivier FC, Singels A. 2006. The effect of crop residue layer on evapotranspiration, growth and yield of irrigated sugarcane. *South African Sugar Technologists' Association* short communication.
- Paes LAD, Oliveira MA. 2005. Potential trash biomass of the sugar cane plant. In: Hassuani SJ. (eds), Biomass power generation: sugarcane bagasse and trash, Série Caminhos para Sustentabilidade - 01, PNUD-CTC, Piracicaba. pp 18-22.
- Page RE, Glanville TJ, Troung PN. 1986. The significance of trash retention trials in the Isis and Maryborough mill areas. *Proceedings of the Australian Society Sugar Cane Technologist*. 8: 95-102.
- Park SE, Robertson M, Inman-Bamber NG. 2005. Decline in the growth of a sugarcane crop with age under high input conditions. *Field Crops Research* 92, 305–320.
- Pearson CH. 1959. The conception of farming on subtropical soils with the use of the crop by-product, trash, as a means to improve yields. *Proceedings of the 10th Congress of the International Society of Sugarcane Technologist*. Hawaii. pp. 578-588.
- Rabothata MF. 2009. Water use, growth and development of sugarcane as affected by trash mulch. MSc dissertation. University of Pretoria, South Africa.
- Ramakrishnarao S, Ramalingaswamy K. 1982. A note on loss of nutrients when cane trash is burnt. *Proceedings of the International Society of Sugar Cane Technologist*. 16, 123-129.
- Ramburan S. 2012. The nature and causes of sugarcane genotype x environment interactions: Integrated approaches to analysis and interpretation. PhD thesis, University of the Free State, South Africa.

- Ridge DR, Dick RG. 1989. The adoption of green cane harvesting and trash blanketing in Australia. *Proceedings of the International Society of Sugar Cane Technologists*. 20: 1034-1041.
- Robertson MJ, Wood AW, Muchow RC. 1996. Growth of sugarcane under high input conditions in tropical Australia. I. Radiation use, biomass accumulation and partitioning. *Field Crops Research* 48, 11–25.
- Rodriguez D, Andrade FH, Goudriaan J. 2000. Does assimilate supply limit leaf expansion in wheat grown in the field under low phosphorus availability? *Field Crop Research* 67: 227-238.
- Romero ER, Scandalariis J, Digonzelli P A, Alonso LG, Leggio F, Giardina JA, Casen SD, Tonatto M J, de Ullivarri JF. 2009. Effect of variety and cane yield on sugarcane potential trash. *Revista industrial y agrícola de Tucumán* 86 (1): 9-13.
- Sanzano GA, Sosa FA, Hernández CF, Morandini M, Quinteros HR, Romero JI, Digonzelli PA. 2009. Evaluación de la erosión hídrica en caña de azúcar con y sin cobertura de maloja. *Avance Agroind.* 30 (3): 16-18.
- Schroeder BL, Robinson JB, Wallace M, Turner PET. 1994. Soil acidification: effects and occurrence in the South African sugar industry. *Proceedings of the South African Sugar Technologists' Association* 68: 70-74.
- Sinclair TR, Muchow RC. 1999. Radiation use efficiency. *Advances in Agronomy* 65, 215–265.
- Singels A, Smit MA, Redshaw KA, Donaldson RA. 2005. The effect of crop start date, crop class and cultivar on sugarcane canopy development and radiation interception. *Field Crops Research*. 92: 249-260.
- Soopramanien GC. 2000. Sugarcane morphology, anatomy and physiology. In: A guide to sugarcane diseases. Rott P, Bailey RA, Comstolk JC, Croft BJ, Saumtally AS (Eds), *International Society of Sugarcane Technologists*. Pp 13-20.
- Thompson GD, Wood RA. 1967. Wet and dry seasons and their effects on rain-fed sugar-cane in Natal. *Tropical Agriculture (Trinidad)* 44(4): 297-307.

- Thompson GD. 1965. The effects of trash conservation on soil moisture and the sugar cane crop in Natal. *Proceedings of the 39th Congress of South African Sugar Technologists' Association*. pp. 143-156.
- Thompson GD. 1966. The production of trash and its effects as a mulch on the soil and on sugarcane nutrition. *Proceedings of the South African Sugar Technologists' Association* 40: 333-342.
- Thompson GD. 1988. The composition of plant and ratoon crops of variety N14 at Pongola. *Proceedings of the South African Sugar Technologists' Association* 62, 185–189.
- Thompson GD. 1990. Report on burning and trashing, South African Sugar Association Experimentation Station, Mount Edgecombe, South Africa.
- Thorburn PJ, Probert ME, Lisson S, Wood AW. 1999. Keating BA. Impacts of trash retention on soil nitrogen and water: An example from the Australian sugarcane industry. *Proceedings of the South African Sugar Technologists' Association* 73:75-84
- Toledo ET, Pohlen HAJ, Velez MRG, Galan AL. 2005. Green sugarcane versus burnt sugarcane – results of six years in the Soconusco region of Chiapas, Mexico. *Sugar Cane International*. 23: 20-23.
- Torres JS, Villegas F. 1995. Green cane management under heavy trash conditions. *Proceedings of the International Society of Sugar Cane Technologists*. 22: 142-148.
- Van Antwerpen R, Meyer JH, Thompson, G.D. 2006. The impact of trashing on yield response in the South African sugar industry: a summary of results from several BT trials. *Proceedings of the South African Sugar Technologist Association* 80: 130-135.
- Van Antwerpen R, Meyer JH, Turner PET. 2001. The effects of cane trash on yield and nutrition from the long-term field trial at Mount Edgecombe. *Proceedings of the South African Sugar Technologists' Association* 75:235-241.
- Van Antwerpen R, Rhodes R, Wynne AT. 2008. Economics of trashing: improvement and sensitivity analysis of this decision support program. *Proceedings of the South African Sugar Technologist Association* 81: 486-488.
- Van Antwerpen R, Thorburn PJ, Horan H, Meyer JH, Bezuidenhout CN. 2002. The impact of trashing on soil carbon and nitrogen: ii: Implications for sugarcane production in

- South Africa. *Proceedings of the South African Sugar Technologists' Association* 76:269-280.
- Varlet-Grancher C, Bonhomme R, Sinoquet H. 1993. Crop structure and light microclimate. 518 p.
- Viator RP, Johnson RM, Richard Jr, EP. 2005. Challenges of post-harvest residue management in the Louisiana sugarcane industry. *Proceedings of the International Society of Sugar Cane Technologists*. 25: 238-244.
- Willcox T, Garside A, Braunack M. 2000. The sugarcane cropping system. In “Manual of sugarcane growing”, M Hogarth, P Allso. eds. Bureau of sugar experiment stations, Indooroopilly Australia.; 127-139.
- Wood AW. 1991. Management of crop residues following green cane harvesting of sugarcane in north Queensland. *Soil and Tillage Research* 20: 69 - 85.
- Wynne AT, van Antwerpen R. 2004. Factors affecting the economics of trashing. *Proceedings of the South African Sugar Technologists' Association* 78: 207-214.
- Yadav RL, Prasad SR. 1988. Moisture use characteristics of sugarcane genotypes under different available soil moisture regimes in alluvial entisols, *Journal of Agricultural Science*. Sci, Cambridge 110 (1): 5-11.

CHAPTER 3

GENERAL MATERIALS AND METHODS

3.1 Trial site characteristics and varieties

Three field trials were established in October 2008 on SASRI research stations in each of the three major sugar producing regions of South Africa (Coastal rainfed (Empangeni), cold Midlands (Glenside), and Northern irrigated (Pongola)). Each trial consisted of eight popular commercial cultivars that are grown in that agronomic region. Within each of the three trials, cultivars differed in their general agronomic characteristics, ranging from quick germinating varieties which have vigorous growth and high stalk population to slow germinating varieties with slower growth and low stalk population. The varieties were chosen based on their popularity within the production region, and their contrasting growth characteristics. In each trial, the cultivars were either burnt or mulched at harvest and their agronomic performance was evaluated over ratoon crops. Soil physical and chemical properties are shown in table 3.1. Details of the experimental sites, trial harvesting cycles and cultivars tested are given in Table 3.2.

Table 3.1 Soil physical and chemical analysis before planting for all three trials at different locations. Soil analysis was conducted at the fertilizer advisory service (FAS).

Soil character	Units	Trail location		
		Coastal rainfed (Empangeni)	Cold Midlands (Glenside)	Northern irrigated (Pongola)
pH (Water)		4.6	5	5.9
Buffer pH (CaCl ₂)		6.8	8.1	7.8
N Category		2	2	2
NH ₃	%	0.2	3.2	2.5
Phosphorus	ppm	33.6	77.8	47.7
Potassium	ppm	138.6	80.4	264.6
Calcium	ppm	744.9	313.7	937.1
Magnesium	ppm	193.1	62.7	> 350
Aluminium	ppm	16.6	14.2	-
Al Saturation	%	3.2	6.4	-
Clay	%	30	24	24
OM Estimate	%	2.6	0.8	0.9

Table 3.2 Details of experimental sites, harvesting cycles, and cultivars for three burning vs. mulching trials conducted in Pongola, Empangeni, and Glenside.

	Irrigated north (Pongola)	Coastal rainfed (Empangeni)	Midlands (Glenside)
Irrigation regime	Fully irrigated	Fully rainfed	Fully rainfed
Cultivars	N25, N32, N36, N40, N41, N43, N46, and N49	NCo376, N27, N29, N39, N41, N42, N45 and N47	94H0049, N12, N16, N31, N37, N44, N48 and N50
Harvest cycle (age at harvest)	12 months	12 months	24 months
Number of crops harvested	Plant crop + four ratoons	Plant crop + four ratoons	Plant crop + one ratoon
Mean annual minimum and maximum temperature (°C)	14.6 27.6	16.4 27.2	11.5 23.4
Mean annual long term rainfall (mm)	725	857	787
Trial coordinates	27°24'0''S 31°35'0''E	28°43'0''S 31°53'0''E	29°25'0''S 30°41'0''E

3.2 Experimental design and treatment application

All trials were laid out as 2 x 8 factorial strip plot designs with two harvesting treatments (burnt vs mulch) as the main plots (strips) and eight cultivars as the sub plots. Each trial was replicated four times, giving a total of 64 plots. Trial plot dimensions were different for each trial. At Empangeni and Glenside, the plots had five gross and three net rows of 7 m and 10 m lengths with a row spacing of 1.2 m and 1 m respectively. At Pongola, the plots had six gross and four

net rows of 10m length with 1.4m row spacing. Field layouts of all trials are presented in Figures 3.1, 3.2 and 3.3.

Empangeni trial

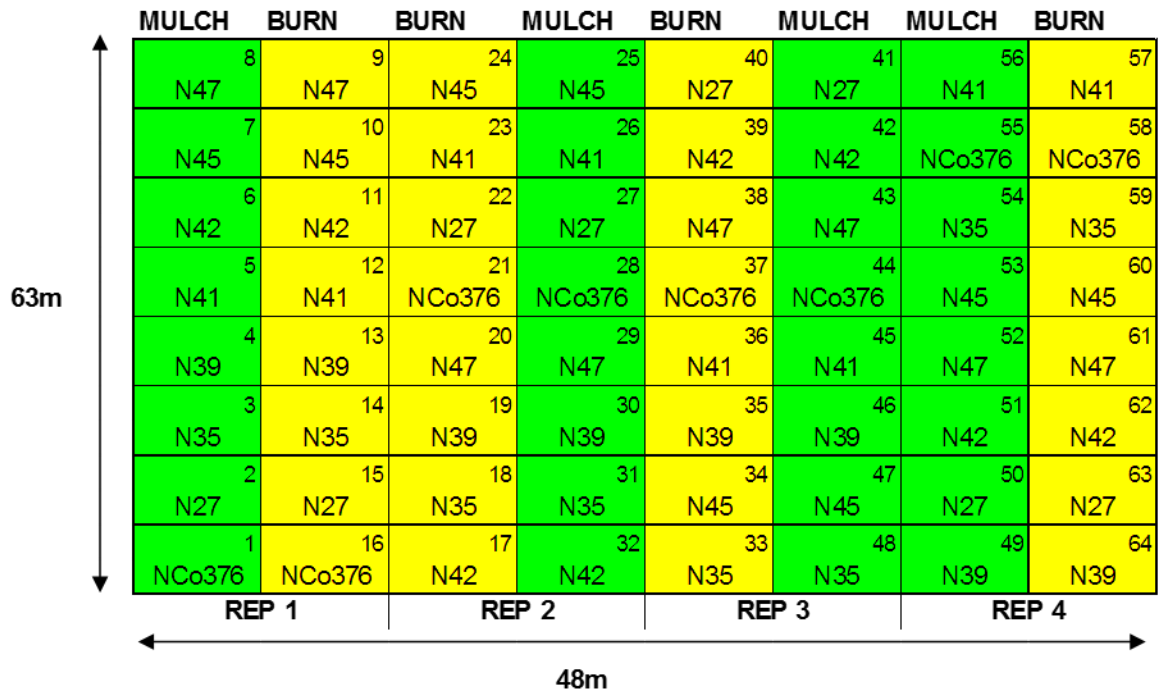


Figure 3.1 Strip plot field layout of the coastal (Empangeni) trial.

Midlands trial

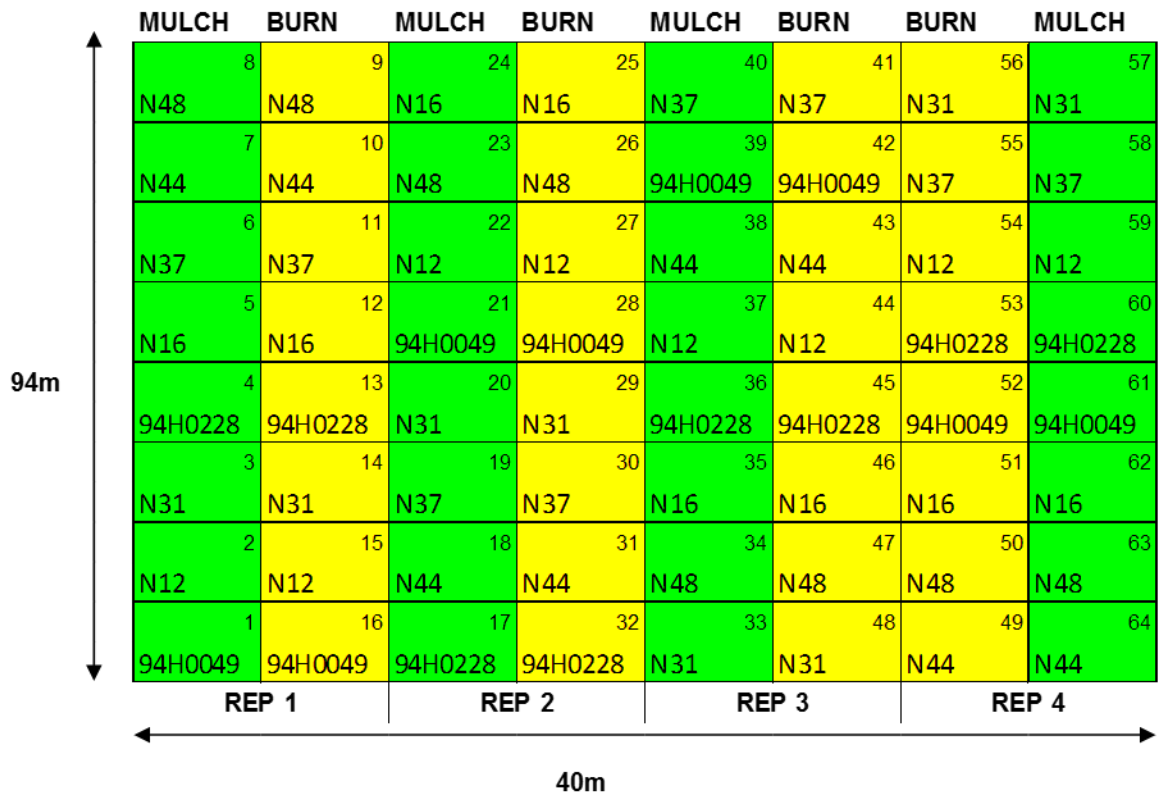


Figure 2.2 Field layout of the Midlands (Glenside) trial.

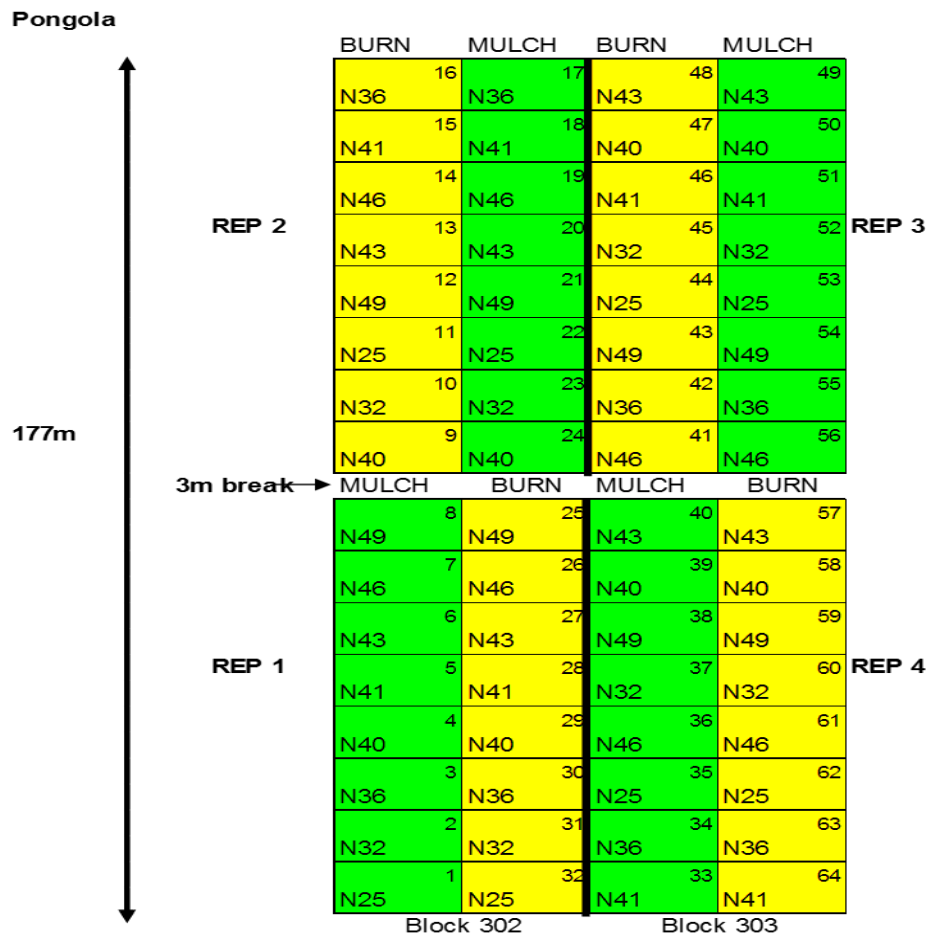


Figure 3.3 Strip plot field layout of the irrigated north (Pongola) trial.

Following trial establishment in 2008, the plant crops were grown to maturity and harvested without any growth measurements being conducted during the growing season. At harvest, mulch blankets were then put down for the mulch treatments, and growing season measurements were then initiated in the first ratoon crops. The same process was then followed for subsequent ratoons. The Empangeni and Pongola trials had the same number of crops harvested with a similar cropping cycle, however, the Glenside trial had fewer crops harvested because of the long (24 months) age at harvest. In general, harvesting was done in October for the first four crops (plant + 3 ratoons), and regrowth through the mulch blankets was therefore evaluated during summer. However, information on ratoon regrowth through mulch during winter was also needed. Therefore, for the purpose of evaluating varietal response to mulching in the early season cutting cycle (June/July), all three trials were cut back in June/July 2013. The Empangeni and Pongola trials were cut back at eight months of age at the fourth ratoon.

Glenside on the other hand, was cut back at eleven months at the second ratoon. A summary of activities from trial establishment to the last harvest at Empangeni and Pongola are presented in Figure 3.4, while similar details for the Glenside trial are presented in Figure 3.5

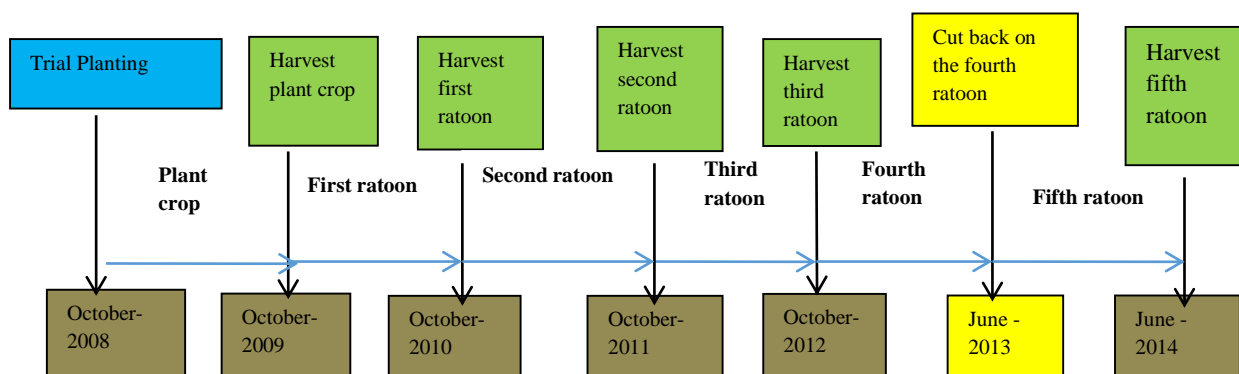


Figure 3.4 Timeline of operations at Empangeni and Pongola from trial establishment up to the last harvested crop at the fifth ratoon.

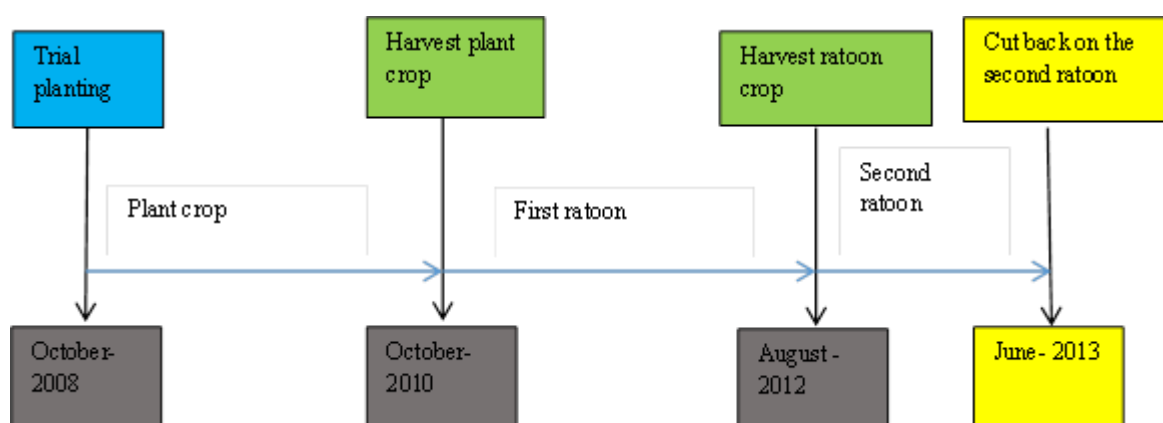


Figure 3.5 Timeline of operations at Glenside from trial establishment up to a cut back at the second ratoon.

The mulch treatment was imposed by physically removing all the dead and green foliage, including tops from the standing crop prior to harvesting and spreading it over the surface. The left hand side of Figure 3.6 shows the mulched panels after harvesting the cane. Dead foliage included all the leaves that had senesced during the development of the crop and green foliage was composed of all the green leaves (including tops) and partially necrotic leaves with more than 50% of green area. All the cutting operations were done manually by cutting stalks on the soil surface using a cane knife. The net rows of the plots from the mulched panels were cut first and stacked in bundles of four for weighing. The burn treatment was imposed by simply

burning the respective plots prior to harvesting (right hand side of Figure 3.7). Similarly, the net rows of the burnt plots were cut and weighed. All the tops and plant materials in the burnt plots were raked and cleared by hand, leaving the soil bare.



Figure 3.6 Burning operation at harvest after mulching was performed (the tractor is watering the breaks to help prevent fire from burning the mulch in the mulched panel on the left).

3.3 Trial management

3.3.1 Planting and fertilizer management

All trials were planted manually using a double stick method by lying cane stalks side by side. The stalks were placed into pre-ridged furrows and were cut into 30-40 cm setts. The trials were fertilized according to SASRI fertilizer advisory service (FAS). Fertilizer application data are shown in Table 3.3.

Table 3.3 Fertilizer application details for the plant and ratoon crops at the three sites

	Pongola	Empangeni	Glenside
Plant crop	At planting - 69 kg ha ⁻¹ N (as urea) and 18 kg ha ⁻¹ P (as superphosphate) and Top dressing – 92 kg ha ⁻¹ N (Urea)	At planting – 20 kg ha ⁻¹ P (as DAP) Top dressing – 96 kg ha ⁻¹ N and 96 kg ha ⁻¹ K (as 1:0:1 (48))	At planting – 20 kg ha ⁻¹ P (as DAP)
First ratoon	Top dressing - 115 kg ha ⁻¹ N (Urea)	Top dressing – 7 kg ha ⁻¹ P (as DAP) and 36 kg ha ⁻¹ N and 36 kg ha ⁻¹ K (as 1:0:1 (48))	Top dressing – 67.6 kg ha ⁻¹ N and 101.4 kg ha ⁻¹ K (as 2:0:3 (49))
Second ratoon	Top dressing - 161 kg ha ⁻¹ N (as urea)	Top dressing - 138 kg ha ⁻¹ N (as urea)	Top dressing -116.8 kg ha ⁻¹ N, 29.2 kg ha ⁻¹ P and 175 kg ha ⁻¹ K (as 4:1:6 (45))
Third ratoon	Top dressing - 161 kg ha ⁻¹ N (as urea)	Top dressing - 138 kg ha ⁻¹ N (as urea)	Top dressing - 120 kg ha ⁻¹ N and 120 kg ha ⁻¹ K (as 1:0:1 (48))
Fourth ratoon	Top dressing - 161 kg ha ⁻¹ N (as urea) and 125 kg ha ⁻¹ K (as Potassium Chloride)	Top dressing – 138 kg ha ⁻¹ N (as urea)	
Fifth ratoon	Top dressing - 161 kg ha ⁻¹ N (as urea) and 125 kg ha ⁻¹ K (as Potassium Chloride)	Top dressing – 132 kg ha ⁻¹ N and 132 kg ha ⁻¹ K (as 1:0:1 (48))	

3.3.2 Weed control

At Pongola, weeds were controlled chemically by spraying with long term herbicides (Tebuthiuron (Tebuzan 500 C) at 2.5 L/ha, propiconazole (Kestrel) at 3 L/ha, and Paraquat Dichloride (Gramoxone) at 0.5 L/ha) within a week after planting and harvesting. Emerging weeds were removed manually.

At Glenside, 0.25 kg/ha Isoxaflutole (Merlin) and 1 kg/ha Hexazinone (Velpar) were used as pre-emergent herbicides. At about 10 to 14 weeks after applying the pre-emergent herbicides, a mixture of 4 L/ha 2-methyl 4-chlorophenoxyacetic acid (MCPA) and 4 L/ha Ametryn were applied as post emergence herbicides. Depending on the infestation of watergrass, 1L/ha Paraquat was also applied on ratoon crops. However, in cases of emerging weeds supplementary manual weed control was applied.

No chemical weed control was done at Empangeni. However, manual weed control was frequently implemented during the growing season.

3.4 Experimental measurements

3.4.1 Stalk height and tiller count (population)

Measurements were taken at two week intervals from 2 x 2 m sections which were randomly assigned to net rows prior to emergence. A diagrammatic representation of a plot is presented in Figure 3.7. Different 2 m sections were demarcated for each crop harvested. Tiller counts (stalk population) were determined from the average of counts done within the 2 m sections, whereas stalk height was measured from 10 randomly selected plants as the length from the base of the tiller up to the top visible dewlap (TVD) of the plant. The TVD leaf is defined by McCray et al. (2005) as the “uppermost fully expanded leaf that has a visible dewlap”.

The final stalk population was determined by counting all of the millable cane from two of the three net rows. Stalk population was subsequently expressed as the number of stalks per hectare.

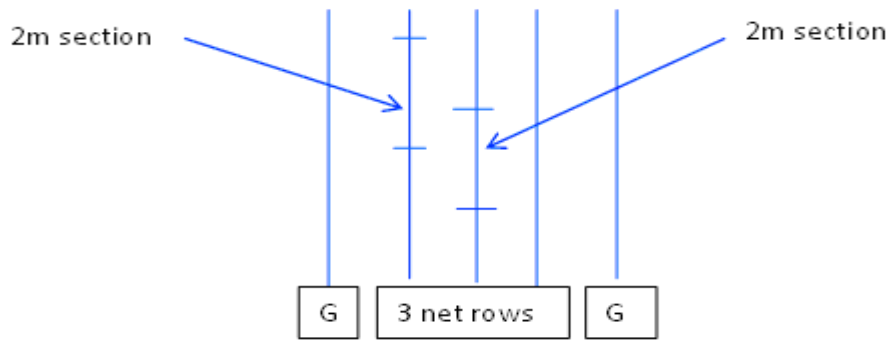


Figure 3.7 Diagrammatic representation of a plot (G stands for guard rows); the 2 x 2 m sections can be randomly allocated to any of the three net rows prior to emergence.

3.4.2 Canopy cover (Fractional interception of PAR)

A ceptometer (LP-80 AccuPAR- Decagon Devices) was used to measure the amount of photosynthetically active radiation (PAR) intercepted by the canopy of the plants. The measurements were taken every two weeks on cloudless days between net rows from every plot. For each plot, an above canopy reading was taken followed by 10 readings below the bottom green leaves. The ceptometer was levelled horizontally at a 45 degree angle relative to the rows before taking the readings. The front end of the device was midway through the rows when the measurements were taken while the back end was in the middle of the inter-row (Figure 3.8). The above and below canopy PAR measurements were used to calculate the fraction of PAR intercepted in percentage as follows:

$$\text{FiPAR} = 1 - (\text{PAR}_{\text{abv}} - \text{PAR}_{\text{blw}}) / \text{PAR}_{\text{abv}} \times 100 \quad 3.1$$

PAR_{abv} is the light intensity measured above the green canopy

PAR_{blw} is the light intensity measured below canopy (average of 10 readings)



Figure 3.8 Ceptometer (LP-80 AccuPAR- Decagon Devices) taking below canopy PAR readings

3.4.3 Yield and quality data

At each harvest, sucrose samples were taken by cutting 12 (Glenside and Empangeni) and 16 (Pongola) stalks from net rows. Stalk heights were then measured from the sucrose samples. The samples were then sent to the SASRI mill room to determine the estimated recoverable crystal percent (ERC %) (Wynne et al. 2009).

$$\text{ERC}\% = a \cdot S - b \cdot N - c \cdot F \quad 3.2.$$

Where ERC % is the estimated quantity of crystal which can be recovered from the incoming cane supply (expressed in terms of crystal % cane)

S = sucrose % in sugarcane delivered

N = non-sucrose % in sugarcane delivered (calculated as brix % cane minus sucrose % cane)

F = fibre % in sugarcane delivered

a = fraction of the sucrose entering the mill in the cane supply relative to that leaving the mill in the form of product sugar, bagasse or final molasses

b = coefficient to account for the loss of sucrose per unit non-sucrose through molasses during processing.

c = coefficient to account for the loss of sucrose in sugar production per unit of fibre.

Cane yield in tons cane/ha (TCANE) was measured by hand-cutting and weighing the net plots with a mechanical grab apparatus fitted with a load cell (Figure 3.9). Tons ERC/ha, which is the most important factor which growers get paid for, was calculated as a product of TCANE and ERC.



Figure 3.9 Weighing operation done using a weighing pickup with a mechanical grab equipped with a load cell.

3.4.4 Mulch quantity

From each of the 12 or 16 stalks used for sucrose sampling, the components of mulch which included green leaves and dead brown leaves were separated and put into brown paper bags. A leaf with more than 50% of its area either dead or yellowing was considered part of dead mulch. These components were dried at 75 °C for approximately 72 hours. The samples were then weighed to calculate mulch yield (tons/ha) for each variety on a dry mass basis.

3.4.5 Soil water content

For some crops, soil water content was measured using soil moisture sensors (Decagon device 10HS). The sensors were installed at 20-25 cm depths in selected burnt and mulched plots and replicated six times. These soil water sensors were read out using an ECH₂O hand held Decagon device, which recorded soil water content as a percentage. The monitoring of soil water was only done in the rainfed regions (Empangeni and Glenside). The readings were taken at two week intervals from selected ratoon crops. In order to get a better resolution of the effects

of mulching on soil water content, an automatic data logger (decagon device Em50 series data logger) logging every 15 minutes was used to monitor water content in adjacent burnt and mulched plots of cultivar N47 in the fourth crop at Empangeni. The data logger was connected to soil moisture sensors (Decagon device 10HS) installed at depths of 20-25 cm and 35-40 cm.

3.4.6 Soil temperature

Hobo data loggers were used to monitor soil temperature at all three sites. The loggers were installed in the fourth crop at Empangeni and Pongola and third crop in Glenside. The loggers were replicated four times in each location. These loggers were set to log temperatures every 15 minutes and were installed at a depth of 15-20 cm in selected mulched and burnt plots of the same cultivar.

3.5 Weather data

Weather data were collected during each growing season (ratoon) from an automatic weather station (AWS) situated at each of the experimental sites. The weather variables collected were solar irradiance ($\text{MJ}/\text{m}^2/\text{d}$), rainfall (mm) and temperature ($^{\circ}\text{C}$). The long term mean (LTM) monthly rainfall was also calculated for each site to characterise the growing seasons in terms of rainfall. The LTM represents the mean monthly rainfall data from 2003 at Empangeni and from 1997 for both Glenside and Pongola. The data was taken up to the harvest dates.

3.6 Statistical analyses

All parameters measured at each harvest were subjected to a combined analysis of variance (ANOVA) to establish main (cultivar, mulch, and ratoon) and interaction effects. Comparison of means was performed using Duncan's LSD test at 5% significance difference and statistical analyses were done using GenStat Statistical Package version 14.

CHAPTER 4

GROWTH AND YIELD RESPONSES OF COMMERCIAL SUGARCANE CULTIVARS TO MULCHING IN THE COASTAL RAINFED REGION

Abstract

Approximately 70% of the total sugarcane production in South Africa occurs under rainfed conditions. Mulching (the physical removal and spreading of leaf material from the previous crop over the next ratoon crop) has been shown to have substantial impact on sugarcane growth, establishment and yield under low rainfall conditions. Recently, there have been industry reports of reduced growth vigour, establishment, and yields of certain South African cultivars produced under mulch blankets. However, no quantitative information exists on the reaction of popular commercial cultivars to mulching in the rainfed regions of the industry.

A field trial was established in 2008 at Empangeni in the rainfed region of sugarcane production in South Africa. The trial comprised eight of the most popular cultivars in the coastal region (NCo376, N27, N35, N39, N41, N42, N45, and N47). The trial was planted as a 2 x 8 factorial strip-plot with four replicates, with burning vs. mulching as the main plot (strips) and cultivar as sub-plots. Cultivar responses to mulching were evaluated over a period of three summer crops (1st, 2nd, and 3rd ratoon) and one winter crop (5th ratoon). Cane yields (TCANE), estimated recoverable crystal (ERC) percentage, ERC yields (TERC), and mulch yields were determined at each harvest. The effects of mulching on stalk population dynamics, stalk height, soil temperatures, and soil water content were monitored during each growing season.

Mulching significantly ($p < 0.05$) improved cane and ERC yields of most cultivars across all four ratoons. Cane yield improvements ranged from as high as 85% (N45) in the winter ratoon to as low as 7% (N41) in the summer ratoon. The ERC% ranged from 20% improvement for cultivar N47 to an 11% reduction for cultivar NCo376. The improvements in cane and ERC yields were attributed to the higher soil water content prevalent under the mulch blanket. Cultivar N47 had the highest improvement (up to 74%) in TERC for the drier summer ratoons, while cultivar N39 had the greatest improvements (up to 92%) in the wet summer ratoons and in the winter ratoon. There were no significant differences in stalk population between burn and mulch treatment in the summer ratoons, however, most cultivars had significantly improved stalk populations when mulched in the winter ratoon. Stalk heights and mass were generally improved for most cultivars in all four ratoons. All cultivars showed delayed

emergence due to mulching both in winter and summer ratoons. This was attributed to lower soil temperatures measured under the mulch blanket. The mulch yields ranged from 7.6 t/ha for cultivar NCo376 in both the third and the fifth ratoon to 20 t/ha for cultivar N47 in the second ratoon. The results show that mulching was beneficial for sugarcane production regardless of the cultivar and ratooning season. This harvest method can thus be recommended for all current commercial cultivars along the coastal rainfed region of South Africa.

4.1. Introduction

Sugarcane in South Africa is grown under a wide range of agro-climatic conditions. Approximately 70% of the total sugarcane production occurs under rainfed conditions. South Africa is known to be one of the world's most water scarce countries, with the sugarcane rainfed region receiving rainfall in a range of 800 to 1200 mm per annum (Van Antwerpen et al. 2006) which is mainly received between November and March. Such conditions have proven to be one of the limiting factors in the rainfed regions, which are mainly located along the coastal areas of KwaZulu-Natal.

Sugarcane in the rainfed regions is typically harvested between April and December. The normal age at harvest is between 12 and 18 months, depending on factors such as cultivar maturity rate, management practices, environmental conditions and pest pressure (particularly *Eldana saccharina*) (Ramburan et al. 2009). Current yields in the coastal region are approximately 60 tons of cane per hectare per annum. However, cane yields can vary depending on the amount and distribution of rainfall received in that season.

Mulching, which is defined as the physical removal and spreading of leaf material from the previous crop over the next ratoon crop (Oliver and Singels 2006) has been shown to have substantial impact on sugarcane yield, especially under low rainfall conditions (De Beer et al. 1995; Digonzelli et al. 2011). Information on the area of cane mulched along the coast is limiting, however, it is well known that the majority of cane growers burn before harvesting. Reasons for the lack of uptake of mulching as routine practice include increased costs, reduction in harvest efficiency of cane cutters, increased transport and maintenance required by machinery, and increased accident risks for manual sugarcane cutters.

On the other hand, there are numerous agronomic and economic advantages associated with mulching. Various studies have linked yield increase in sugarcane with the ability of the mulch

blanket to retain soil water and reduce evapotranspiration. However, having a mulch blanket also modifies the local growing environment by altering soil temperature, radiation interception and weed competition (Wynne and van Antwerpen, 2005). These factors in turn can affect the growth and population dynamics of the crop during the growing season. For example, lower soil temperatures under the mulch blanket have been reported to slow emergence and initial growth of sugarcane (Morandini et al. 2005; Dignonzelli et al. 2009), leading to slower canopy development and thus lower radiation interception. This suggests that the effects of mulching are not always beneficial, and factors such as ratoon age (influences stalk population), time of harvest, and cultivar, are important considerations.

Sugarcane cultivars differ considerably in their agronomic characteristics and their reactions to management practices. Differences in cultivar physiology and phenology will determine how they respond to the agronomic practice of mulching. The South African sugarcane industry has a wide range of cultivars that are bred for specific production regions. Currently, the coastal region of KwaZulu-Natal has about 32 cultivars that are permitted for planting. Of these commercial cultivars, only six to eight currently contribute significantly to sugar production in the region. Recently, there have been industry reports of reduced growth vigour, establishment, and yields of certain cultivars through mulch blankets. However, no quantitative information exists on the reaction of popular commercial cultivars to mulching in the rainfed regions of the industry. An understanding of the reaction of cultivars to mulching will allow for cultivar-specific recommendations and/or adjustments of current agronomic practices to maximise yields.

The objectives of this study were to: (a) quantify effects of mulch vs. burn conditions on yield components of common commercial cultivars in the coastal rainfed region of South Africa, (b) compare these cultivars under mulch vs. burnt conditions with respect to their growth, establishment, and population dynamics, (c) monitor the influence of mulching on factors such as soil water and temperature, and radiation interception in order to explain yield responses, and (d) quantify the amount of mulch material produced by the different commercial cultivars.

4.2 Materials and methods

A field experiment was established in October 2008 on a SASRI research farm located at Empangeni in the north coast of KwaZulu-Natal (28°43'0''S 31°53'0''E). The trial consisted of eight sugarcane cultivars which are commonly grown in the coastal region of KZN. The

details of cultivars, crops, trial design and plot dimensions, and treatment application are detailed in Chapter 3. Briefly, some key aspects of the methodology are mentioned below.

Weather data were collected during each growing season (ratoon) from an automatic weather station (AWS) situated at the experimental site. The weather variable collected was rainfall (mm). The long term mean (LTM) monthly rainfall was also calculated to characterise the growing seasons in terms of rainfall.

Measurements were taken at two week intervals from 2 x 2 m sections which were randomly assigned to net rows prior to emergence. Tiller counts (stalk population) were determined from the average of counts done within the 2 m sections, whereas stalk height was measured from 10 randomly selected plants. The final stalk population was determined by counting all of the millable cane from two of the three net rows at harvest. Stalk population was subsequently expressed as the number of stalks per hectare. The amount of incoming solar radiation intercepted by the canopy was also measured on a two weekly interval on cloudless days, using a ceptometer (LP-80 AccuPAR- Decagon Devices).

At each harvest, sucrose samples were taken by cutting 12 stalks from the net rows. The samples were then sent to the SASRI mill room to determine the estimated recoverable crystal percentage (ERC %). Cane yield in tons cane/ha (TCANE) was measured by hand-cutting and weighing the net plots with a mechanical grab apparatus fitted with a load cell. Tons ERC/ha (TERC), was calculated as a product of TCANE and ERC.

From each of the 12 stalks used for sucrose sampling, the components of mulch which included green leaves and dead brown leaves were separated into brown paper bags. These components were dried at 75 °C for approximately 72 hours. The samples were then weighed to calculate the total mulch yield (tons/ha) for each cultivar on a dry mass basis.

Soil water content was measured using soil moisture sensors (Decagon Devices 10HS). The sensors were installed at 20-25 cm depths in selected burnt and mulched treatments. The readings were taken at two week intervals from selected burn and mulch plots.

Hobo data loggers were used to monitor soil temperature. The loggers were installed in the fifth crop and were replicated four times. The devices were set to log temperatures every 15 minutes and were installed at a depth of 15-20 cm in selected mulched and burnt plots of the same cultivars.

All parameters measured at each harvest were subjected to a combined analysis of variance (ANOVA) to establish main (cultivar, mulch, and ratoon) and interaction effects. Comparison of means was performed using Duncan's LSD test at 5% significance difference and statistical analyses were done using GenStat Statistical Package version 14.

4.3 Results

4.3.1 Seasonal characteristics

Rainfall patterns and distributions differed across all four cropping seasons. The first few summer months after ratooning in the first ratoon (R1) had rainfall similar to the long term means (LTM), however, rainfall dropped below the LTM later in the season in winter (Figure 4.1). Generally, the second ratoon (R2) had above LTM rainfall over most of the cropping period. The highest amount of rainfall of about 230 mm was recorded in January. In contrast, the third ratoon (R3) was generally below the LMT for most months between December and August. The highest rainfall was however received at the end on the growing season in September. The fifth ratoon (R5) started at the end of June and was generally below the LTM for June to September. The months of October and March received the highest rainfall of about 141 and 133 mm respectively. Thereafter the rainfall dropped below the LTM towards the end of the growing season.

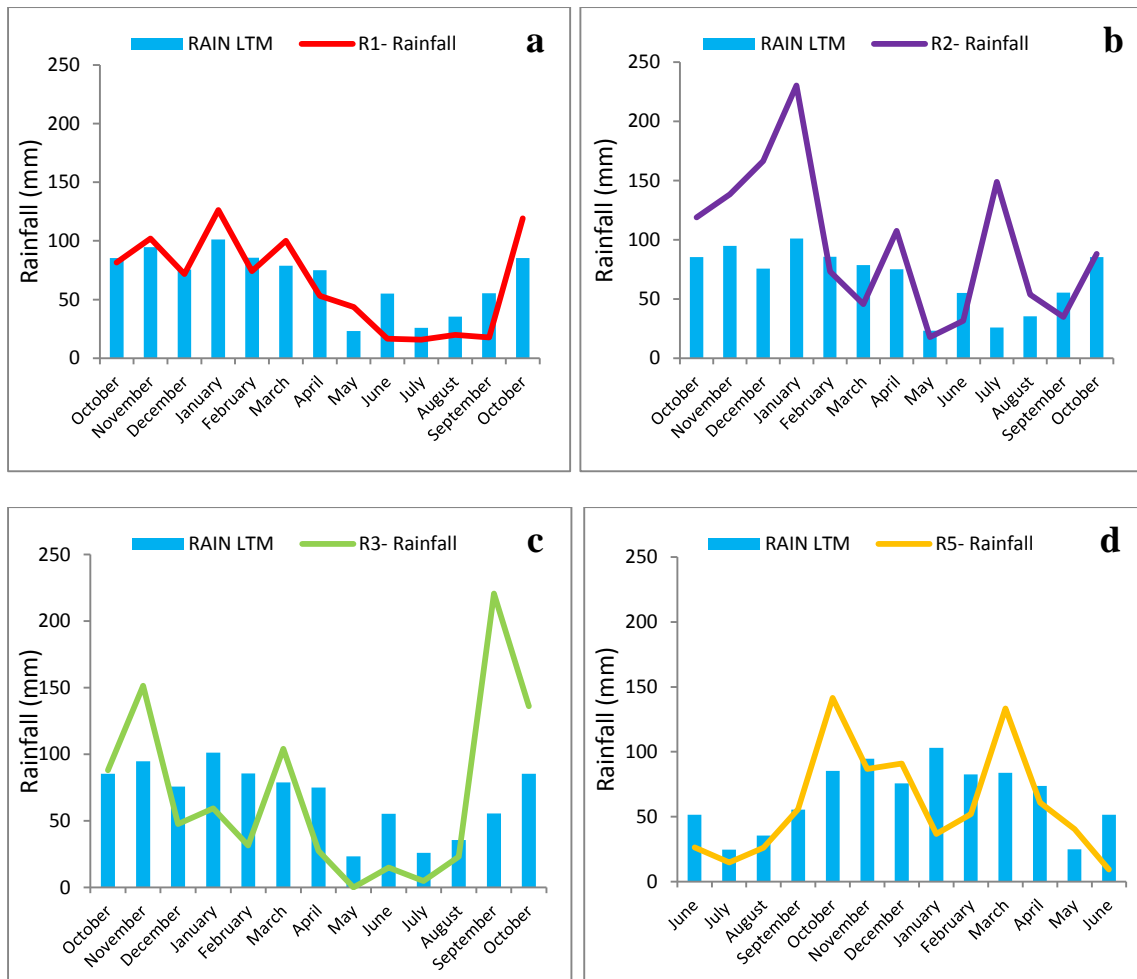


Figure 4.3 Monthly mean rainfall and long term mean (LTM) taken from an automatic weather station in the first (a), second (b), third (c), and fifth (d) ratoon crops at Empangeni (The x-axis are synchronised with the harvesting months).

4.3.2 Yield and yield components

The combined analysis of variance showed that the ratoon (R), mulch (M) and cultivar (C) main effects were significant ($p < 0.05$) for all yield components, in general (Table 4.1). The R x M and R x C interactions were also significant ($P < 0.05$) for most of the yield components with exception of stalk mass. This means that the ranking between the mulch treatments and the ranking between cultivars differed from one ratoon crop to the next. Generally, the C x M interaction and three way R x M x C interaction were not significant with respect to cane yield, TERC, stalk population, stalk heights and stalk mass. This means that the effect that mulching had on cultivar performance with regards to most of the yield components does not change from one ratoon crop to next. However, the C x M interaction was significant ($p = 0.007$) for ERC%, meaning that cultivars differed significantly in their response to mulching with respect to ERC%.

Table 4.4 P values from a combined analysis of variance (ANOVA) for all yield components across four ratoons for eight cultivars under burnt and mulched treatment.

Source of variation	df	Cane yield (t/ha)	ERC%	TERC	Stalk population (h ⁻¹)	Stalk heights (cm)	Stalk mass (g)
Ratoon (R)	3	<.001	<.001	<.001	<.001	<.001	<.001
Mulch (M)	1	0.001	0.017	<.001	0.022	<.001	<.001
Cultivar (C)	7	0.011	<.001	<.001	<.001	<.001	<.001
R x M	3	<.001	0.004	0.001	<.001	<.001	<.001
R x C	21	<.001	<.001	<.001	<.001	<.001	0.083
C x M	7	0.231	0.007	0.053	0.63	0.365	0.238
R x M x C	21	0.322	0.472	0.135	0.176	0.126	0.138

On average, cane yields were highest in the second ratoon and lowest in the third ratoon crops (Figure 4.2). In general, cane yields were significantly ($p < 0.05$) improved by the mulch treatment across all four ratoons crops for most of the cultivars (Figure 4.2). However, in the second ratoon crop, where high rainfall (230 mm) was received before canopy closure (Figure 4.1b), the improvement due to mulching of cultivars N41, NCo376 and N35 were not statistically significant (Figure 4.2b). Similarly in the third ratoon crop cultivar N35 showed no significant improvement due to mulching (Figure 4.2 c). The cane yield improvements due to mulching were different across all four ratoon crops. The highest yield improvements were recorded for cultivars N47 (53%), N39 (27%), NCo376 (58%) and N45 (85%) in the first, second, third and fifth ratoon, respectively (Figure 4.2). The smallest improvements were found for N35 in the first (16%) and third (23%) ratoon crops, N41 (7%) in the second and N27 (44%) in the fifth ratoon crop, respectively (Figure 4.2).

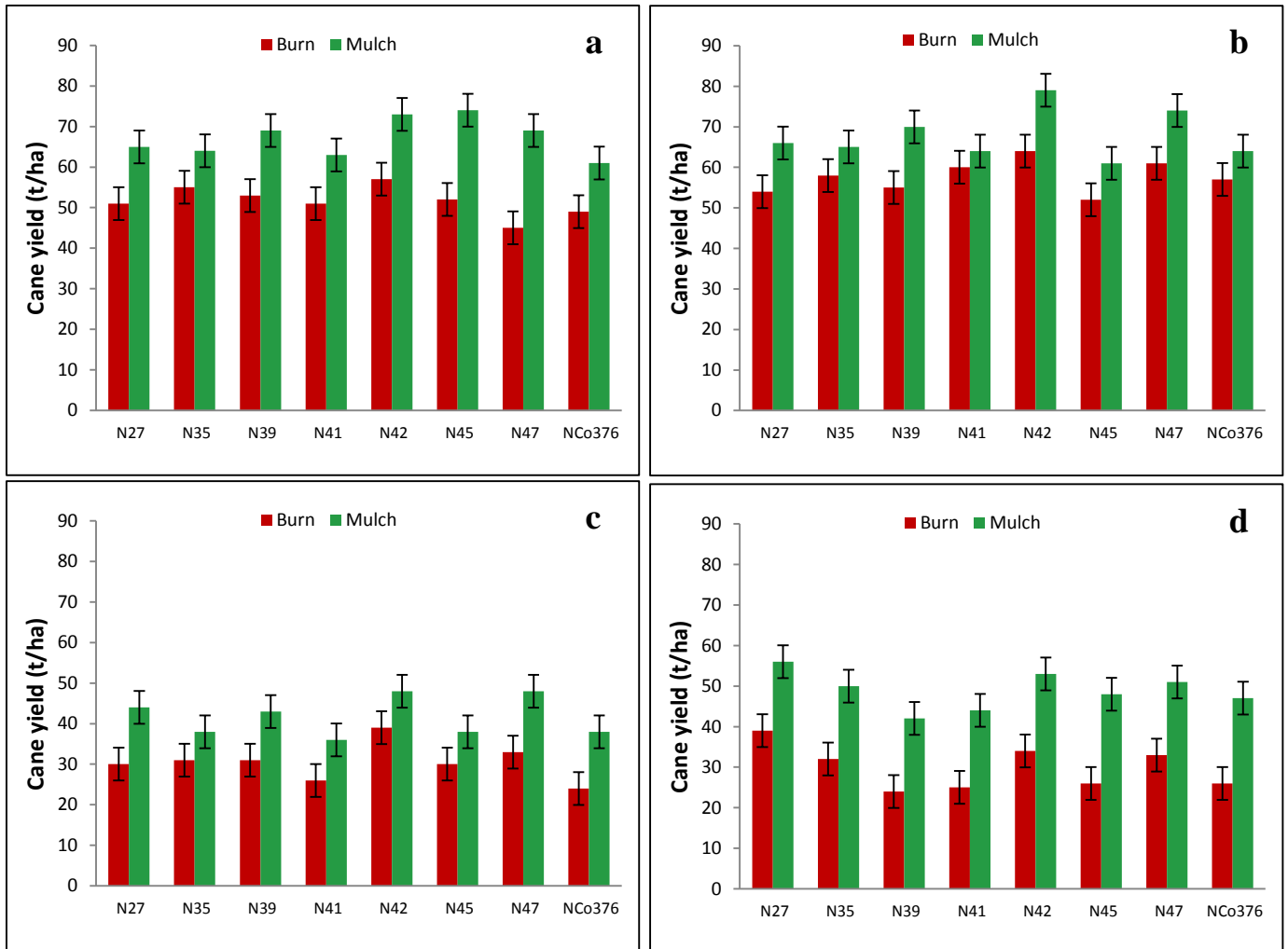


Figure 4.4 Cane yields for eight different cultivars under burn and mulch treatments in the first (a), second (b) third (c) and fifth (d) ratoon crops at Empangeni. Vertical bars represent least significant differences ($p < 0.05$).

In the first and fifth ratoon, only cultivars N47 (10% improvement) and NCo376 (11% reduction) showed significant differences in ERC% between the burn and mulch treatments (Figure 4.3a and d). In the second ratoon crop, only N27, N39 and NCo376 showed significant improvements in ERC of 9, 11 and 12%, respectively when mulched (Figure 4.3b). In the third ratoon crop, most cultivars showed significant improvements in ERC% when mulched, with N47 having the highest improvement in ERC of 20% (Figure 4.3c). In general, there were no significant reductions in ERC% due to mulching. Cultivars N39 and N42, and N41 and, N42 showed reductions in the first and third ratoon crops, respectively, but these reductions were not statistically significant.

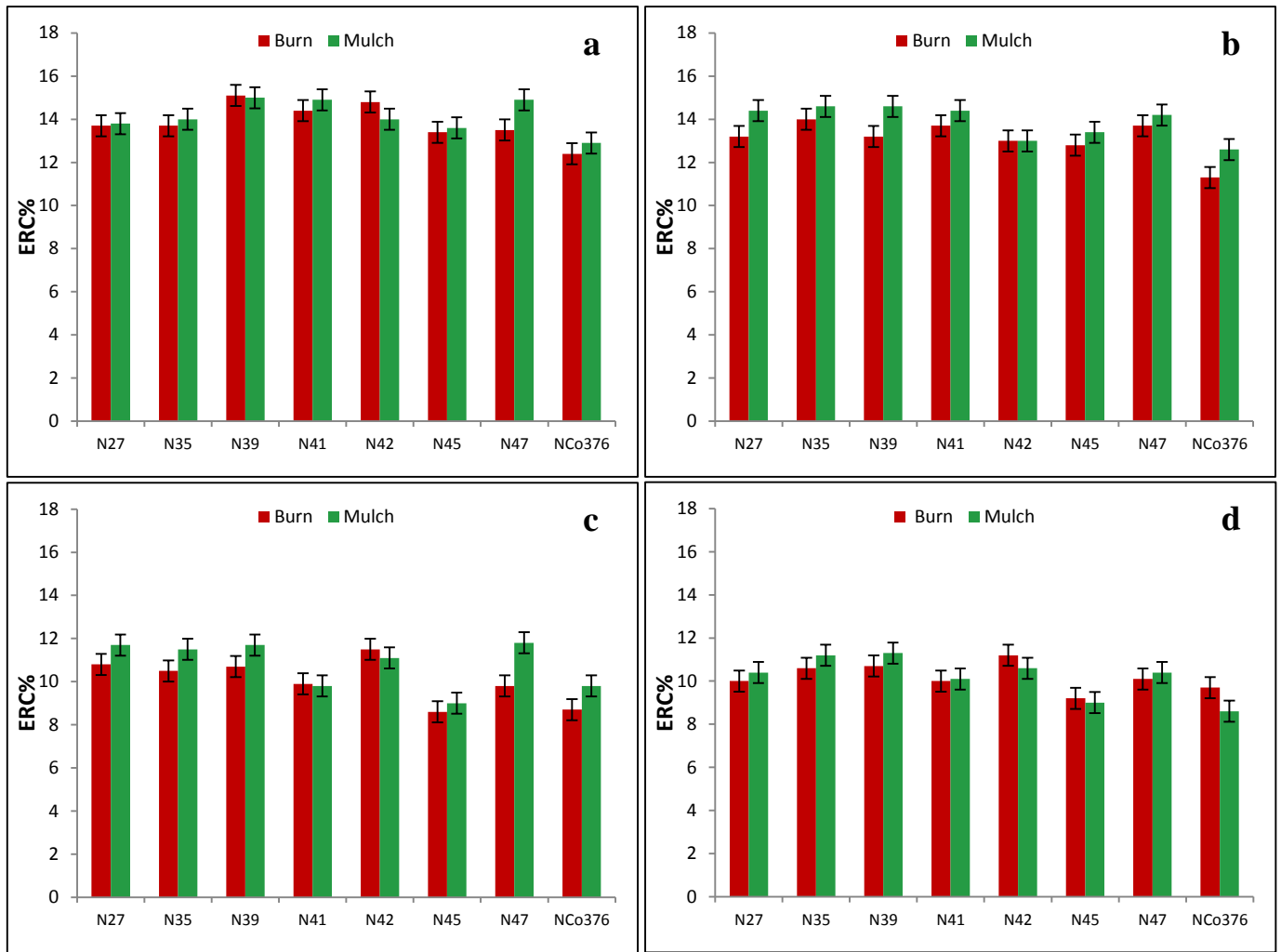


Figure 4.5 ERC for eight different cultivars under burn and mulch treatments in the first (a), second (b) third (c) and fifth (d) ratoon crops at Empangeni. Vertical bars represent least significant differences ($p < 0.05$).

The responses of TERC were similar to the responses of cane yield. The mulch treatment significantly ($P < 0.001$) improved TERC for most cultivars across all four ratoons (Figure 4.4). In the third ratoon however, N42 and N45 did not show any statistical improvements due to mulching (Figure 4.4c). The highest TERC improvements due to mulching were observed for N47, with 72 and 74% in the first and third ratoon, respectively. In the second and fifth ratoon, cultivar N39 showed the highest improvements of 42 and 92%, respectively. The lowest improvements due to mulching were shown by N35 (18%), N41 (15%), and N42 (19%) and (47%) in the first, second, third and fifth ratoon respectively.

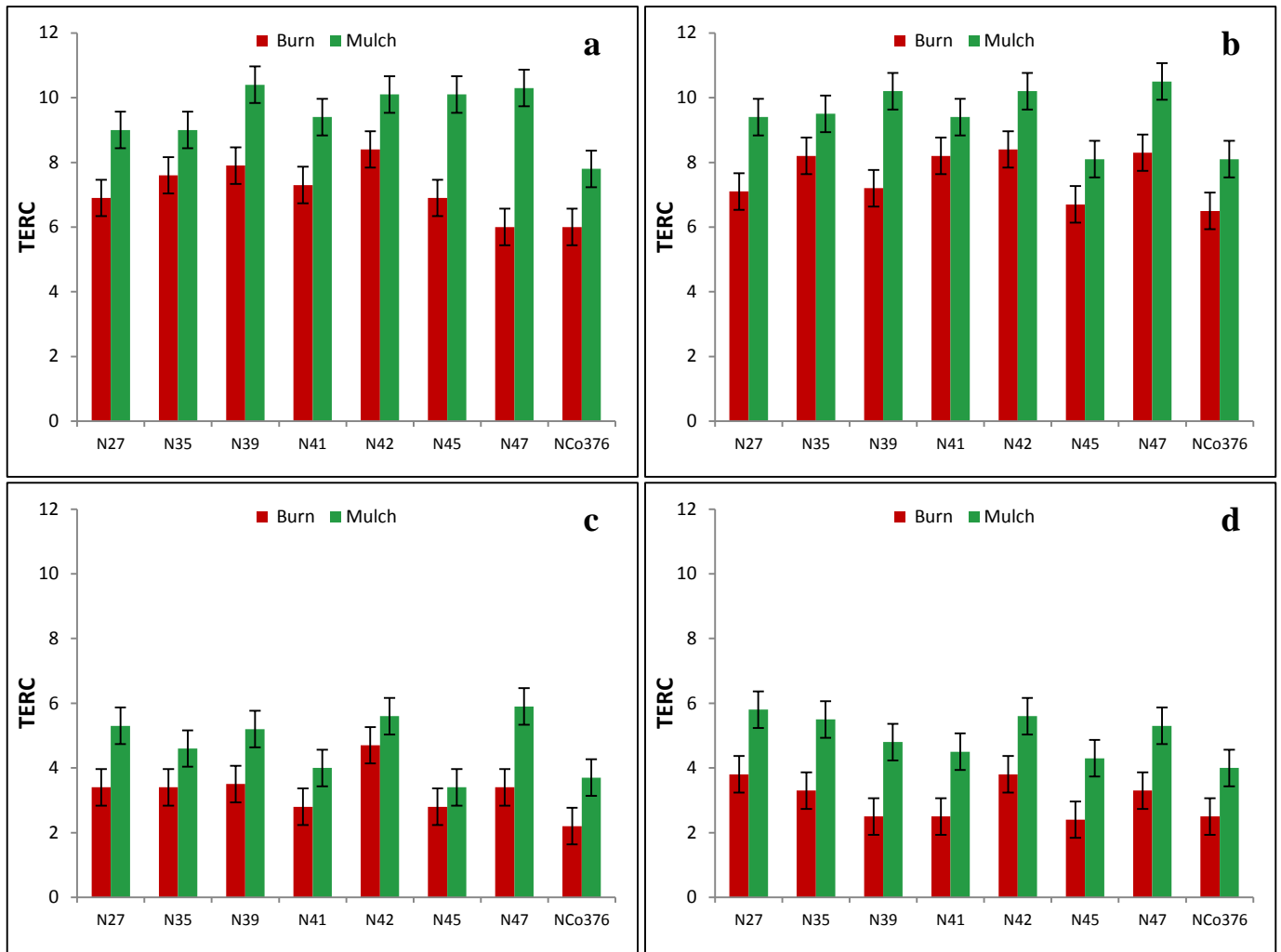


Figure 4.6 Tons ERC (TERC) for eight different cultivars under burn and mulch treatments in the first (a), second (b) third (c) and fifth (d) ratoon crops at Empangeni. Vertical bars represent least significant differences ($p < 0.05$).

There were no significant differences in final stalk population due to mulching for all cultivars in the first and third ratoon crops (Figure 4.5). In the second ratoon crop most cultivars showed no response to mulching, however, there was a significant reduction in stalk population for cultivar NCo376 due to mulching (Figure 4.5b). The winter crop (fifth ratoon) was an exception to the three summer crops (Figure 4.5a, b, c) such that, the mulch treatment significantly improved stalk population for most cultivars with exception to cultivar N42 and N27. Stalk heights on the other hand were significantly improved by mulching for all cultivars in the first, third and fifth ratoon (Figure 4.6a, c and d). This improvement in stalk height was also visually observed at harvest (Figure 4.7a and b). In the second ratoon, only cultivars N39, N42 and N47 had significant improvements in height due to the mulch treatment (Figure 4.5b). The individual stalk mass was improved significantly ($P < 0.001$) by mulching for most cultivars

across most crops (Figure 4.8). The highest improvements were observed for N42, N27, and N47, in the first, second, and third ratoon crop respectively (Figure 4.8a, b and c). In the fifth ratoon (Figure 4.8d), all cultivars showed significant improvements in stalk mass when mulched. The weakest response to mulching in the second ratoon with respect to stalk population (Figure 4.5b), stalk height (Figure 4.6b) and stalk mass can be related to higher rainfall received during the peak growing season (January) (Figure 4.1b). In contrast, the best responses to mulching in the fifth ratoon for the same yield components (Figure 4.5d, 4.6d and 4.8d) was related to low rainfall during peak growing season in January (Figure 4.1d). These results give an indication of the effect of the mulch layer in both high rainfall (sufficient water available (Figure 4.1b)) and water limiting (Figure 4.1d) seasons.

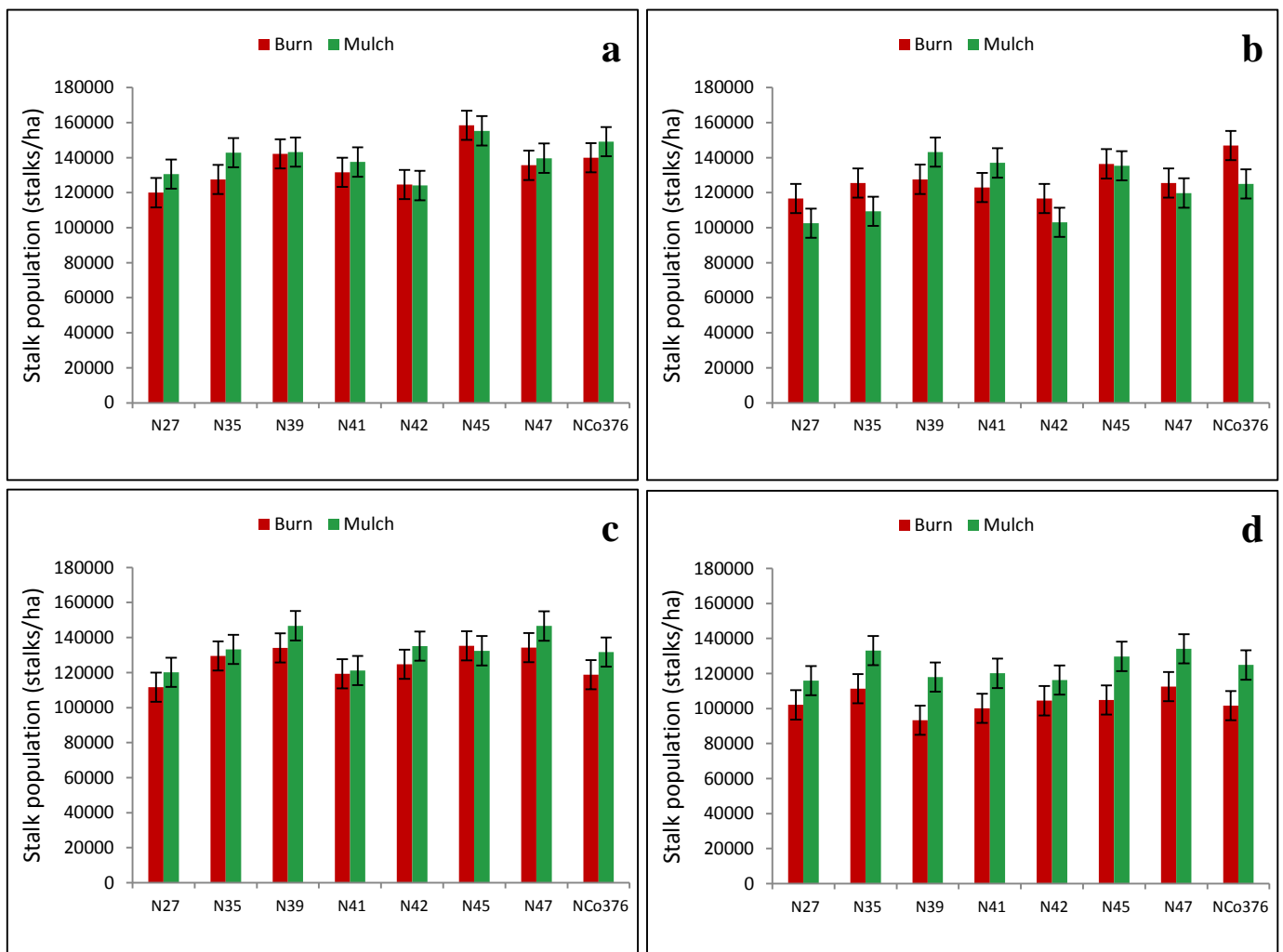


Figure 4.7 Final stalk populations for eight different cultivars under burn and mulch treatments in the first (a), second (b), third (c), and fifth (d) ratoon crops at Empangeni. Vertical bars represent least significant differences ($p < 0.05$).

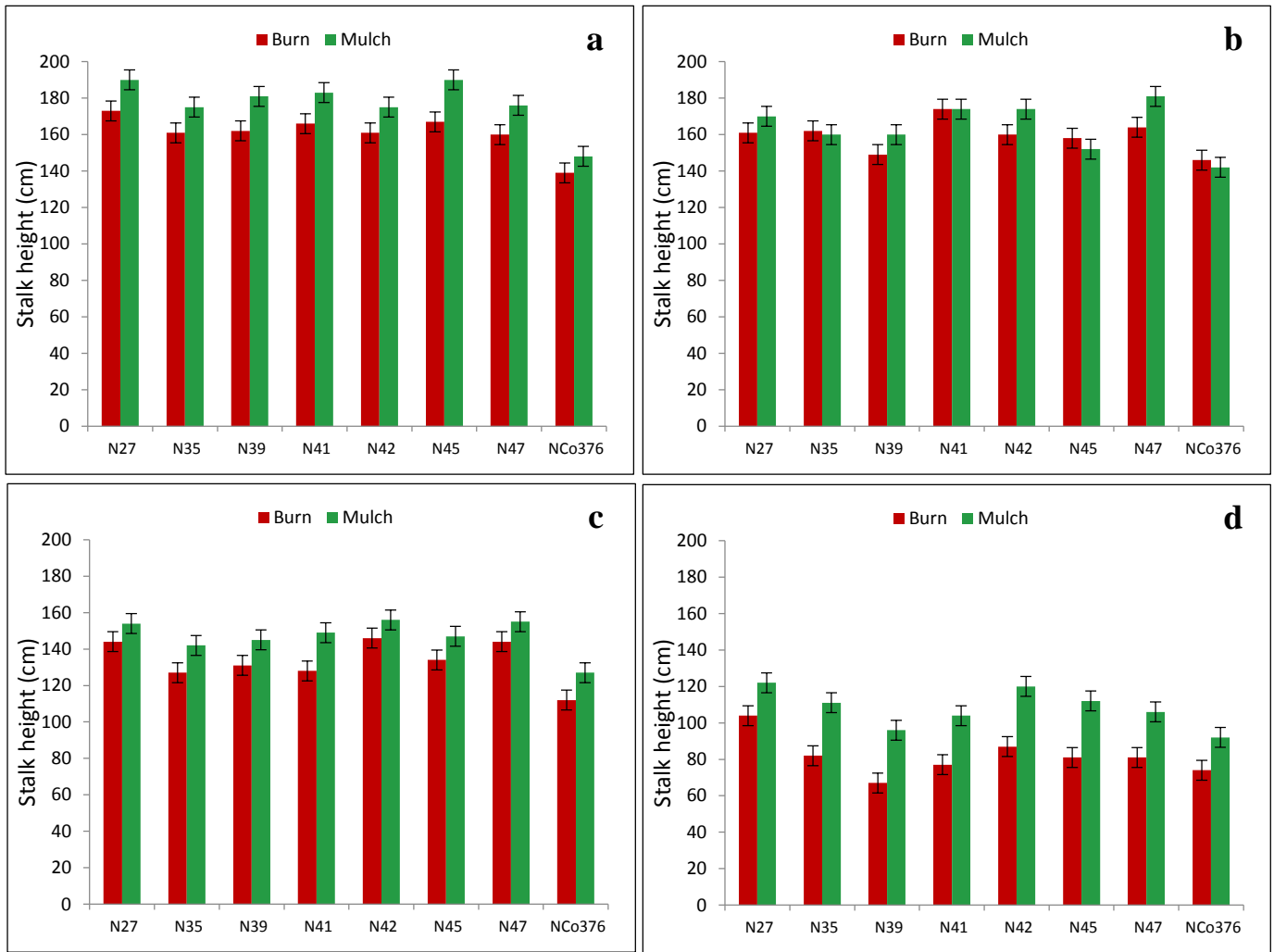


Figure 4.8 Stalk heights for eight different cultivars under burn and mulch treatments in the first (a), second (b) third (c) and fifth (d) ratoon crops at Empangeni. Vertical bars represent least significant differences ($p < 0.05$).

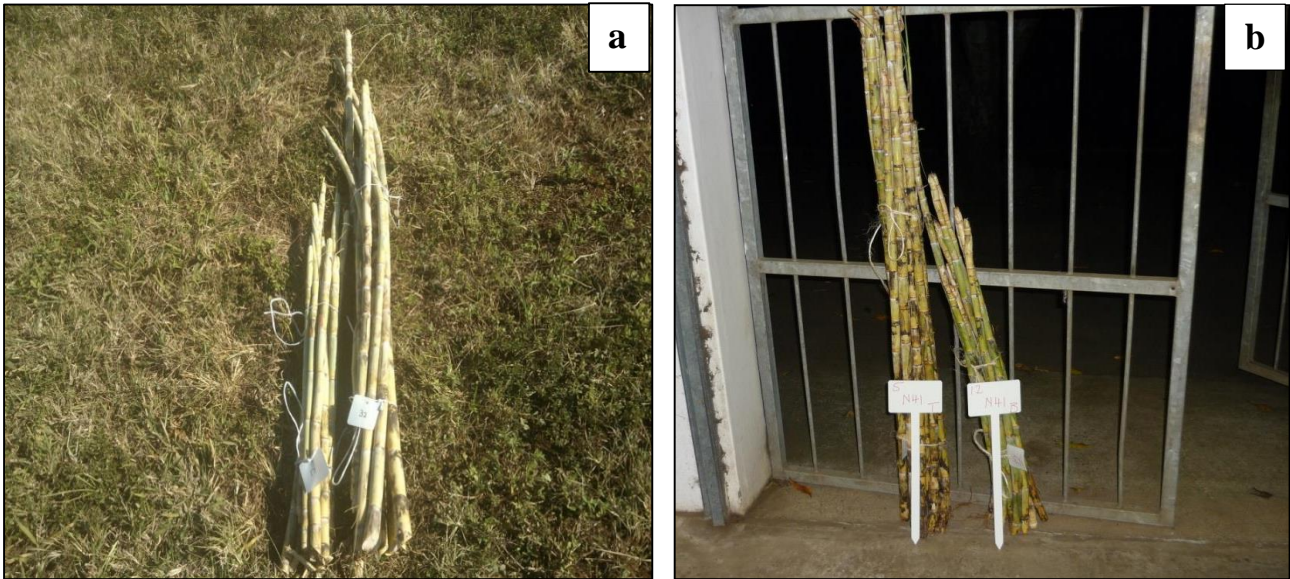


Figure 4.9 Height differences at harvest for cultivar N42 under burnt treatment on the left and mulch treatment on the right in the third ratoon (a); height differences at harvest for cultivar N41 under mulch treatment on the left and burnt treatment on the right in the fifth ratoon (b).

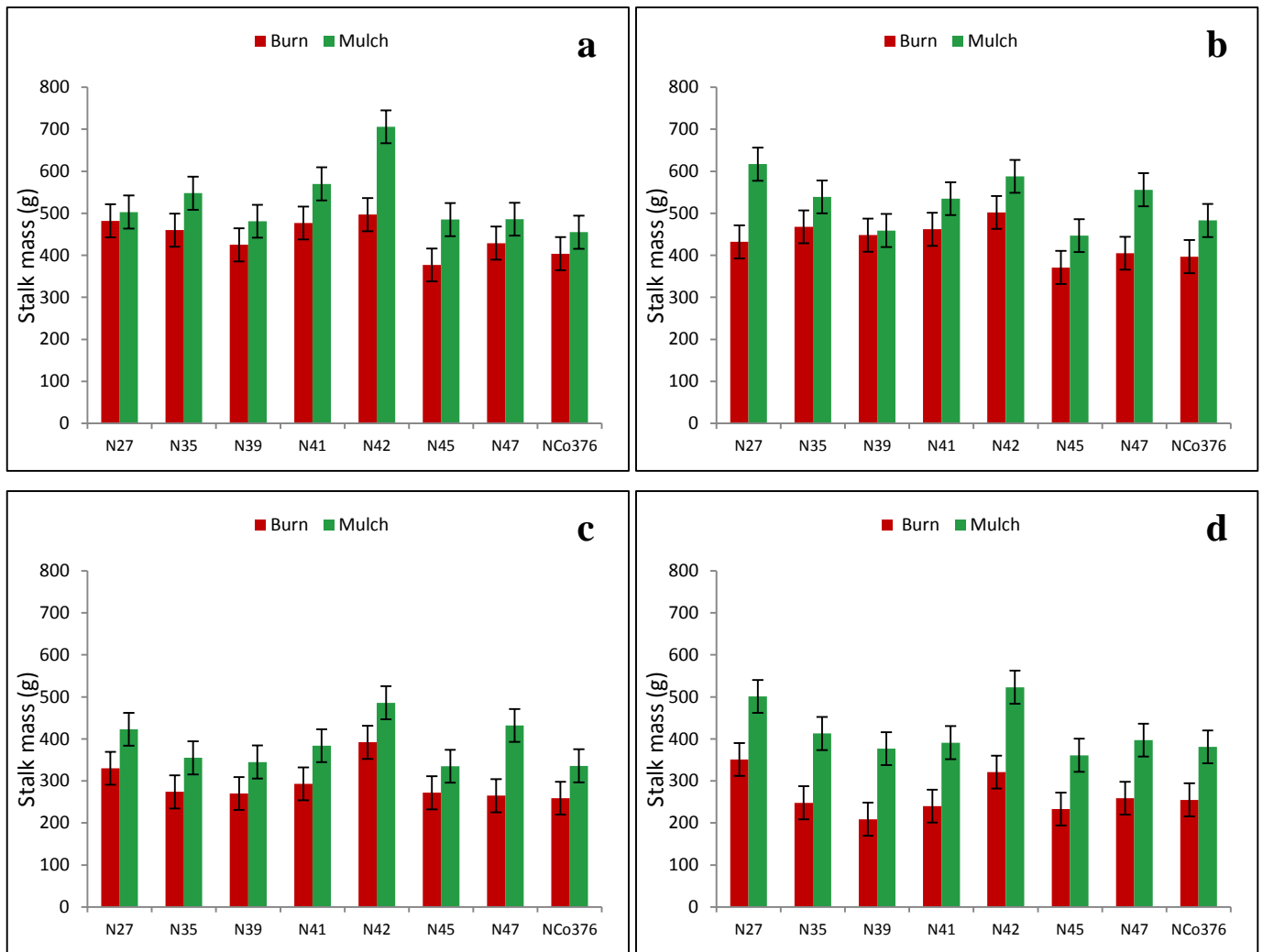


Figure 4.10 Stalk mass for eight different cultivars under burn and mulch treatments in the first (a), second (b), third (c) and fifth (d) ratoon crops at Empangeni. Vertical bars represent least significant differences ($p < 0.05$).

4.3.3 Effects of mulching on canopy development

In all the ratoon crops the growth patterns were similar for most cultivars when stalk population and stalk heights for each cultivar x mulch treatment was plotted as a function of days after ratooning. The mean of all cultivars which reacted similarly in both treatments are shown, together with any cultivar that had a different response to mulching (Figures 4.9 to 4.12). The burn treatment generally had significantly higher stalk population at the early emergence stage compared to the mulch treatments and this was consistent across all ratoons for all cultivars. In

the first ratoon, the differences lasted until peak stalk population, after this period the differences between the treatments were no longer significant for the rest of the season (Figure 4.9a and b).

In the second ratoon, the significantly higher stalk population in the burn treatment was observed only at the early emergence stage for most of the cultivars. These differences were no longer present from peak stalk population onwards (Figure 4.10a). Cultivar NCo376 showed a slightly different response than the other cultivars, as its stalk population was significantly reduced in the mulch treatment throughout the growing season (Figure 4.10b).

In the third ratoon, there was a change in the ranking of treatments about 68 days after ratooning for NCo376, as the mulch treatments significantly improved stalk population consistently throughout the growing season (Figure 4.11b). For the other cultivars (Figure 4.11a), the higher stalk population in the burn treatments only lasted until peak stalk population, thereafter the differences faded away.

The winter crop (Figure 4.12) took more time to reach peak stalk population when compared to the three summer crops (Figures 4.8, 4.9, and 4.10) for both the mulch and the burn treatments. The higher stalk population in the burn treatment persisted even after peak stalk population, however, about 209 days after ratooning the differences declined (Figure 4.12a and b). At the end of the period of measurements the mulch treatment for cultivar NCo376 had a significantly higher stalk population than the burn treatment (Figure 4.12b).

When stalk height was plotted against days after ratooning, two phases were observed for all cultivars in both treatments. The first phase showed rapid stalk elongation, followed by the maturation period. In the first ratoon (Figure 4.9), no differences in stalk height were observed between the burn and mulch treatment at the beginning of the rapid stalk elongation phase up to 76 days after ratooning for N45, N35, N41, N39 and 91 days after ratooning for NCo376, N27, N47, N42. Thereafter, the stalks in the mulch treatment were consistently taller compared to the burn treatment throughout the growing season.

There were no significant differences in stalk height amongst the burn and the mulch treatment in the second ratoon throughout the growing season for most cultivars (Figure 4.10). However, cultivars N47, N42 and N39 had a higher stalk elongation rate in response to mulching but the differences never reached significance since the second ratoon had adequate rainfall (Figure 4.1b).

In the third ratoon, stalks in the mulch treatment elongated faster at 91 days after ratooning for most cultivars. However, the differences amongst the treatments became more significant in the very dry winter periods (Figure 4.1c) as the crops approached maturation period (Figure 11a). Cultivar NCo376 on the other hand had rapid stalk elongation at the mulch treatment earlier than other cultivars (Figure 4.11b).

The mulch treatment (as compared to the burn) had a much more rapid stalk elongation in the fifth ratoon (winter crop) (Figure 4.12) than the three summer crops (Figure 4.9 to 4.11). The rapid stalk elongation was observed from emergence but became more significant from about 97 days after ratooning (Figure 4.12).

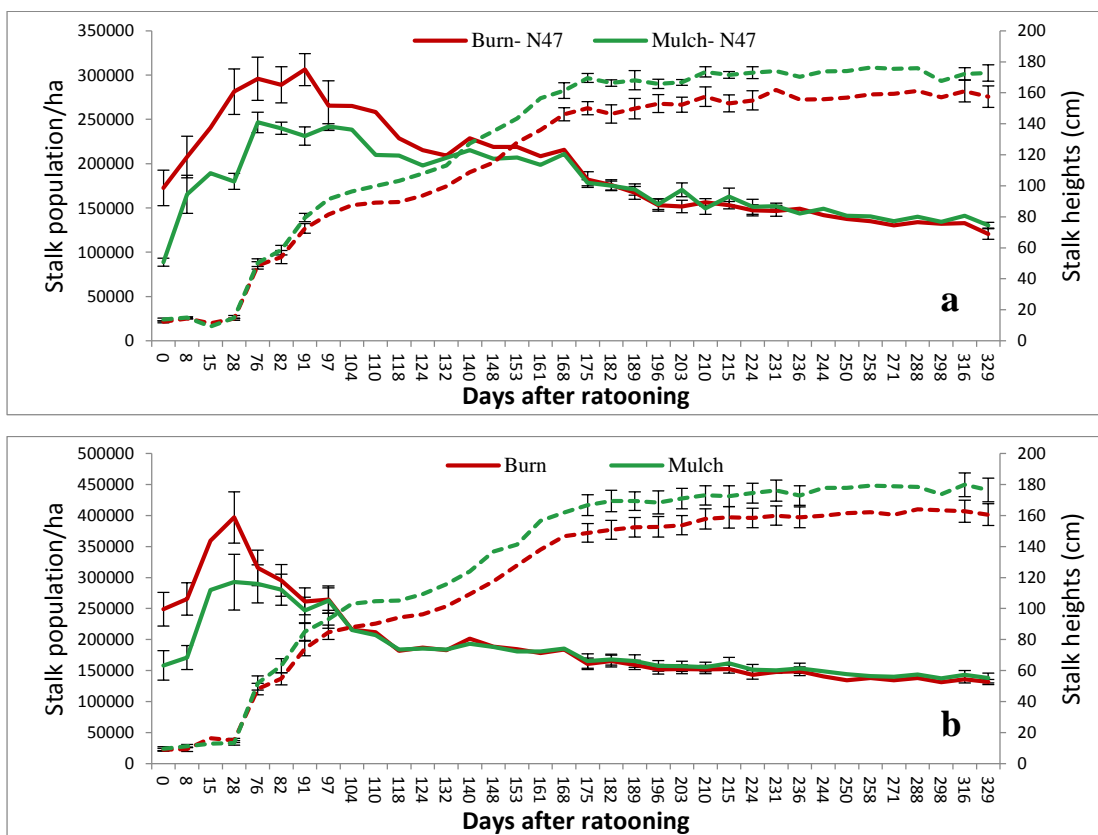


Figure 4.11 Stalk population on the primary axis (solid) and stalk heights on the secondary axis (square dots) for (a) cultivar N47 and (b) mean of N27, N35, N39, N41, N42, N45 and NCo376 as a function of dates after ratooning as affected by burn and mulch treatments at the first ratoon. The sampling error is indicated by error bars at selected points.

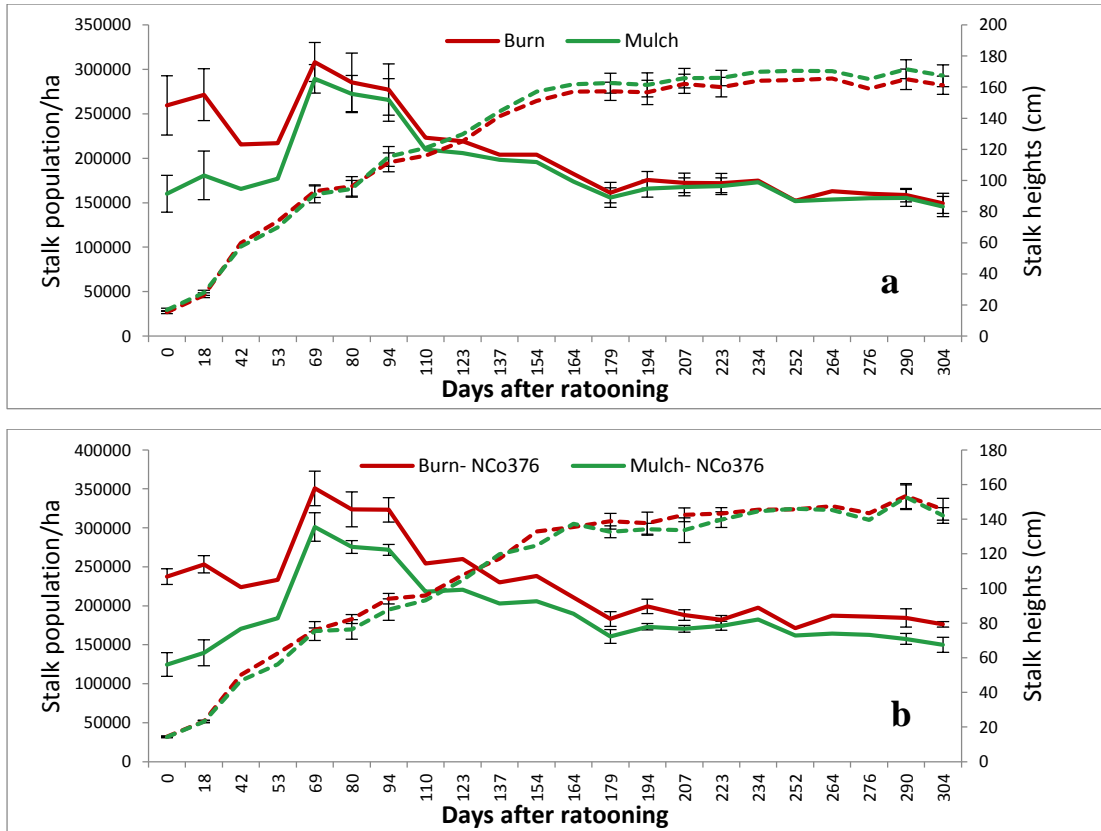


Figure 4.12 Stalk population on the primary axis (solid) and stalk heights on the secondary axis (square dots) for (a) mean of cultivars N27, N35, N39, N41, N42, N45 and N47 and (b) NCo376 as a function of dates after ratooning as affected by burn and mulch treatments at the second ratoon. The sampling error is indicated by error bars at selected points.

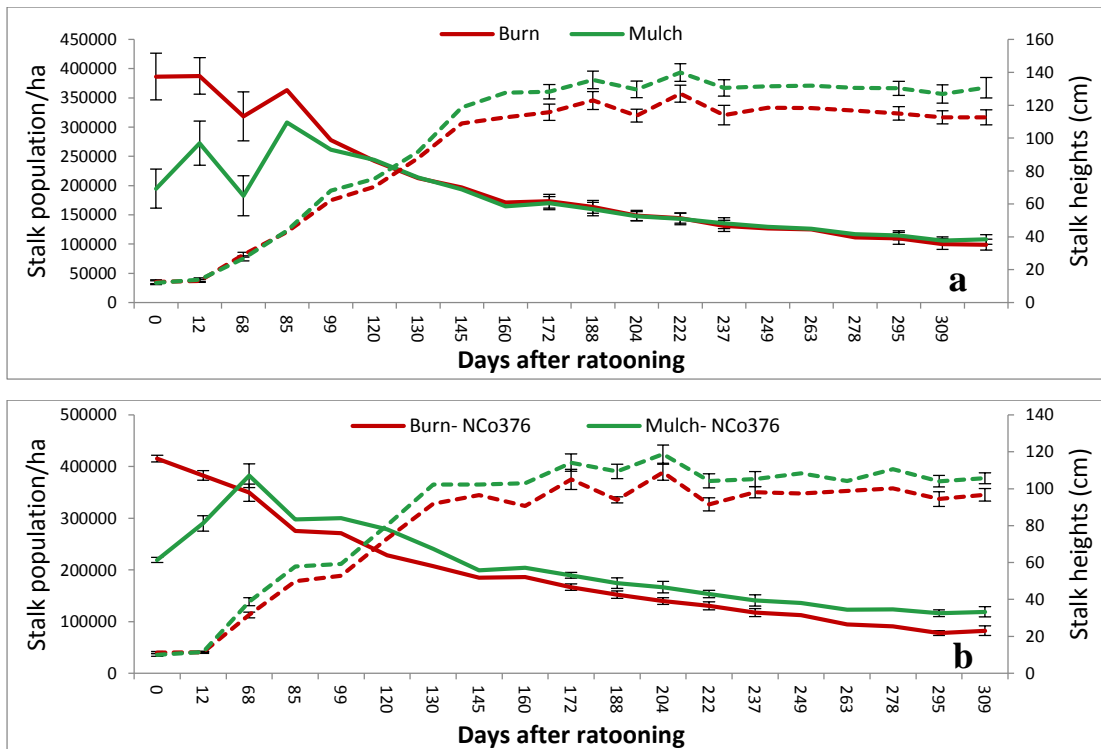


Figure 4.13 Stalk population on the primary axis (solid) and stalk heights on the secondary axis (square dots) for (a) mean of cultivars N27, N35, N39, N41, N42, N45 and N47 and (b) NCo376 as a function of dates after ratooning as affected by burn and mulch treatments at the third ratoon. The sampling error is indicated by error bars at selected points.

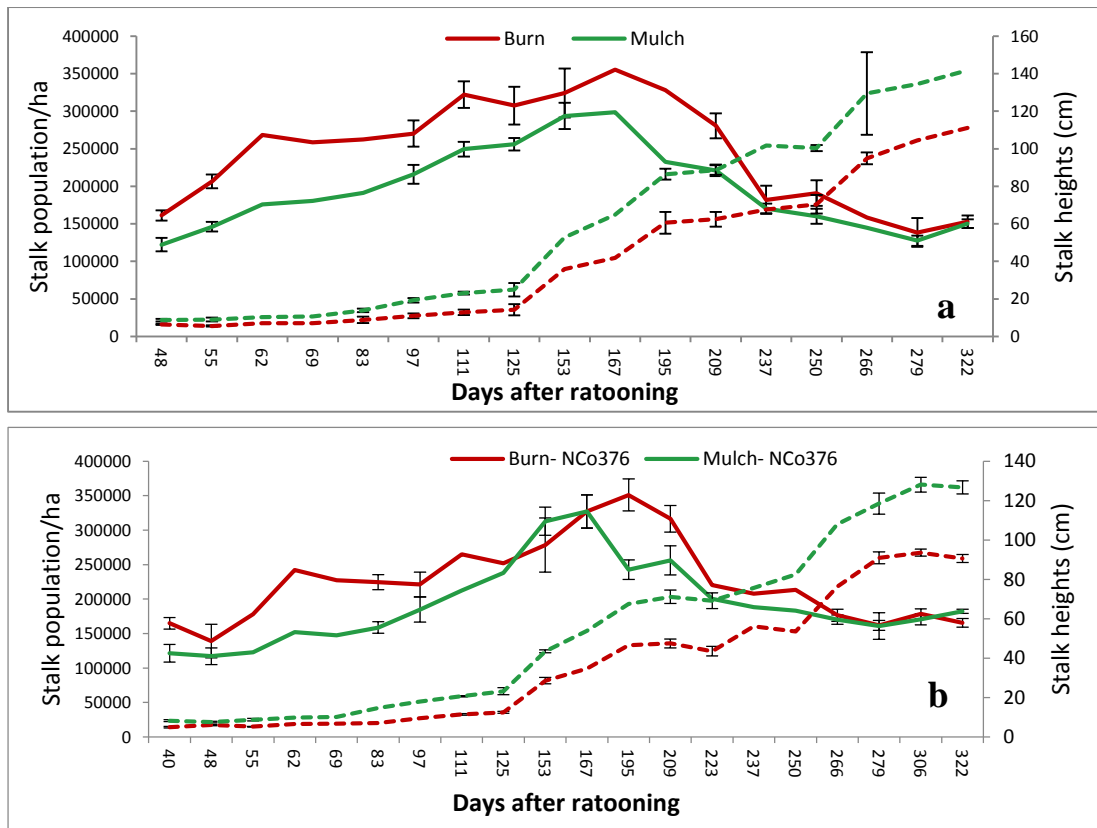


Figure 4.14 Stalk population on the primary axis (solid) and stalk heights on the secondary axis (square dots) for (a) mean of cultivars N27, N35, N39, N41, N42, N45 and N47 and (b) NCo376 as a function of dates after ratooning as affected by burn and mulch treatments at the fifth (winter) ratoon.

Fractional intercepted radiation was measured occasionally from 42 days after ratooning in the second ratoon crop. Cultivar NCo376 and N45, which displayed similar trends were averaged and plotted (Figure 4.13a). Similarly, cultivars N27, N35, N39, N41, N42 and N47 had similar trends and were therefore averaged and plotted (Figure 4.13b). In the third and fifth ratoon all cultivars responded in a similar manner and therefore averaged as burn vs mulch results were plotted (Figure 4.14 and 4.15 respectively).

In the second ratoon, the average response of NCo376 and N45 showed that mulching significantly reduced FiPAR at 42 days after ratooning (Figure 4.13a). However, 94 days after ratooning the differences were no longer significant. The average response of the rest of the cultivars (N27, N35, N37, N41, N42 and N47) showed that radiation capture was also reduced in the mulch treatment but the differences between the treatments never reached significance at any measurement period (Figure 4.13b).

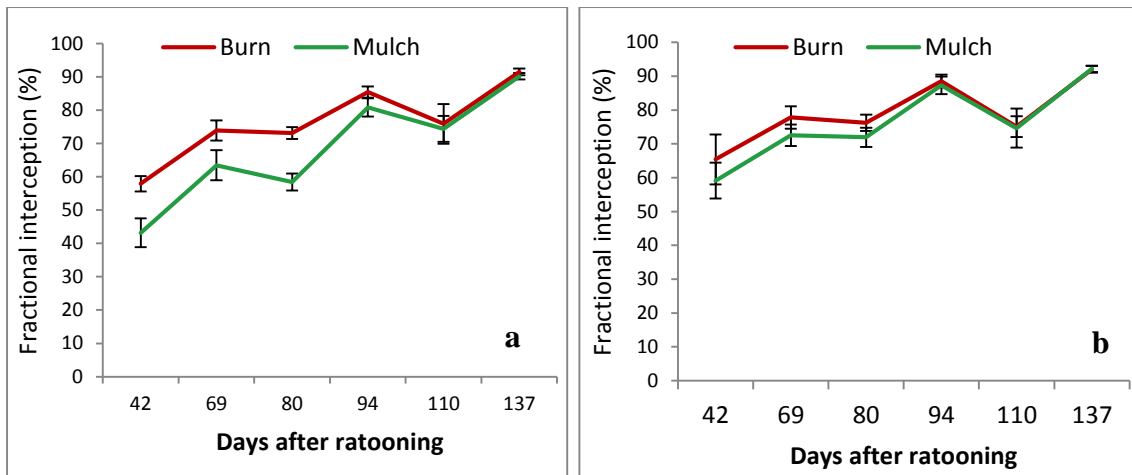


Figure 4.15 Fraction of intercepted photosynthetically active radiation (FiPAR) as affected by burn and mulch treatment in the second ratoon for (a) mean of NCo376 and N45 and (b) mean of N27, N35, N39, N41, N42 and N47 as a function of days after ratooning.

In the third ratoon crop (Figure 4.14), measurements of FiPAR were started at 85 days after ratooning; this corresponded to the time between peak stalk population and tiller senescence. In general, all cultivars reacted similarly to the mulch treatment. There were no significant differences in canopy development and FiPAR between the burn and the mulch treatment in the period when measurements were taken (Figure 4.14).

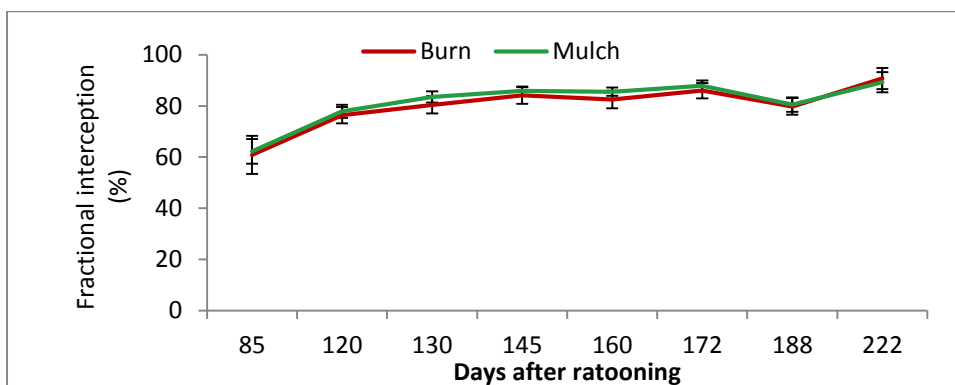


Figure 4.16 Fraction of intercepted photosynthetically active radiation (FiPAR) as affected by burn and mulch treatment in the third ratoon for mean of all cultivars as a function of days after ratooning.

In the fifth ratoon, 62 days after ratooning no significant differences in fractional interception were observed between mulch and burn treatments (Figure 4.15). Thereafter, the mulch treatment intercepted higher fractions of radiation than the burn treatment. Differences were however not significant at about 80% fractional interception 266 days after ratooning (Figure 4.15). This trend was in contrast to the second ratoon (summer ratoon), where the burn treatment showed higher FiPAR compared to the mulch treatment.

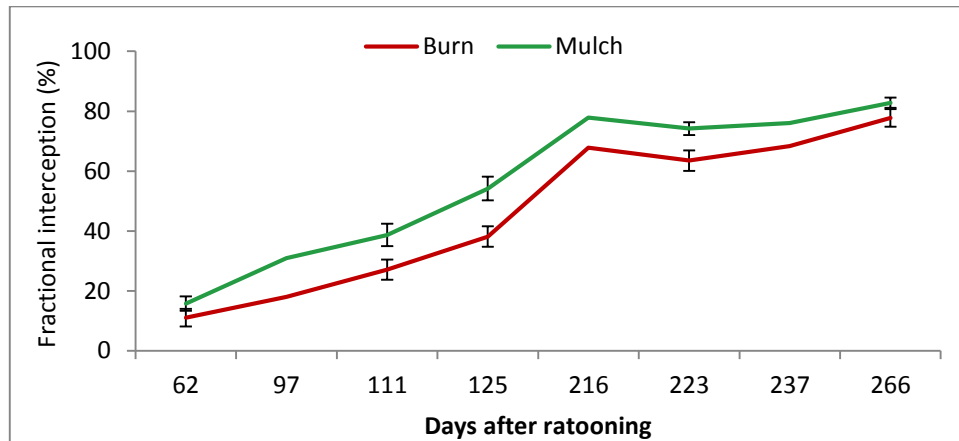


Figure 4.17 Fraction of intercepted photosynthetically active radiation (FiPAR) as affected by burn and mulch treatment in the fifth ratoon for mean of all cultivars as a function of days after ratooning.

4.3.4 Effects of mulching on soil water content

Soil water content was consistently higher in the mulch treatments throughout the growing season for all ratoons (Figure 4.16). The first ratoon (Figure 4.16a) generally had the smallest percentage water content difference as compared to the other ratoons. In the first and fifth ratoons, the differences in soil water content were higher early in the growing season, and these differences became smaller as the season progressed. In the second and third ratoons, the differences between burn and mulch treatments remained consistent throughout the growing season.

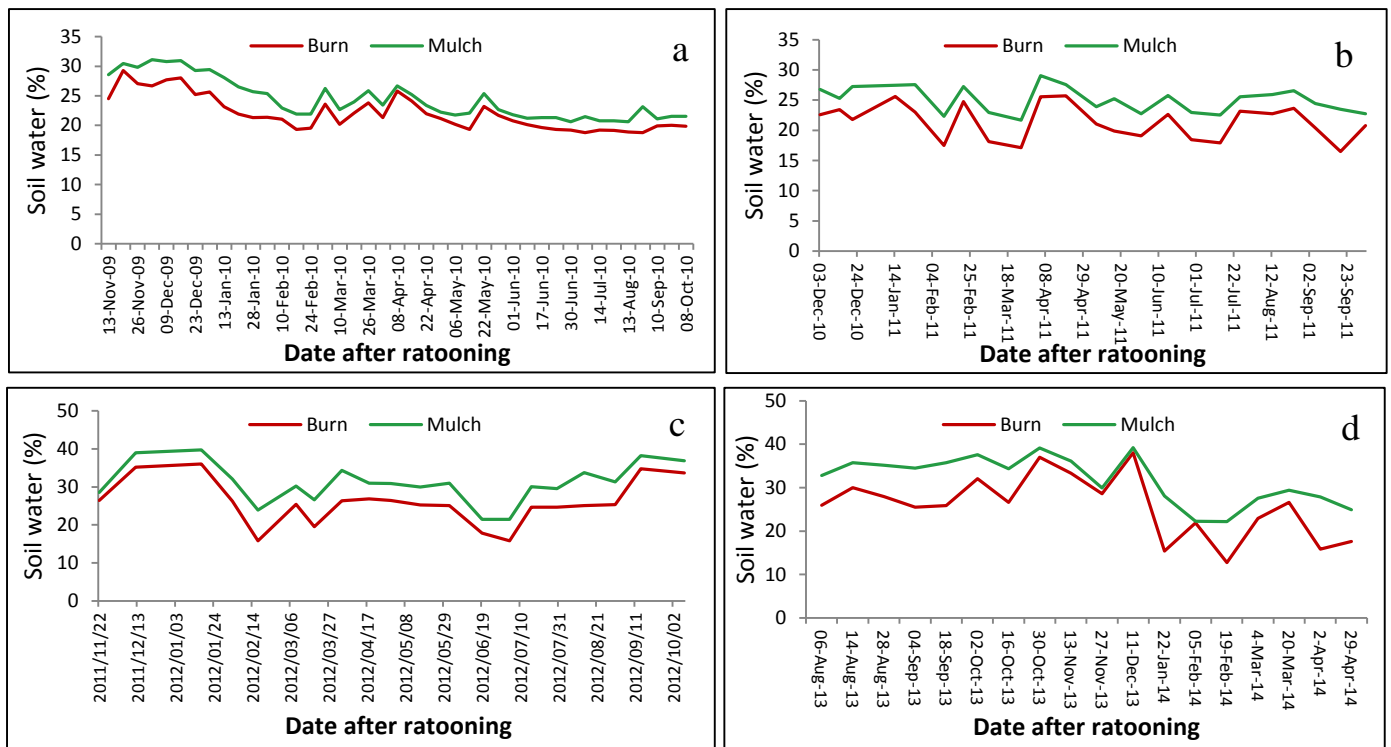


Figure 4.18 Changes in soil water content (in percentage) across the growing season as affected by burn and mulch treatment for (a) first ratoon crop (b) second ratoon crop (c) third ratoon crop and (d) fifth ratoon crop.

4.3.5 Effects of mulching on soil temperature

Soil temperature differences between burnt and mulched treatments are shown for three periods of the growing season during the fifth ratoon crop in Figure 4.17. Diurnal temperature variations were remarkably reduced by mulching in all parts of the growing season. Early (June 2013- August 2013) in the season (Figure 4.17a) soil temperatures under mulch were kept at an average of 18 °C, but temperatures increased later in the season. Daily maximum soil temperatures in the burn treatment were always greater than the mulch treatment throughout the growing season. However, minimum soil temperatures early in the season (Figure 4.17a) were sometimes lower than for the mulch treatment. Soil temperature differences between burn and mulch were greater early (Figure 4.17a) and mid-season (September 2013- February 2014) (Figure 4.17b) at partial canopy closure. The temperatures under mulch were kept at a constant average of about 25 °C during the mid-season. The differences between the two treatments faded away later in the season as the canopy closed (March 2014- June 2014) (Figure 4.17c). The burn treatment at this point had also reduced diurnal soil temperature fluctuations. At the

end of the season soil temperatures under the burn treatments were lower than those under the mulch treatment.

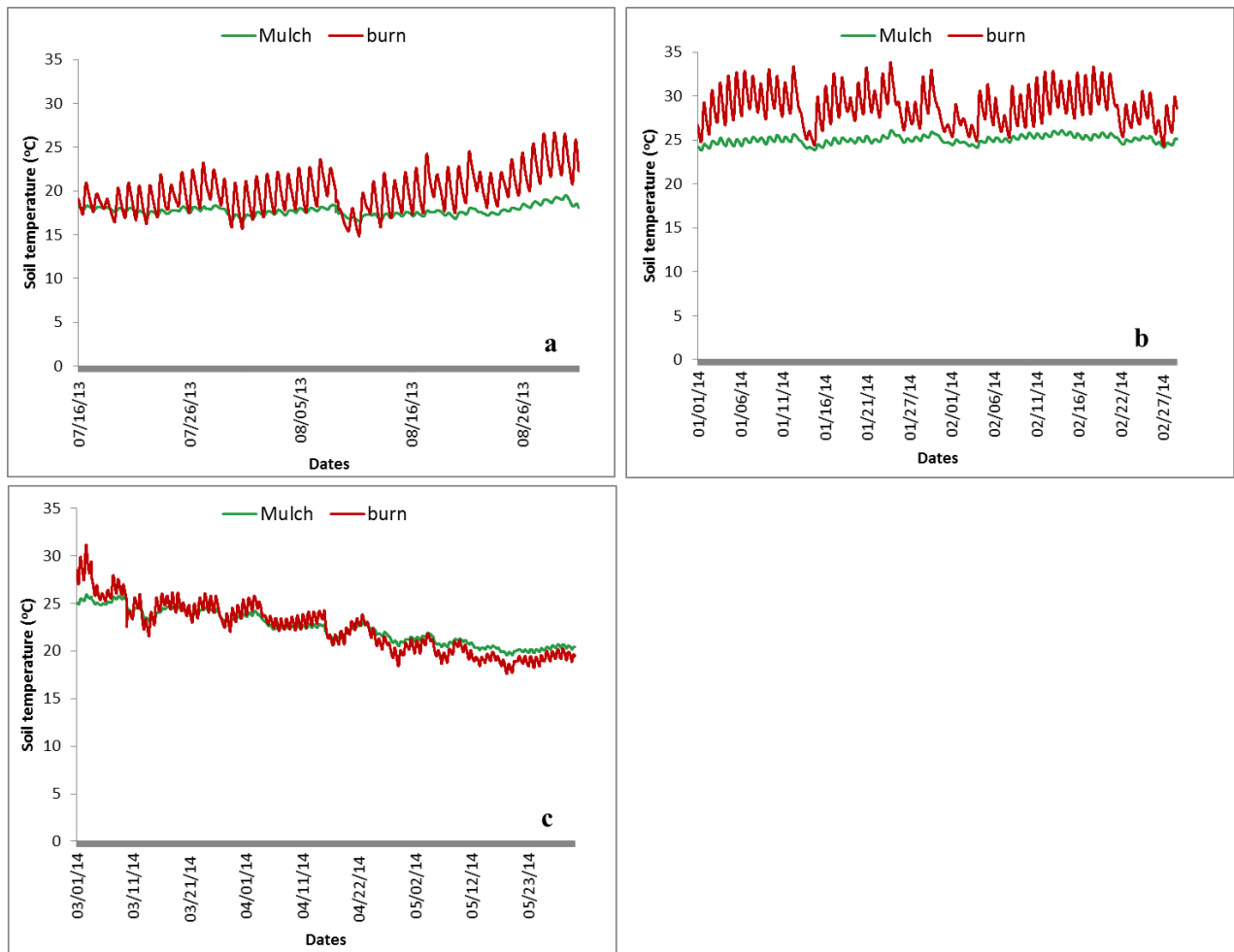


Figure 4.19 Soil temperature regimes under mulch and burn treatment on a fifth ratoon crop. Temperatures logged every 15 minutes at 15 cm depth during (a) early in the season, (b) mid-season and (c) late in the season.

4.3.6 Mulch production by cultivars

The estimated mulch production by different cultivars was different in each production season (Figure 4.18). The second ratoon (R2) had the highest mulch yields in general. Generally, the estimated mulch production decreased with each successive ratoon. Cultivar N47 was the highest mulch yielding cultivar, ranging from as high as 20 t ha⁻¹ in the second ratoon (sufficient water, no stress) to 10 t ha⁻¹ in the fifth ratoon (water stressed). N45 was the lowest mulch yielding cultivar (13 t ha⁻¹) in a high production year (R2), while NCo376 produced the lowest quantities of mulch in both the third and the fifth ratoon, with 7.6 t ha⁻¹ in both seasons.

The mulch yield/cane yield ratios per cultivar ranged from 30% for cultivar N47 to 23% for both cultivars N41 and N45 in the second ratoon. In the third ratoon the ratios ranged from 33% for N47 to 24% for cultivar N35. In the fifth ratoon the ratios ranged from 24% for both cultivars N49 and N39 to 20% for cultivar N47 (Data not presented). However, there were no strong correlations ($R^2= 0.486$) in the second ratoon. In the third and fifth ratoon there were positive and moderate correlations ($R^2= 0.78$ and $R^2= 0.65$ respectively) between mulch yield and cane yield.

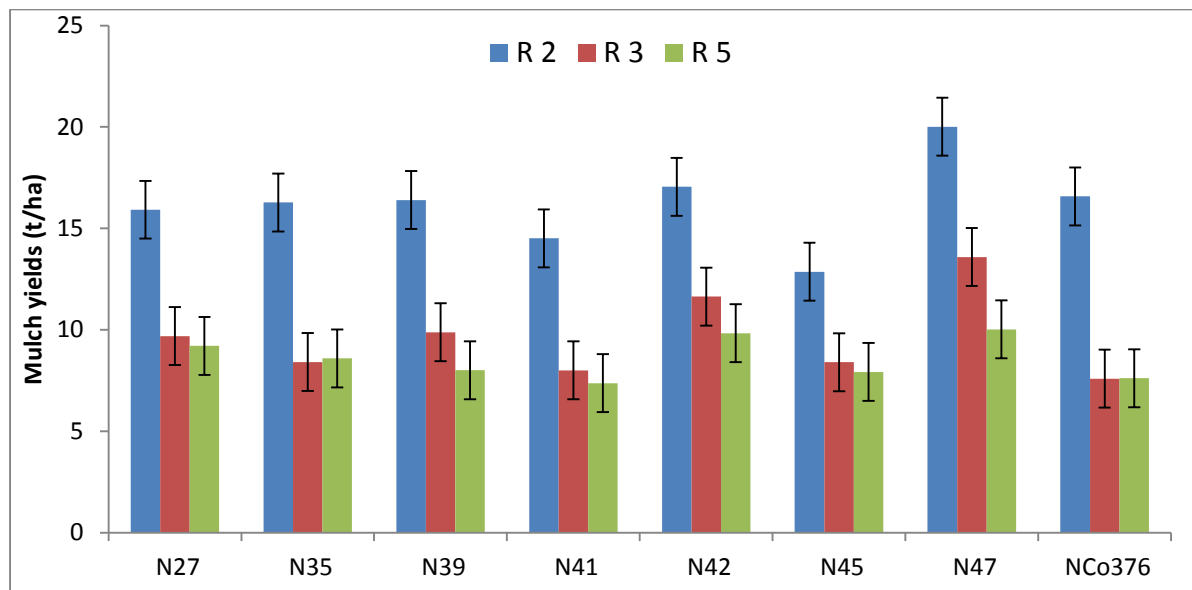


Figure 4.20 Mulch yield estimates of eight cultivars at Empangeni over a period of three ratoon crops.

Discussion

Mulching generally improved cane yields regardless of the ratooning season (summer crop and winter crop) (Figure 4.2). The cane yield improvements due to mulching were however variable from one crop to the next and between cultivars within the same cropping season. The differences in improvement were likely due to the difference in amount and seasonal distribution of rainfall from one crop to the next (Figure 4.1). From the rainfall data, it was clear that the second ratoon crop had above LTM rainfall in most of the critical sugarcane growing period and therefore did not suffer much water stress as compared to the other crops. This resulted in the second ratoon crop having the least improvements due to mulching. These results are in agreement with those reported by Van Antwerpen et al (2001), who found that the yield response to mulch treatment decreased with increase in rainfall from as much as 10 t

ha⁻¹ to less than 3 t ha⁻¹. De Beer et al. (1995) also reported that yield gains under mulched conditions can mostly be observed in exceptionally dry or low rainfall areas. Furthermore, Van Antwerpen et al. (2001) found 12% (9 t h⁻¹) improvements by mulching in the coastal regions in dry periods. Studies conducted with mulching have mostly associated cane yield improvements with its ability to retain soil water better as compared to bare conditions. In the current study, the mulch treatment maintained higher soil water content throughout the growing season for all four ratoon crops (Figure 4.16). The soil water differences between burn and mulch treatment was the driving force for cane yield improvements, especially in ratoons (crops) with below LTM rainfalls in critical times of the growing season. Thompson (1965) also reported that the potential conservation of water by mulching would be more beneficial under conditions of inadequate rainfall in South Africa. In contrast to the results obtained from this study, Viator and Wong (2011) conducted a study in a humid, temperate environment of Louisiana. In their study they found that cane yields were significantly reduced by mulching, presumably because the cultivars planted could not recover from the cool and wet climate prevalent during crop emergence and establishment.

Cane yield measures sugarcane mass per land unit. It is therefore a function of final stalk population (millable stalks/ha) and individual stalk mass (Orgeron 2000). The combined analysis of the three summer crops showed that stalk population was not significantly affected by the mulch treatments (results not presented). A study by Dingonzelli et al. (2011) also reported that there were no significant differences in stalk population between the burn and the mulch treatment of a 2006/2007 crop harvested in summer. Furthermore, Chapman et al. (2001) and Kingston (2002) also found no significant differences in final stalk population when comparing burn and mulch treatments.

When the winter ratoon crop (fifth ratoon) was added to the analysis of variance, the mulch treatment had a significant ($P=0.022$) effect on final stalk population (Table 4.1). This was further illustrated by Figure 4.5d, where stalk population for most of the cultivars was significantly improved by the mulch treatment. Digonzelli et al (2011) found significantly higher stalk population at harvest for sugarcane grown under mulch compared to burn conditions. The significantly higher stalk population at harvest for the mulch treatment at the fifth ratoon contributed to better improvements in cane yield as compared to the three summer crops. However, it is not final stalk population alone that determines the final yield improvements for a specific cultivar. As already mentioned, mean stalk mass is another important variable that drives the final cane yield. This means that cultivars with a lower final

stalk population can have yield compensations if their mean stalk mass was improved by mulching to a greater extent and the reverse is true for cultivars with low mean stalk mass. For instance in the first ratoon crop, Figure 4.5a shows that there was a 2% reduction in final stalk population for cultivar N41 and a 42% improvement in mean stalk mass due to mulching (Figure 4.8a), thereby having cane yield improvements of 28% compared to the burn treatment.

Mean stalk mass is further determined by components such as stalk height and stalk diameter. In this experiment stalk diameter was not measured. Mulch treatments significantly ($P < 0.001$) affected stalk heights. Figure 4.6 shows that mulching improved stalk height for some cultivars in most of the ratoons crops. Water stress soon after tillering has been reported to reduce stalk elongation, thus reducing final stalk height. The mulch treatment had higher water contents relative to the burn treatment throughout the growing season for all four ratoon crops (Figure 4.16). The higher soil water content in the mulch plots led to taller stalks at harvest, especially in the fifth ratoon (winter crop) (Figure 4.6d and 4.7). This was because in the fifth ratoon crop there was below LTM rainfall for five months (September to January) (Figure 4.1d), which was a period for stalk elongation in the winter crop. In contrast, stalk heights for most cultivars was not significantly affected by mulching in the second ratoon crop (Figure 4.6b); the reason being that the second ratoon crop received above LTM rainfall for most part of the growing season (Figure 4.1b), thereby eliminating the advantage of having a mulch blanket. The second and the third ratoon crops were the extremes of the study when it comes to the effect of rainfall amount and distribution. In the first and third ratoon crop, final stalk height was improved by mulching in most cultivars (Figure 4.6a and b) but to a lesser extent compared to the fifth ratoon crop.

Estimated recoverable crystals (ERC %) or sucrose percentage is one of the important components of the overall yield for a specific cultivar. The mulch treatment had a significant ($P = 0.017$) effect on ERC%, however not all cultivars reacted in a similar manner to the mulch treatments (Figure 4.3). The inherent characteristics of cultivars determine their response to mulching; furthermore Cardozo and Sentelhas (2013) reported that the ripening of sugarcane cultivars is significantly variable for early season cultivars. In the present study it was unclear how mulching affected the response of the cultivars. However, it was evident that mulching improved ERC% for cultivars N27, N35 and N47, regardless of the harvesting season even though in some ratoons crops the improvement was not significant (Figure 4.3).

TERC is a product of cane yield and ERC and is a key economic factor to consider when choosing a cultivar. It was apparent that cultivar N39 and N47 have higher economical returns when mulched and the least economic returns can be expected from N35, N41 and N42 (Figure 4.4). The higher TERC in the mulched treatment for both cultivar N47 and N39 were a result of improvement in both cane yield and ERC% of these cultivars. In the first ratoon crop N39 and N42 had significantly improved cane yields (Figure 4.2a) and both had reduced ERC% (Figure 4.3a), but had significantly improved TERC due to mulching (Figure 4.4a). Accordingly, in the fifth ratoon crop, cultivar NCo376 had significantly improved cane yields, but significantly reduced ERC% due to mulching, but the TERC was still significantly improved. However, in the third ratoon crop, the cane yield improvements for N45 was not significant, and although ERC% were numerically higher in the mulch treatment compared to the burn, this led to TERC that was not significantly improved. All of these prove that even though both cane yield and ERC% contribute to final TERC, a healthier crop, hence higher cane yield, contributes to a greater extent to improvements in TERC. Ahmed and Khaled (2008) also reported that cane yield is the most important component of sugar yield (TERC).

In order to understand fully the effects that the mulch treatments (burn and mulch) have on sugarcane cultivars, it was important to study their growth and development during the growing season. In this study the significant delay in emergence due to mulching that was observed for all cultivars in all four ratoons (Figure 4.9 - 4.12) was possibly due to lower soil temperatures under the mulch blanket. In the winter ratoon lower soil temperatures early in the season under mulch were indeed recorded (Figure 4.17a). The results of the present study are in line with those reported by Torres and Villegas (1995) and Morandini et al. (2005), who also found a reduction in stalk population where cane was mulched. In their study reduction was also attributed to lower soil temperature prevalent under the mulch blanket. Beater and Maud (1962) also reported that mulching has a retarding effect on initial crop growth and tillering. In contrast, Digonzelli et al. (2011) reported no significant differences in emergence between the burn and mulch treatment in a summer ratoon, and they attributed this to temperatures that were always above 20 °C throughout the growing season.

Generally, after peak stalk population and canopy closure, differences between burn and mulch treatment fade away (Chapman et al. 2001, Olivier and Singles 2012). This was in agreement with the findings in this study in the first ratoon crop (Figure 4.9). The similarities in stalk population between the treatments were also manifested in the final stalk population at harvest, although most cultivars had numerically higher stalk population in the mulch (Figure 4.5a).

Cultivar NCo376 in the second ratoon (Figure 4.10b) had significantly higher stalk population in the burn treatment throughout, possibly because soil water was not limiting in that growing season. The burn treatment for cultivar NCo376 intercepted higher incoming solar radiation throughout the period of measurements (Figure 4.13a), possibly as a result of better canopy development resulting from a higher stalk population. Zhou et al. (2003) reported that tiller population for cultivar NCo376 was more important than leaf size in PAR interception. On the other hand, the differences between the treatments regarding stalk population and stalk heights for the rest of the cultivars were not significant (Figure 4.10a). Hence, differences in fractional interception were also not significant (Figure 4.13b).

In contrast, the third ratoon was a relatively dry season with below LTM rainfall in most parts of the growing season (Figure 4.1). This resulted in higher competition for water which eventually reduced tillers more in the burn treatment for cultivar NCo376 (Figure 4.11b). However, the difference in stalk population between the burn and mulch treatment was not enough to significantly affect fractional interception in these cultivars (Figure 4.14).

In the winter crop (Figure 4.12) the differences in stalk population were not as pronounced as those of the three summer crops. However, the mulch treatment had much higher stalk elongation rate, hence higher leaf appearance which resulted in faster canopy formation and higher fractional interception compared with the burn treatment (Figure 4.15).

In the first, third, and fifth ratoon crop (Figure 4.9, 4.11, and 4.12 respectively) the stalks in the mulched treatment elongated faster than the burn treatment because of soil water differences between the treatments (Figure 4.16 a, c, d). Olivier and Singles (2012) also presented similar results; they also reported that stalk elongation was highly sensitive to water stress. On the other hand, the second ratoon did not experience much water stress, hence no significant differences in stalk height were observed (Figure 4.10).

Conclusions

Mulching generally improved cane yield of all cultivars across all four seasons along the coastal rainfed region. While stalk population was not affected by mulching in the summer ratoons, the mulch treatment had taller stalks which were attributed to improved stalk height. In addition to the preceding improved yield components, the winter crop also had higher stalk populations due to mulching and thus had larger improvements in cane yield due to mulching.

The improvements in cane yield differed from one cultivar to the next and with ratoons, with drier seasons having a higher cane yield improvement due to mulching. The improvements in cane yield were attributed to the higher soil water contents prevalent under the mulch blanket.

Although ERC% response to mulching was variable for cultivars and across seasons, TERC for all cultivars was significantly improved by mulching, regardless of the ratoon. Cultivar N47 had the highest improvement in TERC for the drier summer ratoons and cultivar N39 had the highest improvements in a wet summer ratoon and in a winter ratoon. Improvements in TERC were mostly due to improved cane yields rather than higher ERC%.

All cultivars had delayed emergence due to mulching, both in winter and summer ratoons. This delay in emergence and establishment was attributed to lower soil temperatures measured under the mulch blanket. In general, this retarding effect of the mulch blanket was compensated for during the season and as a result no significant differences in stalk population were observed towards the end of the growing season for most cultivars.

The amount of mulch produced was dependent on the cane yields produced in that season and varied with cultivars. High cane yielding seasons had higher mulch yields and vice versa. Moreover, the positive and moderate correlation coefficient between mulch and cane yield in the third and fifth ratoon indicate that the higher the production level (cane yield), the higher the mulch yields to be expected in the field. In the second ratoon the weak correlation between mulch and cane yield was probably due to experimental error caused by the large number of samples, since the production level (cane yield) was high. Cultivar N47 and N42 had greater mulch yields as compared to the other cultivars. The results show that mulching was beneficial for sugarcane production, regardless of the cultivar and ratooning season. This harvest method can thus be recommended for all current commercial cultivars along the coastal rainfed region of South Africa.

REFERENCES

- Ahmed AZ, Khaled KM. 2008. Detection of Genetic similarity of Sugarcane Genotypes Retrieved 05 24, 2009, from Gene Conserve -an electronic journal:http://www.geneconserve.pro.br/artigo_63.htm.
- Beater B, Moud R. 1962. The effect of trash on soil temperature in the sugar bealt of Natal. *Proceedings of the International Society of Sugar Cane Technologists* 11: 378-380.
- Cardozo NF, Sentelhas PC. 2013. Climatic effect of sugarcane ripening under the influence of cultivars and crop age. *Scientia Agricola* 70: 449-456.
- Chapman LS, Larsen PL, Jackson J. 2001. Trash concervation cane yield in the Mackay district. *Proceedings of the Australian Society Sugar Cane Technologist* 23: 176- 184.
- De Beer AG, Hudson C, Meyer E, Seigmund B. 1995. Green cane harvesting and trash management. *International Society Sugar Cane Technologists (ISSCT)*: 133 - 141.
- Digonzelli PA, Fernández de Ullivarri J, Romero E, Giardina J, Alonso L, Casen S, Tonatto J, Leggio Neme M, Scandaliaris J. 2009. Assessment of two sugarcane management systems: with or without post-green-cane-harvest residue retention. In: *Proceedings. ISSCT Agronomy Workshop*, 8, Uberlandia, Brasil. pp 27-28.
- Digonzelli PA, Romero ER, Alonso L, de Ullivarri FJ, Quinteros HR, Fajre S. 2011. Assessing a sustainable sugarcane production system in Tucumán, Argentina. Part 1: Dynamics of sugarcane harvest residue (trash) decomposition. *Revista Industrial y Agrícola de Tucumán* 88: 1-12.
- Kingston G. 2002. Recognising the in~pacot f climate on CCS of sugarcane across tropical and sub-tropical regions of ttle Australian sugar industry. *Proceedings of the Australian Society Sugar Cane Technologist* 24: 145-152.
- Morandini M, Figueroa R, Pérez Zamora F, Scandaliaris J. 2005. The effects of green cane trash blanket on soil temperature, soil moisture and sugarcane growth. In: *Proceedings of the ISSCT Congress*, 25, Guatemala, Guatemala. pp. 231-236.
- Olivier FC, Singels A. 2006. The effect of plant residue layers on water use and growth of irrigated sugarcane. *Proceedings of the South African Sugar Technologists' Association*. 80 178-181.

- Orgeron AJ. 2000. Planting rate effects on sugarcane yield trials. MSc thesis, B.S. Louisiana State University, Louisiana.
- Ramburan S, Sewpersad C, Mcelligott D. 2009. Effects of variety, harvest age and aldana on coastal sugarcane production in South Africa. *Proceedings of the South African Sugar Technologist Association* 82: 580-588.
- Thompson GD. 1965. The effects of trash conservation on soil moisture and the sugar cane crop in Natal. *Proceedings of the 39th Congress of South African Sugar Technologists' Association*. pp 143-156.
- Torres JS, Villegas F. 1995. Green cane management under heavy trash conditions. *Proceedings of the International Society of Sugar Cane Technologists*. 22: 142-148.
- Van Antwerpen R, Meyer JH, Thompson, G.D. 2006. The impact of trashing on yield response in the South African sugar industry: a summary of results from several BT trials. *Proceedings of the South African Sugar Technologist Association* 80: 130-135.
- Van Antwerpen R, Meyer JH, Turner PET. 2001. The effects of cane trash on yield and nutrition from the long-term field trial at Mount Edgecombe. *Proceedings of the South African Sugar Technologists' Association* 75:235-241.
- Viator HP, Wang JJ. 2011. Effects of residue management on yield after three production cycle of a long-term sugarcane field trial in Louisiana. *Journal American Society of Sugar Cane Technologists* 31: 15-25.
- Wynne AT, van Antwerpen R. 2004. Factors affecting the economics of trashing. *Proceedings of the South African Sugar Technologists' Association* 78: 207-214.
- Wynne AT, Murray TJ and Gabriel AB. 2009. Relative cane payment: realigning grower incentive to optimise sugar recovery. *Proceedings of the South African Sugar Technologists' Association* 82: 50-57.
- Zhou M, Singles A, Savage MJ. 2003. Physiological parameters for modelling differences in canopy development between sugarcane cultivars. *Proceedings of the South African Sugar Technologists' Association* 77: 610-621.

CHAPTER 5

GROWTH AND YIELD RESPONSES OF COMMERCIAL SUGARCANE CULTIVARS TO MULCHING IN THE NORTHERN IRRIGATED REGION

Abstract

Approximately 25% of sugarcane in South Africa is produced under irrigated conditions. Water is increasingly becoming a major limiting factor, particularly for irrigated crops, and water conserving practices such as mulching are generally recommended. Recently, there have been industry reports of reduced growth vigour, establishment, and yields of certain South African cultivars when using mulch blankets under irrigated conditions. However, no quantitative information exists on the reaction of popular commercial cultivars to mulching in the irrigated regions of the industry.

A field trial was established in 2008 at Pongola in the irrigated region. The trial comprised eight of the most popular cultivars in the irrigated region (N25, N32, N36, N40, N41, N43, N46 and N49). The trial was planted as a 2 x 8 factorial strip-plot with four replicates, with burning vs. mulching as the main plot (strips) and cultivar as sub-plots. Irrigation was scheduled according to the burnt treatment's crop water requirements. Cultivar responses to mulching were evaluated over a period of three summer crops (1st, 2nd, and 3rd ratoon) and one winter crop (5th ratoon). Cane yields (TCANE), estimated recoverable crystal (ERC) percentage, ERC yields (TERC), and mulch yields were determined at each harvest. The effects of mulching on stalk population dynamics, stalk height, soil temperatures, and soil water content were monitored during each growing season.

Cane and ERC yields were not significantly affected by mulching for most cultivars in all four ratoons. However, the mean cane yields for all cultivars in the first, third and fifth ratoon were slightly reduced. The reductions ranged from 2% in the first ratoon to 7% in the fifth winter ratoon. Mean ERC yields ranged from an improvement of 1% in the second ratoon to a reduction of 10% in the fifth ratoon. Cultivar N25 in the fifth ratoon was the only cultivar with a significant reduction in TERC (22%). The reductions in cane yields were attributed to the reduced stalk population, especially in the first and third ratoon. The pronounced reductions in cane and ERC yields in the fifth winter ratoon were as a result of the combined effect of lower soil temperature and higher soil water under the mulch blanket. Stalk heights and stalk mass were not significantly affected by the mulch treatments for all cultivars in all the ratoons. Stalk

heights, however, showed reduction for most of the cultivars in the winter ratoon. The response of stalk population during the growing season to the mulch treatments were similar to those reported in Chapter 4 (rainfed region). The lower stalk population in the mulched plots at the beginning of the growing season can be attributed to lower soil temperatures under the mulch blanket and possibly a physical barrier created by mulch. In the fifth winter ratoon this could have been amplified by a combination of lower soil temperatures and higher soil water content from irrigation under the mulch blanket for a longer period of time. Cultivar N40 had consistently higher mulch yield in all three the ratoons and N43 had highest mulch yields in the summer ratoons. These cultivars can be potentially used for energy co-generation. The results from this study show that the currently grown cultivars exhibit no added benefits from mulching if irrigation is not adjusted for mulched conditions. Thus a similar study is required to test these cultivars under burn and mulched conditions with reduced/adjusted levels of irrigation in the mulch treatments.

5.1 Introduction

South Africa is regarded as one of the most water limited countries in the world and the division of water resources is becoming more under scrutiny. In the year 2000 irrigated agriculture used about $7\,900 \times 10^6 \text{ m}^3$ of runoff which is around 61% of the total $12\,900 \times 10^6 \text{ m}^3$ runoff water used by all sectors during that year (DWAF 2004). With about 25% of South African sugarcane production occurring in the northern irrigated region, water efficient agronomic practices need to be implemented to ensure that water resources are being used as efficiently as possible.

Irrigation water use efficiency (IWUE) is a term commonly associated with water use efficiency (WUE), and can be defined as the cane yield response per unit of irrigation water applied (Olivier and Singels 2003). More efficient water-conserving agronomic practices such as mulching (defined in Chapter 4) are potential means to increase the efficiency at which sugarcane uses water. Many researchers have supported mulching as a means to increase the effectiveness of irrigation by reducing evaporative losses of water (Olivier and Singels 2006). Nunez and Spaans (2007) reported a reduction in daily evapotranspiration rates of up to 39% under a mulch blanket, thus resulting in reduced irrigation frequency. Furthermore, Murombo et al. (1997) reported irrigation water saving of 288 mm with mulching. This was later confirmed by Morandini et al. (2005). They reported that burnt cane had higher water requirements, whereas mulching reduced the irrigation by two cycles.

Despite these reports, the northern irrigated region of South Africa stands at the industry extreme, where almost 100% of the cane fields are burnt (Van Antwerpen et al. 2006). Some of the reasons for the lack of uptake of this practice have been mentioned in Chapter 4. Furthermore, the yield advantages of mulching when there is ample supply of water have been reported to be much less than those obtained in the rainfed regions under conditions of low rainfall (Van Antwerpen et al. 2001). In an experiment conducted in Zimbabwe, Gosnell and Lonsdale (1977) reported that at unadjusted levels of irrigation, burn treatments had greater cane and sugar yields, as well as stalk population compared to the mulched treatments. This was later confirmed by Olivier and Singles (2006) who found that a mulch treatment reduced cane yields by 15% compared to the burnt treatment in an experiment in South Africa.

Generally, the duration of the harvesting season in South Africa is about 38 weeks, in which the mills operate from April until December (Jenkins 2013). The optimal harvest age varies between different regions of the industry due to different growing conditions. The average harvesting age in the northern irrigated region is 12 months and the average expected yields within that period is approximately 100 t ha⁻¹ (Meyer 2005) as opposed to an average of 60 t ha⁻¹ achieved in the coastal rainfed regions. The continuous supply of irrigation water and the type of cultivars grown are amongst the important factors that contributes to higher cane yields in the northern irrigated parts of South Africa.

The final expression of yield (cane and sugar) is the result of interactions between the genetic makeup of the cultivar, cultural practice, and environmental factors (Ahmed et al. 2008). Sugarcane cultivars differ considerably in their agronomic characteristics and their reactions to management practices. Differences in cultivar physiology and phenology will determine how they respond to the agronomic and management practices i.e. mulching under irrigated conditions. The South African sugarcane industry has a wide range of cultivars that are bred for specific production regions. Currently, the northern irrigated region has about 19 cultivars that are permitted for planting. Of these commercial cultivars, only a few currently contribute significantly to sugar production in the region. Recently, there have been industry reports of reduced growth vigour, establishment, and yields of some cultivars through mulch blankets. This is often seen as a limitation to the uptake of mulching as a best management practice. However, little quantitative information exists on the reaction of popular commercial cultivars to mulching in the irrigated regions of the industry. An understanding of the reaction of cultivars to mulching will allow for cultivar-specific recommendations and/or adjustments of current agronomic practices to maximise yields with mulching.

Therefore, the objectives of this study were to: (a) quantify effects of mulch vs. burnt conditions on yield components of common commercial cultivars in the northern irrigated region of South Africa, (b) compare these cultivars under mulch vs. burnt conditions with respect to their growth, establishment, and population dynamics, (c) monitor the influence of mulching on factors such as soil temperature and radiation interception in order to explain yield responses, and (d) quantify the amount of mulch material produced by the different commercial cultivars.

5.2 Materials and methods

A field experiment was established in October 2008 on a SASRI research farm located at Pongola in the northern part of KwaZulu-Natal (27°24'0''S 31°35'0''E). The trial consisted of eight sugarcane cultivars which are commonly grown in the northern irrigated regions (Pongola and Mpumalanga). The details of cultivars, crops harvested, trial design and plot dimensions, and treatment application are detailed in Chapter 3. For brevity, some key aspects and variations in the methodology are mentioned below.

Weather data were collected during each growing season (ratoon) from an automatic weather station (AWS) situated at the experimental site. The weather variables collected were rainfall (mm) and air temperature (°C). The long term mean (LTM) monthly rainfall was also calculated to characterise the growing seasons in terms of rainfall. A drip irrigation system with in-line spacing of 0.60 m was used to irrigate all four crops. Both treatments (burnt and mulch) were irrigated according to the burnt treatment's water requirement to simulate the practical situation of local farmers who do not adjust irrigation to suit mulched conditions.

Growth measurements during the season were only taken in the first, second and fifth ratoon at two week intervals from 2 x 2 m sections which were randomly assigned to net rows prior to emergence. Tiller counts (stalk population) were determined from the average of counts done within the 2 m sections, whereas stalk height was measured from 10 randomly selected plants. The final stalk population was determined by counting all of the millable cane from two of the three net rows at harvest. Stalk population was subsequently expressed as the number of stalks per hectare. The amount of intercepted incoming solar radiation was also measured at a two-weekly interval on cloudless days, using a ceptometer (LP-80 AccuPAR- Decagon Devices).

At each harvest of the four ratoons, sucrose samples were taken by cutting 16 stalks from the net rows. The samples were then sent to the SASRI mill room in Pongola to determine the estimated recoverable crystal percent (ERC %). Cane yield in tons cane/ha (TCANE) was

measured by hand-cutting and weighing the net plots with a mechanical grab apparatus fitted with a calibrated load cell. Tons ERC/ha (TERC) was calculated as a product of TCANE and ERC.

In the third and fifth ratoon, from each of the 12 stalks used for sucrose sampling, the components of mulch which included green leaves and dead brown leaves were separated into brown paper bags. These components were dried at 75 °C for approximately 72 hours. The samples were then weighed to calculate the total mulch yield (tons/ha) for each cultivar on a dry mass basis. However, in the second ratoon, soon after the cane was mulched and spread evenly onto the plots, the quantity of mulch was measured by clipping 0.5 m² quadrants randomly placed on the plots. Within the quadrants, mulch material was separated into different components (green leaves, dead leaves and dead stalks) which were then dried in brown paper bags and weighed, as was done in the third and fifth ratoon.

Soil water content was measured using soil moisture sensors (Decagon Devices 10HS). The sensors were installed at 20-25 cm depths in selected burnt and mulched treatments. The readings were taken at two week intervals from selected burn and mulch plots. The actual TAM (Total Available Water) of the soil was not determined, the focus of the study was on the relative water contents of the burnt vs mulch treatments.

Hobo data loggers were used to monitor soil temperature. The loggers were also installed in the fifth crop. The devices were set to log temperatures every 15 minutes and were installed at a depth of 15-20 cm in selected mulched and burnt plots of the same cultivars.

All parameters measured at each harvest were subjected to a combined analysis of variance (ANOVA) to establish main (cultivar, mulch, and ratoon) and interaction effects. Comparison of means was performed using Duncan's LSD test at 5% significance difference and statistical analyses were done using GenStat Statistical Package version 14.

5.3 Results

5.3.1 Seasonal characteristics

Irrigation in this experiment was scheduled such that the amount of irrigation water applied varied within months in each cropping season, however, the same amount of irrigation water

was applied to each individual month across the seasons. All plots were irrigated according to the burnt treatment's crop water requirements. This means that any seasonal differences in the total water received by the crop was due to irrigation as indicated in Table 5.1. The total amount of water (irrigation +rainfall) is shown in Figure 5.1.

Table 5.1. The amount of irrigation water applied per month

Months	Amount of irrigation water applied (mm)			
	1 st ratoon	2 nd ratoon	3 rd ratoon	5 th ratoon
October	68	68	68	68
November	102	102	102	102
December	0	0	0	0
January	204	204	204	204
February	136	136	136	136
March	0	0	0	0
April	102	102	102	102
May	68	68	68	68
June	68	68	68	68
July	60	60	60	60
August	0	0	0	0
September	34	34	34	34

The rainfall amount and distribution differed from one ratoon to the next. However, the distribution of rainfall within the season seemed to have played a bigger role. The first ratoon (Figure 5.1a) received the highest rainfall of 914 mm, which was higher than the long term mean (LTM) rainfall (812 mm), thereby characterising a high rainfall season. The highest rainfall of 249 mm was received in January. However the winter period (between April and August) only received 40 mm out of the total seasonal rainfall. In the second ratoon (Figure 5.1b) the total seasonal rainfall was 773 mm, which was less than the rainfall LTM and is

therefore characterised as a low rainfall season. The highest rainfall (155 mm) was received at the beginning of the growing season (October). However, the winter period received 111 mm of the total rainfall within the season. The third ratoon (Figure 5.1c) received average to low rainfall during most parts of the growing season. Even though the total rainfall (879 mm) received during the growing season was higher than LTM rainfall, it was characterised as an average to low rainfall season. The last two months (September and October) contributed a larger portion of the total rainfall (365 mm), while the period between April and August only contributed 17 mm to the total seasonal rainfall. The fifth winter ratoon (Figure 5.1d) was characterised as an average rainfall season, with the total rainfall of 713 mm (LTM of 729 mm) received throughout the season.

The average air temperature was similar for all four ratoons. The average maximum temperature was 28 °C and average minimum temperature was 15 °C for all four ratoons. In the first, second, third and fifth ratoon the highest temperatures were experienced in December (30°C), March (33°C), January (32°C) and February (33°C) respectively. All four ratoons experienced lowest temperatures in June (9 °C).

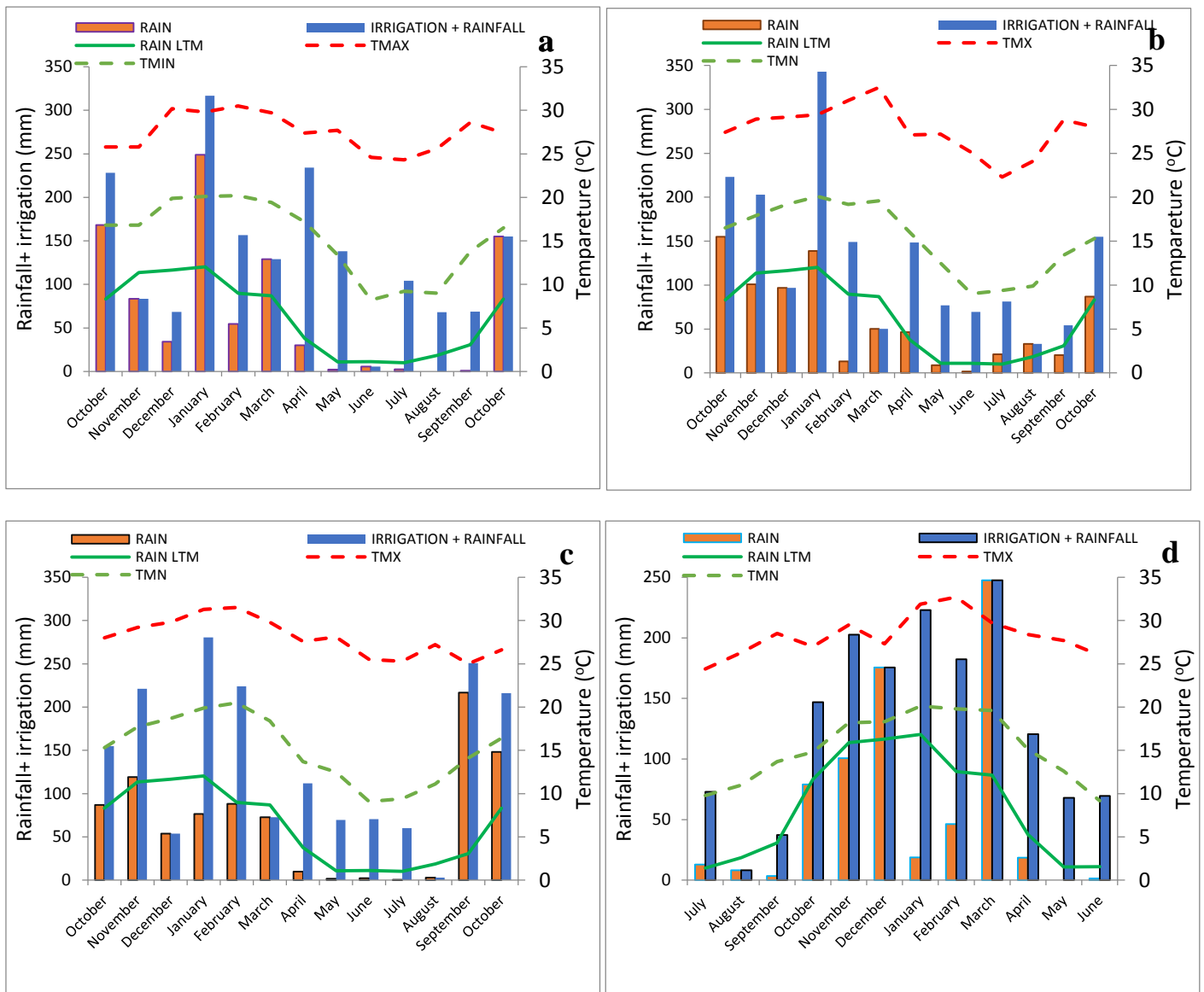


Figure 5.21 Monthly mean rainfall (bars), irrigation + rainfall (total water for the month), rainfall long term mean (LTM) (solid line) on the primary axis and air temperature (dotted lines) on the secondary axis, taken from an automatic weather station for the first (a), second (b), third (c), and fifth (d) ratoon crops at Pongola. (The x-axis are synchronised with the harvesting months)

5.3.2 Yield and yield components

The combined analysis of variance showed that both the ratoon (R) and cultivar (C) main effects were significant ($p < 0.001$) for all of the yield components. However, the mulch (M) main effect was not significant for most of the yield components (with exceptions for stalk

population and stalk heights). This meant that out of all the yield components, only stalk population and heights responded ($p < 0.05$) to the mulch treatments. The R x M, C x M and R x M x C interactions were not significant for most of the yield components, except for stalk population. This non-significant R x M interaction meant that the ranking between the mulch treatments was the same with each ratoon. The non-significant C x M and R x M x C interactions meant that the effect that mulching had on cultivar performance with regards to most of the yield components did not change with each ratoon. The R x C interaction was significant ($p < 0.05$) for cane yield, stalk population and stalk heights. This meant that the ranking of cultivars changed from one ratoon to the next.

Table 5.5 P values from a combined analysis of variance (ANOVA) for all yield components across four ratoons for eight cultivars under burnt and mulched treatments at Pongola.

Source of variation	df	Cane yield (t/ha)	ERC%	TERC (t/ha)	Stalk population (h^{-1})	Stalk heights (cm)	Stalk mass (g)
Ratoon (R)	3	<.001	<.001	<.001	<.001	<.001	<.001
Mulch (M)	1	0.459	0.654	0.547	0.023	0.018	0.101
Cultivar (C)	7	<.001	<.001	0.003	<.001	<.001	<.001
R x M	3	0.057	0.44	0.073	<.001	0.16	0.492
R x C	21	0.046	0.425	0.141	<.001	0.001	0.128
C x M	7	0.754	0.461	0.411	0.026	0.697	0.744
R x M x C	21	0.686	0.376	0.965	0.843	0.572	0.774

In general, there were no significant differences in cane yield between the burn and mulch treatments for all cultivars in all four ratoon crops (Figure 5.2). In the first ratoon (Figure 5.2a), cultivars N49, N25, N32 and N36 had a tendency of reduced cane yield due to mulching whereas mulching improved cane yields for cultivars N40, N41 and N43. The mean response across all cultivars was a 2% reduction in cane yield due to mulching. In the second ratoon (Figure 5.2b), there were no significant differences between the treatments. Cultivar N36, however, had the highest improvement in cane yield of about 16% due to mulching. On average, mulching improved cane yield by 2% over the burn treatment. Cane yield in the third

ratoon (Figure 5.2c) was generally reduced by mulching for most cultivars with exceptions of N40 and N49, which showed slight improvements in cane yield when mulched. The mean reduction in cane yield was 4% across all cultivars. In the fifth ratoon (Figure 5.2d), mulching reduced cane yield for most of the cultivars with the exception of cultivar N36. The reduction in cane yield was greater in the winter ratoon as compared to the three summer ratoons. The highest reduction in cane yield of 13% was observed for cultivar N43. The mean response across all cultivars was 7% reduction due to mulching, which was higher than that observed for the summer ratoons.

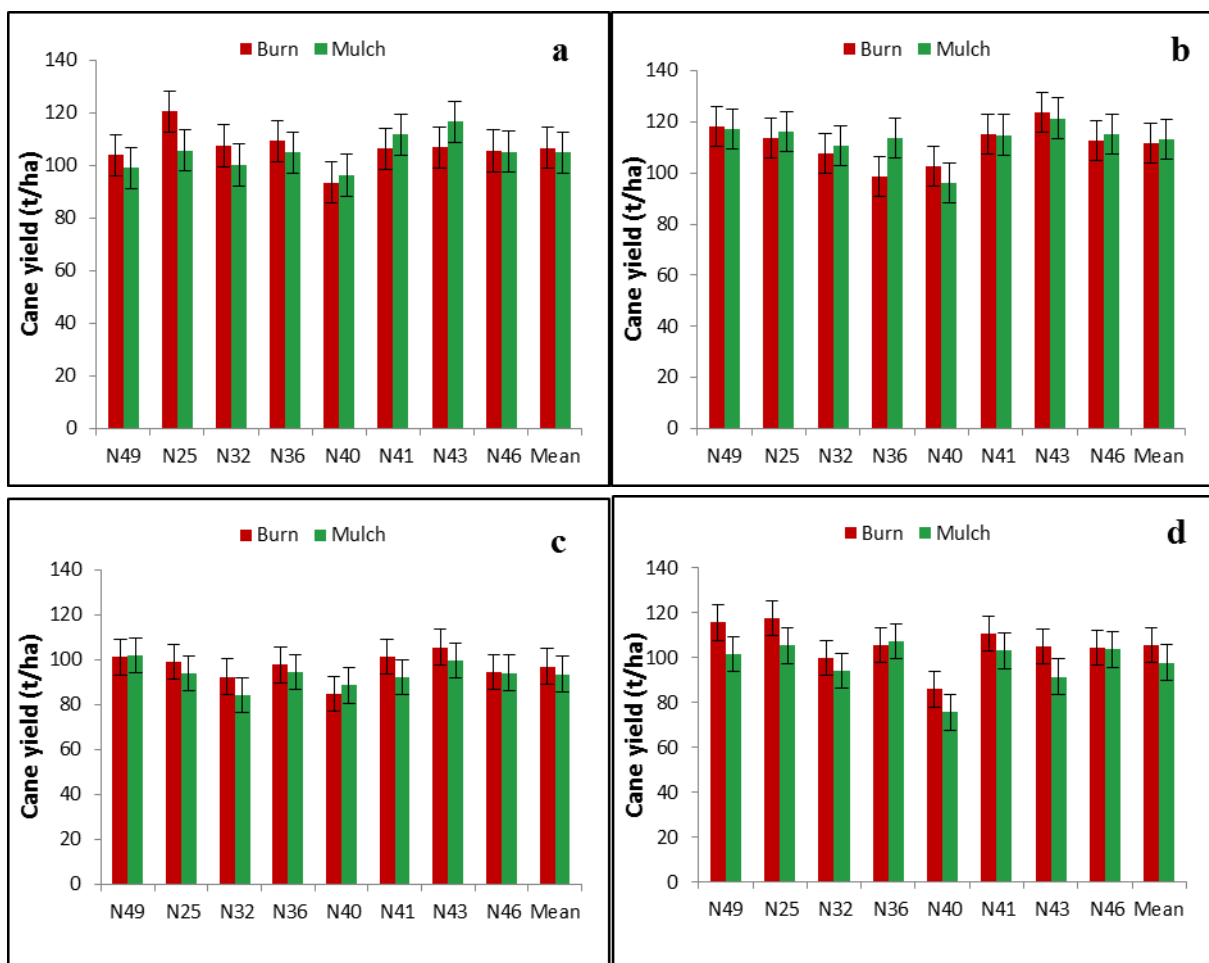


Figure 5.22 Cane yields for eight different cultivars (and their mean) under burn and mulch treatments in the first (a), second (b) third (c) and fifth (d) ratoon crops at Pongola. Vertical bars represent least significant differences ($p < 0.05$).

There were generally no significant differences in ERC% between the burn and the mulch treatment for all cultivars in all four ratoon crops (Figure 5.3). In the first ratoon (Figure 5.3a), mulching reduced ERC% of cultivars N25, N36 and N41 while the rest of the cultivars had

slight improvements in ERC% due to mulching. In the second ratoon there were also minor differences between the burn and mulch treatment, all of which were not significant. Cultivar N40 had the highest improvement of about 6% and cultivar N25 had the greatest reduction of about 6% ERC due to mulching (Figure 5.3b). In the third ratoon, most cultivars had lower ERC% with mulching. Only cultivars N49, N32 and N43 had improved ERC% due to mulching. The improvements due to mulching ranged from 8% for cultivar N43 to a significant reduction of 11% for cultivar N40 (Figure 5.3c). Similarly, in the fifth ratoon, most cultivars had reduced ERC% due to mulching. Only cultivars N40 and N46 showed improvements with mulching of 6 and 4%, respectively. The ERC% for cultivar N25 was 13% lower as compared to its burnt counterpart (Figure 5.3d).

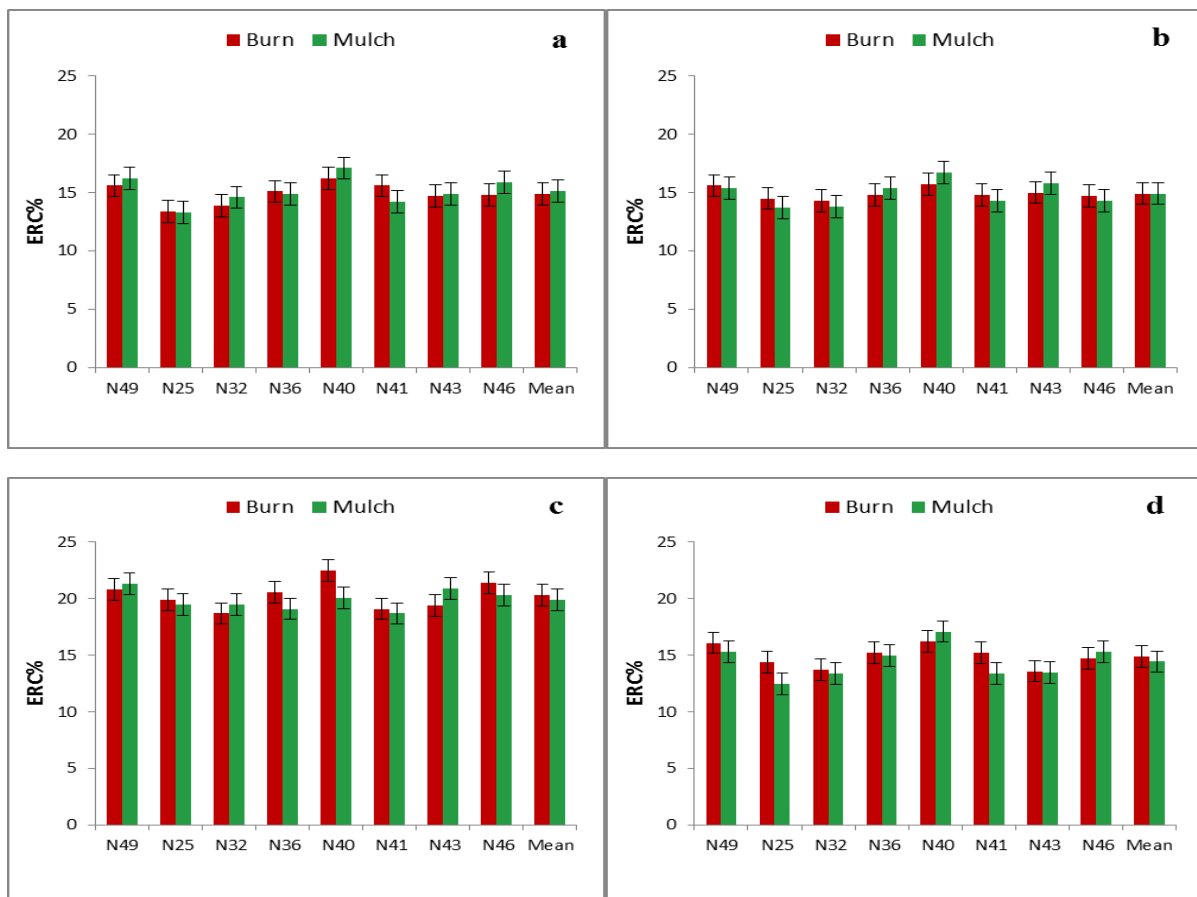


Figure 5.23 ERC for eight different cultivars (and their mean) under burn and mulch treatments in the first (a), second (b) third (c) and fifth (d) ratoon crops at Pongola. Vertical bars represent least significant differences ($p < 0.05$).

The responses of TERC were similar to the responses of cane yield. In general, mulching reduced TERC for most of the cultivars in all four ratoons but there were no significant differences in TERC between the burn and the mulch treatment (Figure 5.4). In the first ratoon,

most cultivars had slightly reduced TERC due to the mulch treatment, with exception of cultivars N40, N43 and N46. Cultivar N25 had the highest reduction in TERC of 13% due to mulching. There were no differences between burn and mulch when all cultivars were averaged (Figure 5.4a). Similarly in the second ratoon, mulching had no effects on the TERC of most cultivars. Only cultivar N36 showed a substantial (20%) increase in TERC with mulching. Overall mulching gave a mean increase of 1% in TERC over the burn treatment (Figure 5.4b). In the third ratoon, cultivar N41 had the largest reduction of 12% due to mulching. However, the mean reduction in TERC was 3% due to mulching (Figure 5.4c). In the fifth winter ratoon the reductions in TERC were more pronounced as compared to the three summer ratoons (Figure 5.4d). Cultivar N25 had the largest reduction in TERC of about 22%. The mean reduction in TERC was 10% due to mulching. Even though no significant differences were recorded between the treatments, most cultivars in all four ratoons showed a reduction in TERC with mulching.

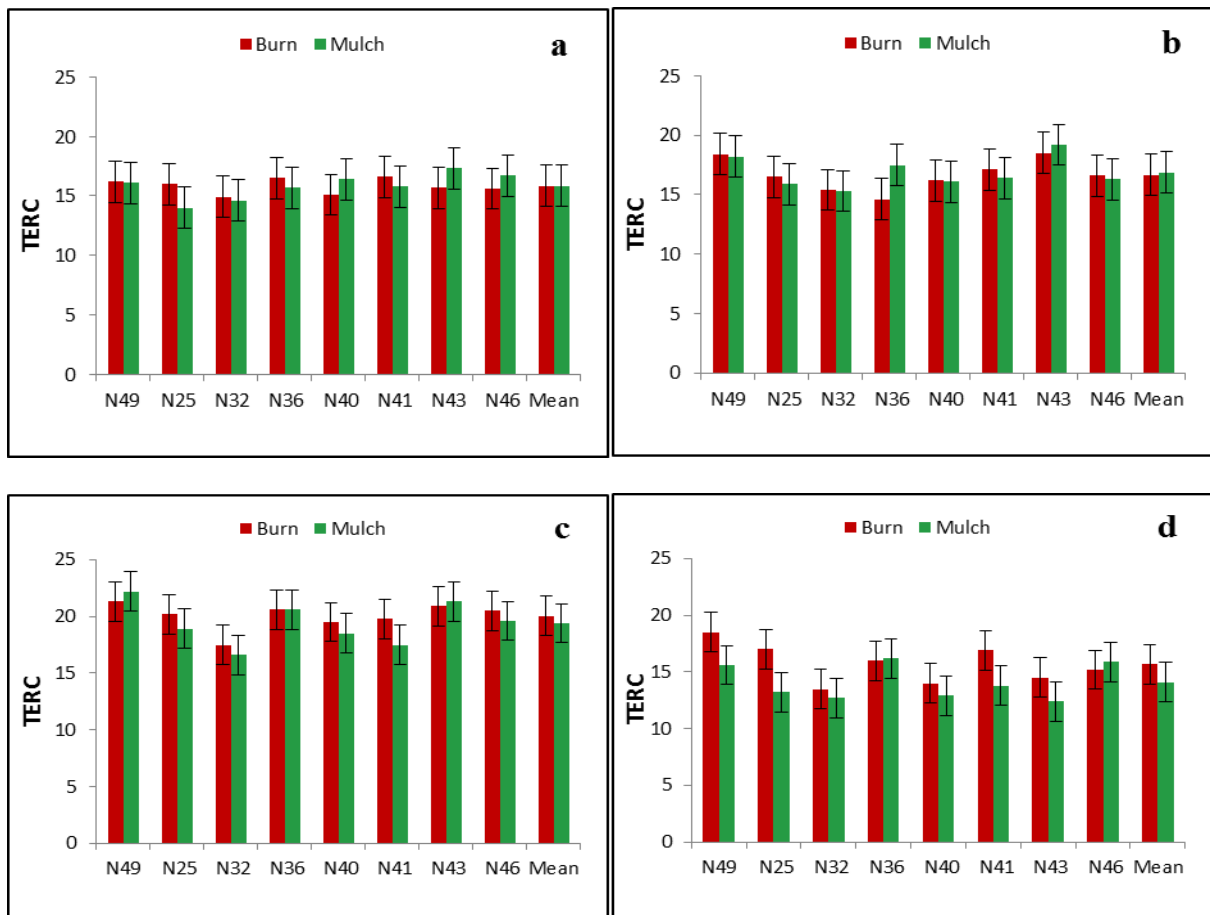


Figure 5.24 Tons ERC (TERC) for eight different cultivars (and their mean) under burn and mulch treatments in the first (a), second (b) third (c) and fifth (d) ratoon crops at Pongola. Vertical bars represent least significant differences ($p < 0.05$).

Stalk population was generally reduced by mulching for most cultivars in all four ratoon crops (Figure 5.5). In the first ratoon most cultivars had reduced stalk population due to mulching (Figure 5.5a). The only exception was cultivar N40, which showed a slight improvement due to mulching. However, significant reductions in stalk population were only found for cultivars N25, N32, N41 and N43. Similarly in the second ratoon, most cultivars had reduced stalk population due to mulching but the reduction in stalk population was only significant for cultivars N32 and N41 (Figure 5.5b). Mulching significantly reduced stalk population for all cultivars in the third ratoon; cultivars N25 and N43 had the largest reduction of about 30% (Figure 5.5c). In the fifth winter ratoon the differences between the burn and mulch treatment were not significant for all cultivars (Figure 5.5d).

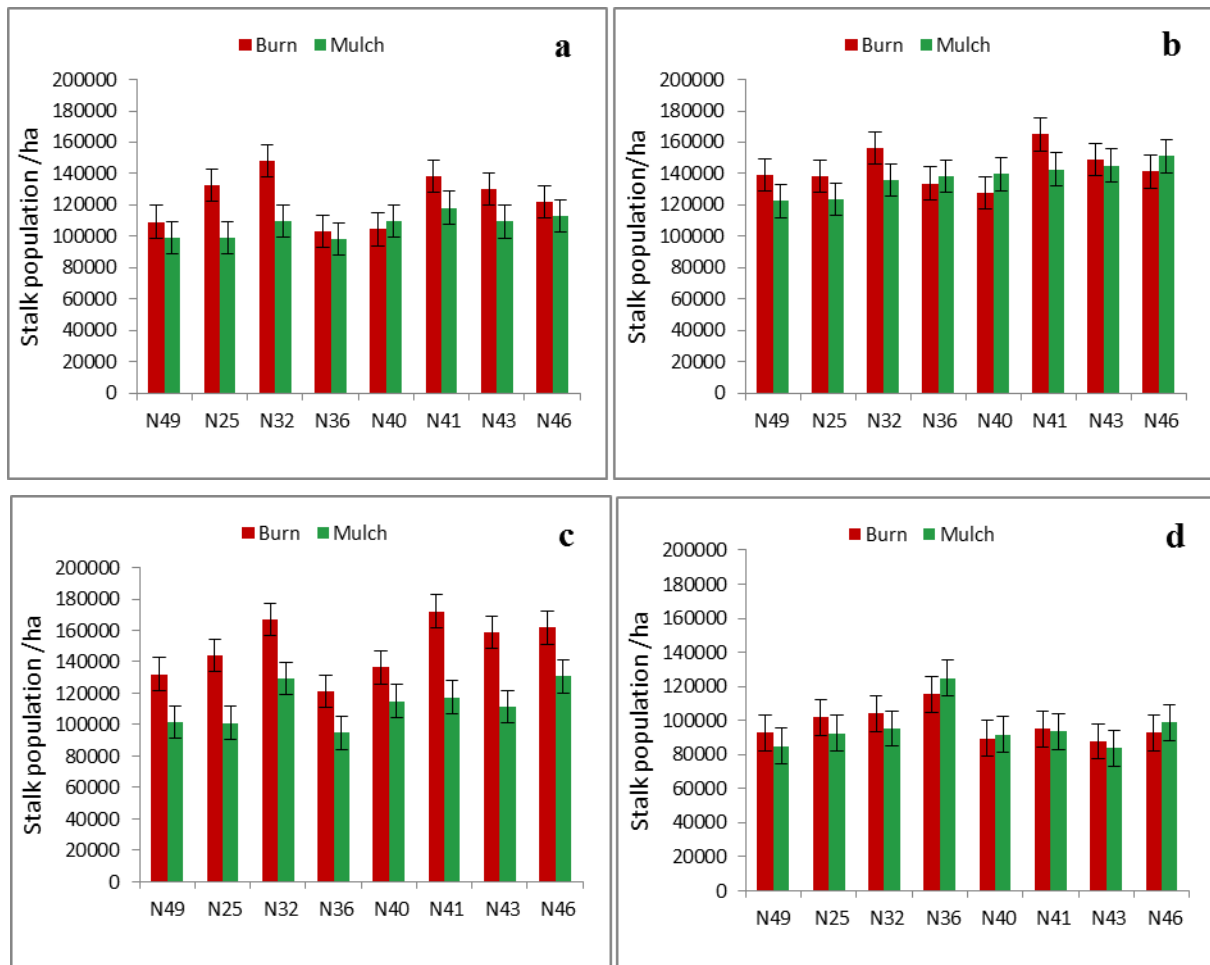


Figure 5.25 Final stalk populations for eight different cultivars under burn and mulch treatments in the first (a), second (b), third (c), and fifth (d) ratoon crops at Pongola. Vertical bars represent least significant differences ($p < 0.05$).

Stalk height was not significantly affected by the mulch treatments in general (Figure 5.6). The exception was cultivar N49 in the fifth winter ratoon, where it had a significant reduction in stalk heights due to mulching (Figure 5.6d). On the other hand, individual stalk mass was improved by mulching for most of the cultivars in all the ratoons but the improvements were mostly not significant (Figure 5.7). In the first and fifth ratoon crop however, only cultivars N49 and N25 respectively had significantly improved individual stalk mass (Figure 5.7a and d). In the second and third ratoon no significant improvements were observed (Figure 5.7b and c).

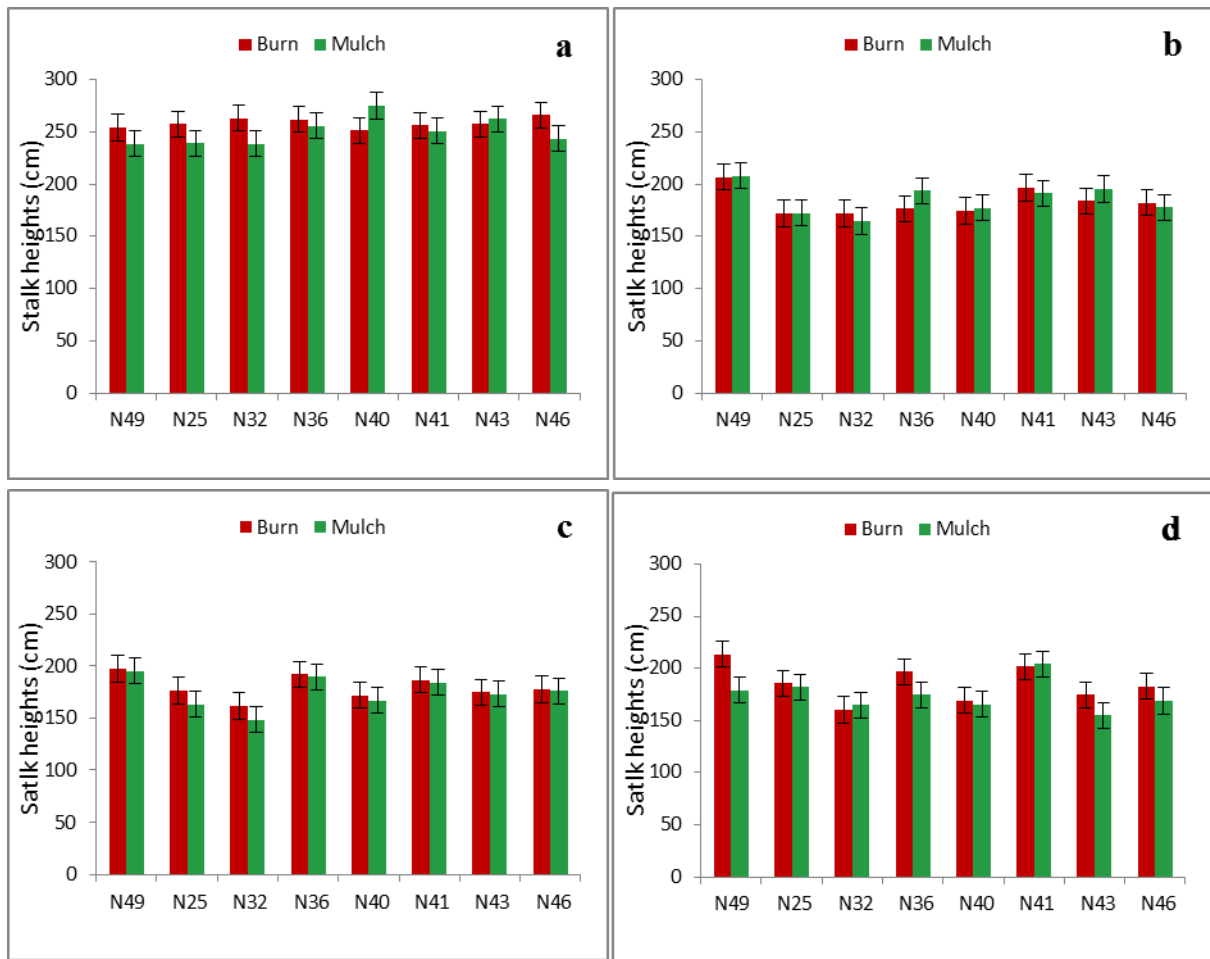


Figure 5.26 Final stalk heights for eight different cultivars under burn and mulch treatments in the first (a), second (b) third (c) and fifth (d) ratoon crops at Pongola. Vertical bars represent least significant differences ($p < 0.05$).

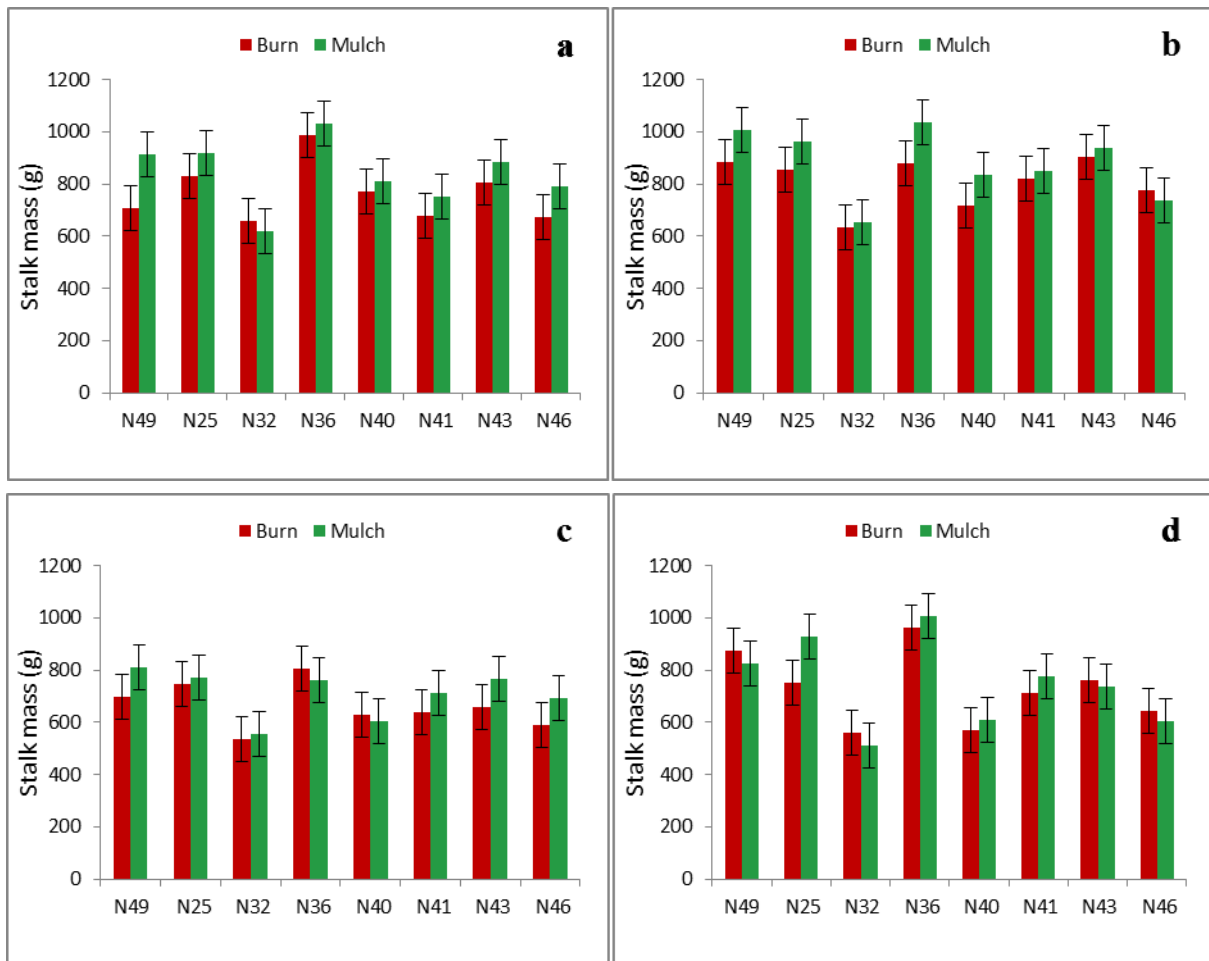


Figure 5.27 Stalk mass for eight different cultivars under burn and mulch treatments in the first (a), second (b), third (c) and fifth (d) ratoon crops at Pongola. Vertical bars represent least significant differences ($p < 0.05$).

5.3.3 Effects of mulching on canopy development

The growth patterns were similar for most cultivars in all the ratoons when stalk population and stalk heights for each cultivar x mulch treatment was plotted as a function of days after ratooning. Consequently, the means across all eight cultivars were plotted and will be discussed here (Figures 5.8- 5.10). In the first ratoon (Figure 5.8), the burn treatment generally had a consistently higher stalk population compared to the mulch treatment from emergence up until the end of the growing season. At emergence the differences between the treatments were significantly large, but these differences were reduced towards the end of the growing season. No significant differences in stalk heights were observed at any point during the growing season. However, the burn treatment had consistently taller stalks than the mulch treatment.

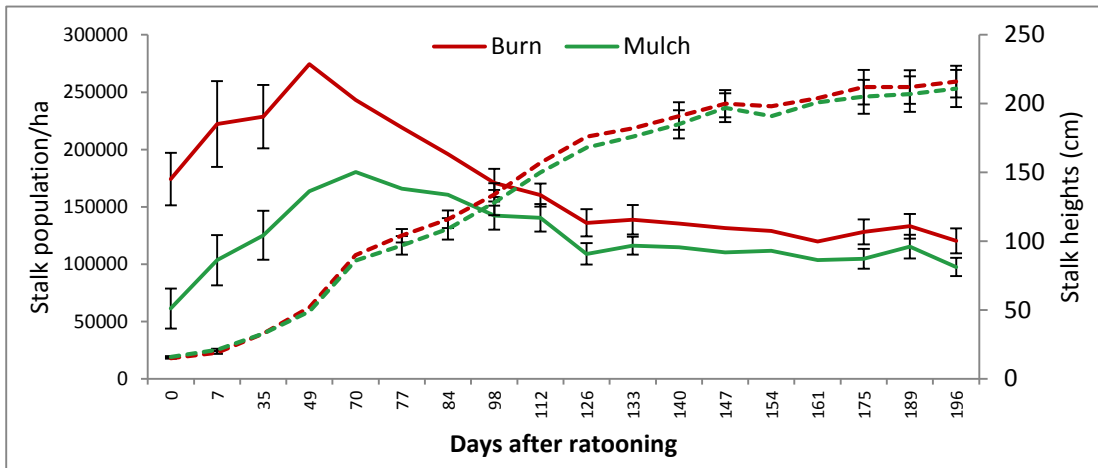


Figure 5.28 Stalk populations (on the primary axis; solid lines) and stalk heights (on the secondary axis; square dots) for the mean of all cultivars at Pongola as affected by burn and mulch treatments, plotted as a function of days after ratooning in the first ratoon. The sampling error is indicated by error bars at selected points.

There were no significant differences in stalk population between the two treatments at any point during the growing season in the second ratoon (Figure 5.9). However, at emergence, a considerably higher stalk population was observed in the burn treatment compared to the mulch treatment. Stalk heights for both burn and mulch treatment were similar throughout the growing season (Figure 5.9).

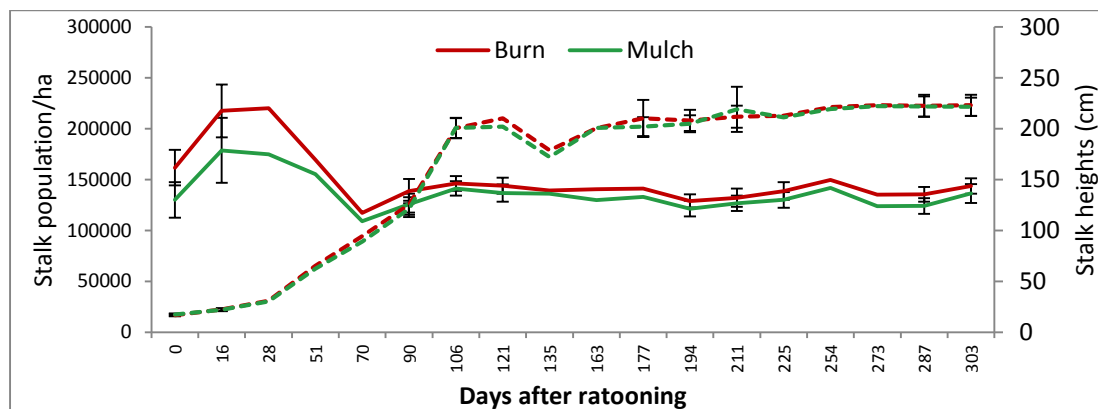


Figure 5.29 Stalk populations at the primary axis (solid) and stalk heights at the secondary axis (square dots) for the mean of all cultivars at Pongola as affected by burn and mulch treatments plotted as a function of dates after ratooning at the second ratoon. The sampling error is indicated by error bars at selected points.

In the fifth ratoon (Figure 5.10), the mulched treatment significantly reduced the initial stalk population. The largest differences between the burn and mulch treatments were observed at the beginning of the growing season and persisted longer than those in the summer ratoons. These differences eventually declined as the season progressed. At the end of the growing season no significant differences in stalk population were detected between the treatments, however, the burnt treatment had a tendency of higher stalk population. At the beginning of the growing season stalk heights for the burn and mulched treatments were very similar. However, after about 111 days after ratooning, cane stalks under the burn treatment tended to elongate faster than those under the mulch treatment, but the differences never reached significance.

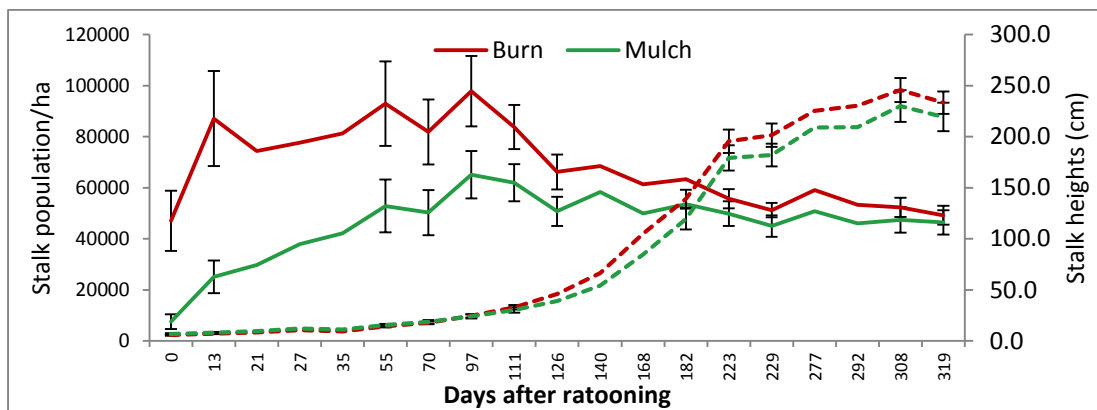


Figure 5.30 Stalk populations at the primary axis (solid) and stalk heights at the secondary axis (square dots) for the mean of all cultivars at Pongola as affected by burn and mulch treatments plotted as a function of dates after ratooning at the fifth ratoon. The sampling error is indicated by error bars at selected points.

Fractional interception of radiation in the second and third ratoon was measured from 28 to 106 and 0 to 199 days after ratooning, respectively. The mean of all cultivars are presented since all cultivars reacted in a similar way to mulching in both ratoons. In the second ratoon, the mulch treatment showed reduced radiation interception in relation to the burn treatment but the reduction was not significant at any point during the period of measurements (Figure 5.11). In the fifth ratoon, the radiation interception was similar for both treatments from the beginning of the measurements until 77 days after ratooning. Thereafter, the mulch treatment significantly reduced fractional interception from 168 days until the end of the measurements (Figure 5.12).

In general, the results suggest that mulching had a delaying effect on canopy development for all measured variables. Stalk population, especially at the beginning of the growing season,

was most affected. The retarding effect of the mulch blanket seemed to be more pronounced in the winter ratoon as compared to the summer ratoons.

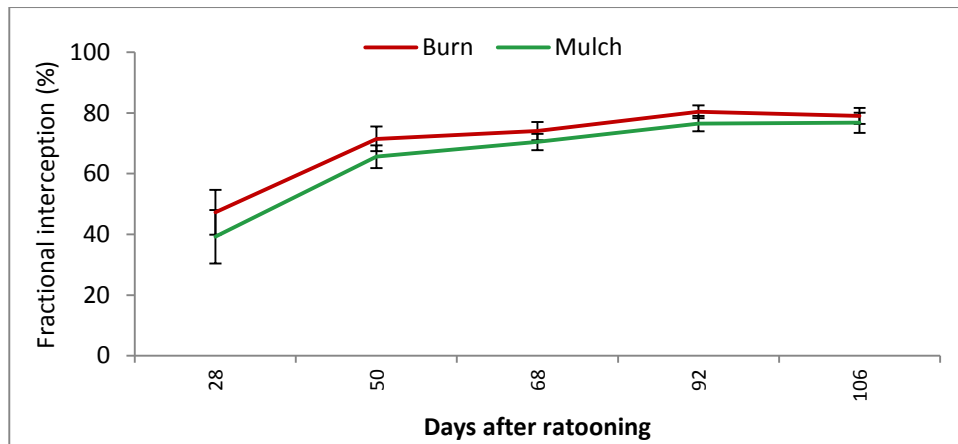


Figure 5.31 Fraction of intercepted photosynthetically active radiation (FiPAR) as affected by burn and mulch treatment at the second ratoon for mean of all cultivars as a function of days after ratooning.

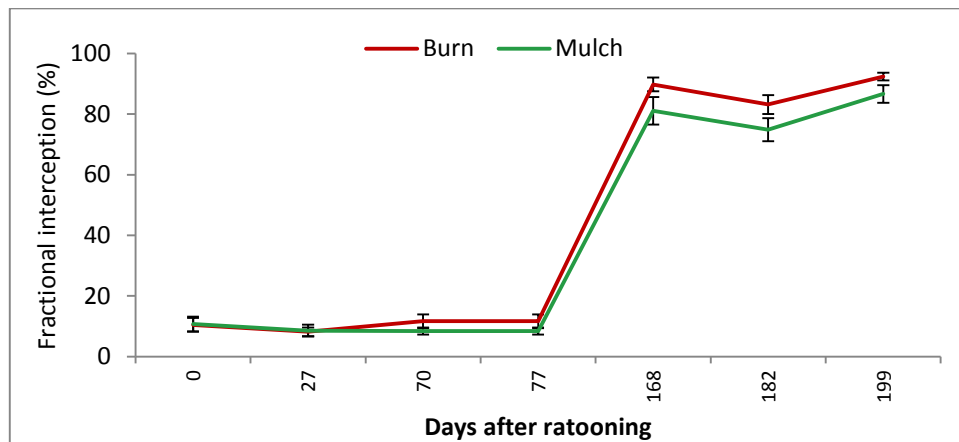


Figure 5.32 Fraction of intercepted photosynthetically active radiation (FiPAR) as affected by burn and mulch treatment at the fifth ratoon for mean of all cultivars as a function of days after ratooning.

5.3.4 Effects of mulching on soil water content

In general, the relative soil water content was higher under the mulch treatment as compared to burn plots. In the first ratoon (Figure 5.13a), soil water content was similar for both the treatments at the start of the measurements (February). As the crop developed canopy later on

in the season, the mulched plots had higher soil water content and this was consistent throughout the measurements. In the second ratoon (Figure 5.13b) the mulched plots had consistently higher soil water content throughout the period of measurements.

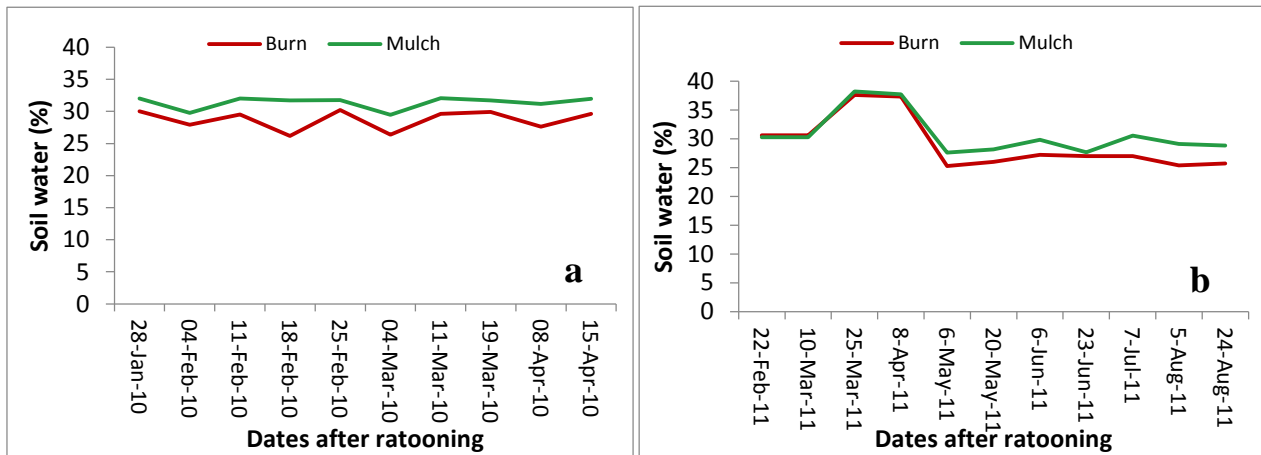


Figure 5.33 Changes in soil water content (in percentage of total available water) across the growing season as affected by burn and mulch treatment for (a) first ratoon crop and (b) second ratoon crop.

5.3.5 Effects of mulching on soil temperature

For ease of visualisation, the differences in soil temperature between the burn and mulched treatment for the whole growing season of the fifth winter ratoon has been split into three graphs representing the early (July 2013- August 2013), mid (September 2013- December 2013), and later (January 2014- June 2014) parts of that season (Figure 5.14). Mulching reduced diurnal temperature variation remarkably, especially in the early and in the mid-season, while diurnal variations were similar between the treatments in the late season. Daily maximum and minimum soil temperatures were lower under the mulch blanket in the early to mid-season (Figures 5.14a and b), while these differences seemed to disappear later in the season because of canopy closure (Figure 5.14c). Early in the season maximum soil temperature on the burn and mulched plots were kept in a range of 19 - 28 °C and 17- 18 °C respectively (Figure 5.14a). Similarly in the mid-season, maximum soil temperatures were higher at the burn treatment, however, between 10/18/13 and 10/25/13 soil temperature under the burn treatment dropped almost to a similar level as the mulched treatment (Figure 5.14b). The differences between the two treatments faded away later in the season as the crop

developed full canopy. The burn treatment at this point had reduced diurnal soil temperature fluctuations (Figure 5.14c).

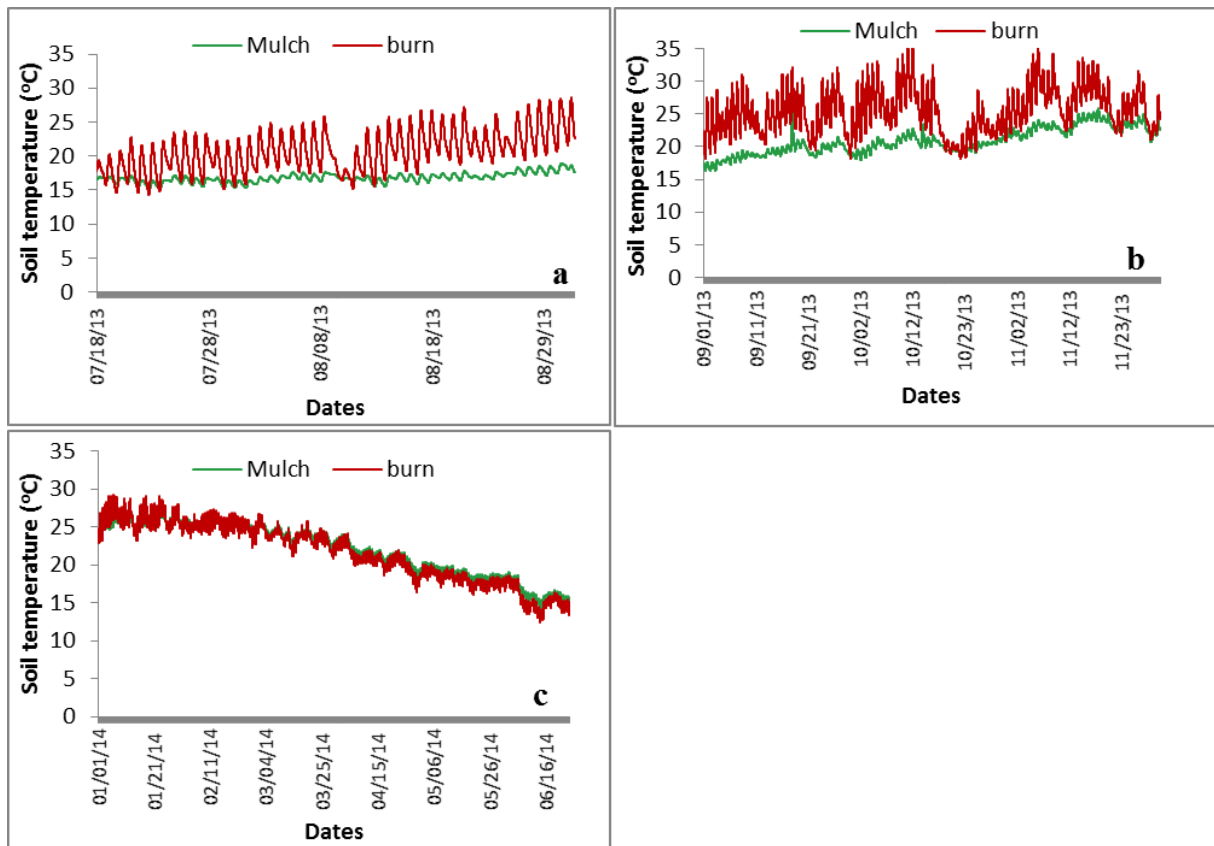


Figure 5.34 Soil temperature regimes under mulch and burn treatment on the fifth ratoon crop. Temperatures logged every 15 minutes at 15 cm depth from (a) early season, (b) mid-season and (c) late season.

5.3.6 Residue production by cultivars

The total potential residue yield produced by the cultivars (as obtained from cane stalks) in the irrigated region varied with each ratoon (Figure 5.15). There was no consistency in the ranking of the cultivars from one ratoon to the next. Cultivar N41, which was ranked the lowest residue yielding cultivar in the second ratoon with 11 t/ha, was the highest residue yielding cultivar in the third ratoon, producing about 18 t/ha of residue along with cultivar N46. In the second and fifth ratoon the highest residue yielding cultivars were N40 and N49, yielding 17 and 10 t/ha of residue respectively. The lowest residue yields in the second and fifth ratoon were recorded for cultivars N25 and N36, with 13 and 6 t/ha respectively. In general, the summer ratoons (second and third ratoon) out-yielded the fifth winter ratoon. The ratio of mulch yields to cane yields per cultivar ranged from 9% for cultivar N40 to 6% for cultivars N25, N32, N41 and

N46 in the second ratoon. The third ratoon had the highest mulch yield/cane yield ratio as compared to the second and fifth ratoon. The ratio ranged from 21% for N41 to 13% for cultivar N25. In the fifth ratoon the ratio ranged from 10% for cultivars N41 to 6% for both cultivars N36 and N43 (Data not presented). However, in the second and fifth ratoon there were positive but very weak correlations ($R^2 = 0.002$, and $R^2 = 0.012$ respectively) between mulch yield and cane yield. In the third ratoon a very weak and negative correlation of $R^2 = 0.03$ was observed between mulch and cane yield (Data not presented).

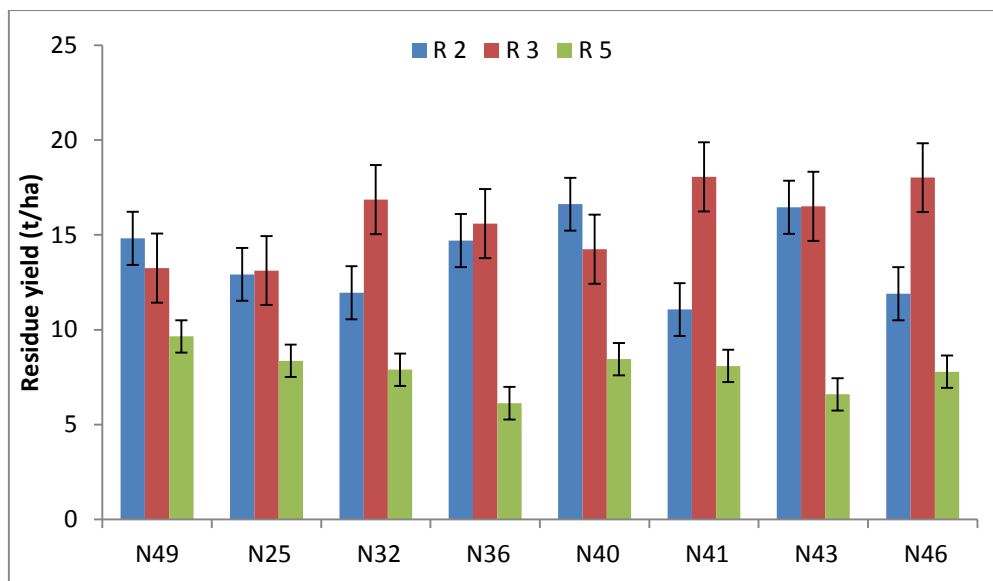


Figure 5.35 Residue yield estimates of eight cultivars at Pongola over a period of three ratoon crops.

Discussion

There were significant ($p < 0.05$) differences in cane yield amongst the four ratoons. This was due to differences in amounts and distribution of rainfall within each ratoon rather than differences in temperature. However, most yield components, including cane yield, were not significantly affected by the mulch treatments (Table 5.1). This was also observed in Figure 5.2, where there were no significant cane yield differences between the burn and mulch treatment for all cultivars in all four ratoons. This was probably due to the fact that none of the treatments reached a water stress level that could have induced a significant reduction in cane yield. The mean cane yield increase across all cultivars of 2% observed in the second ratoon can be associated with a relatively lower total water (irrigation + rainfall) received in that

season (Figure 5.1b). De Beer et al. (1995) reported that yield gains under mulched conditions can mostly be observed in low rainfall areas. Furthermore, Van Antwerpen et al. (2001) also found that yield response to the mulch treatment decreased with increase in rainfall (in the case of the present study, application of irrigation) from as much as 10 t ha⁻¹ to less than 3 t ha⁻¹. This effect was not observed in the other ratoons since rainfall was mostly above rainfall LTM (Figure 5.1).

In the first and third summer ratoons there was a mean cane yield reduction of 2 and 4% respectively. This reduction in cane yield was in agreement with those reported by Gosnell (1970). In their study they reported that at 100% irrigation of A-pan evaporation the mulched treatment reduced cane yield by 8 t h⁻¹ compared to the burn treatment. Furthermore, reports from semi-arid regions also showed that mulching under full irrigation resulted in a substantial yield depression (Gosnell and Lonsdale, 1977). The burn treatment produced 17 000 stalk ha⁻¹ more than the mulch treatment. This tendency was later confirmed by Olivier et al. (2009). In their experiment, the mulch treatment applied at standard irrigation reduced cane yield by 8% (not statistically significant) as compared to the burn in the ratoon crop. They associated the reduction in cane yield with the reduced rate of tillering and reduced radiation. The mulch treatment in their study was over irrigated as was the mulch treatment in this study. Similarly, in the current study, irrigation was not reduced/adjusted for the mulch treatment, which probably resulted in the reduced final stalk population under mulching for most cultivars in all four ratoons (more pronounced in the first and third ratoon in general). This also resulted in reduced radiation capture which was observed in Figures 5.12 and 5.13. Other yield components such as stalk heights and stalk mass were not significantly affected by the mulch treatments for all cultivars in all the ratoons. Stalk heights, however, showed reduction for most of the cultivars in the winter ratoon. The results from this study therefore provide confirmation of the responses seen in other studies under irrigated conditions.

The greatest reduction in mean cane yield across cultivars (7%) due to mulching occurred in the fifth winter ratoon, but this reduction was also not statistically significant (Figure 5.2d). Soil temperatures in the winter ratoon were lower under the mulch blanked for most parts of the growing season (Figure 5.14). The pronounced reduction in cane yield in the winter ratoon compared to summer ratoons could have been exacerbated by moist conditions interacting with cooler winter conditions. Viator and Wang (2011) also reported reduced cane yield with full mulch blanketing under cool and wet conditions in Louisiana (USA), however, in their study reduction in cane yield was significant.

The TERC was not significantly affected by the mulch treatment (Table 5.1). There were also no differences in mean cultivar response between the two treatments in the first ratoon. Even though there was a reduction in the mean cultivar response of cane yield (2%) (Figure 5.2a), mean ERC% which is another component of TERC, increased by 1% due to mulching (Figure 5.3a). The mean increase in TERC observed in the second ratoon (Figure 5.4b) was due to mean cultivar improvements in cane yield due to mulching. In contrast, the reduction in mean cultivar response for TERC in the third and fifth ratoon was as a result of both reduced cane yield and reduced ERC% under mulched conditions. None of the mean cultivar responses mentioned above reached statistical significance. Cultivar N40 in the third ratoon had a significantly reduced ERC% (Figure 5.3c), but TERC was not significantly reduced since cane yield was improved by mulching. Cultivar N25 in the winter ratoon was the only cultivar with a significantly reduced ERC% along with TERC. The significant reduction in TERC (22%) can mostly be ascribed to the significant reduction in ERC% due to mulching, since there was no statistical significance in cane yield between the two treatments. Olivier et al. (2009) reported that sucrose yield was decreased by 23% on the mulched plots as compared to the burn plots. In their study, however, they ascribed reduction in sucrose yield to decreased cane yields under unadjusted irrigation rather than reduced sucrose content. Gosnell (1970) also found that the burn treatment produced 2 tons more sucrose yield than the mulch treatment at the highest irrigation level.

The response of stalk population during the growing season to the mulch treatments were similar to those reported in Chapter 4 (rainfed region). The lower stalk population in the mulched plots at the beginning of the growing season can be attributed to lower soil temperature under the mulch blanket and possibly due to the physical barrier created by the mulch blanket. In the fifth winter ratoon this could have been amplified by a combination of lower soil temperatures (Figure 5.16) and higher soil water content from irrigation under the mulch blanket for a longer period of time (Figure 5.13). This was in agreement with the results reported by Viator et al. (2009) when they found that not removing mulch before winter dormancy resulted in lower stalk population for the mulched treatment. Viator and Wang (2011) further reported that cool and wet conditions reduced emergence and tillering in Louisiana. In Zimbabwe, Morombo et al. (1997) reported that the combination of low temperature and high moisture in the presence of the mulch blanket caused stool rotting, especially in cold months and hence no regrowth. Furthermore, they reported that cane

emerging under the mulch blanket took longer than in the burnt plots since it struggled to come through the mulch blanket. This was further alluded to by Donaldson (2009).

Many studies have documented the potential water retaining properties of the mulch blanket as well as its ability to reduce evaporation (Thompson 1965; Thompson 1976; Van Antwerpen et al. 2002). In the current study it was also observed that the mulched plots had higher water content compared to the burnt plots (Figure 5.13) even under irrigated conditions. This may have resulted in over irrigation of the mulched treatment plots as irrigation was not adjusted for the mulching. Furthermore, the burn treatment in this study was observed to have yield advantages over the mulched treatment. Other authors (Gosnell 1970; Olivier et al. 2009) mentioned above also observed similar yield advantages for the burn treatment under unadjusted irrigated scheduling such as in the current study. With such observations it becomes clear that a possibility exist to reduce irrigation which leads to saving irrigation water using mulching in irrigated regions. Olivia et al. (2009) recommended that the frequency of irrigation should be adjusted to suit either mulched or burn conditions, especially prior to the development of full canopy. Nunez and Spaans (2007) reported a reduction in daily evapotranspiration rate of up to 39% under the mulch blanket, thus resulting in the reduced irrigation frequency. Furthermore, Murombo et al. (1997) found a 288 mm irrigation water saving with mulching. This was later confirmed by Morandini et al. (2005). They reported that the burnt cane had higher water requirements, whereas mulching reduced the irrigation by two cycles.

Conclusions

In general, mulching had no significant effect on cane yield, ERC%, TERC, stalk height and stalk mass for most cultivars, despite probably being over irrigated. However, numerical reductions in cane yield were observed in high rainfall seasons. These reductions in cane yield were attributed to reduced stalk population under mulching. Reductions in cane yield were more pronounced in the winter ratoon than in the summer ratoons. The numerical reductions in TERC which were mainly observed in the third and fifth ratoon was to a larger extent a result of reduced cane yield than reduced ERC% due to mulching. Only cultivar N40 and N25 in the third and fifth ratoon respectively had significant reductions in ERC% due to mulching.

However, it was only cultivar N25 that had significant reductions in TERC because it also had reduced cane yield.

The determination of the TAM for the soil was an oversight so it was unclear if there actually was over irrigation or not. The focus of the study was on the relative water contents of the burnt vs mulch treatments. The TAMs are in a process of being determined and actual soil water relations in the treatments will be re-analysed and re-interpreted moving forward.

Cultivars had similar growth patterns under burn and mulch conditions for measured variables (stalk population, stalk heights and fractional intercepted radiation) during the season for all measured ratoons. Lower soil temperatures under the mulch blanket significantly delayed emergence and initial tillering in the first and fifth ratoon, but in the second ratoon the differences were not significant. Stalk height on the other hand was not significantly affected by mulching in both the summer and winter ratoons.

Residue produced by cultivars in the irrigated region was variable and differed from one ratoon to the next. Residue produced in the summer ratoons was substantially higher than that produced in the winter ratoon and this was consistent for all cultivars. Cultivar N40 had consistently higher residue yield in all the three ratoons, even though it was not ranked highest in all ratoons. Cultivar N43 also had consistently highest residue yields in the summer ratoons. These cultivars can be potentially used for energy co-generation. However, the weak correlation between mulch and cane yields in all three ratoons limits the potential use of models to estimate the amount of mulch in cane fields.

The results from this study show that the currently grown cultivars exhibit no added benefits from mulching under fully irrigated conditions. Most studies have related ineffectiveness of mulching in improving some growth variables and yield components under mulching with higher levels of irrigation. Furthermore, it was evident in Chapter 4 of this study and previous studies that benefits from mulching can mostly be achieved under water limiting conditions. Perhaps mulching could have been more beneficial in improving yield components if irrigation levels were adjusted accordingly. Furthermore, if the mulch treatment is irrigated according to the crop water demand, this could result in water and electricity savings. Thus a similar study is required to test these cultivars under burn and mulched conditions with reduced/adjusted levels of irrigation in the mulch treatments.

REFERENCES

- Ahmed W, Khan NU, Khalil MR, Parveen A, Aimen U, Saeed M, Samiullah, Shah SA. 2008. Genetic variability and correlation analysis in upland cotton. *Sarhad Journal of Agriculture*. 24: 573-580.
- De Beer AG, Hudson C, Meyer E and Seigmund B (1995) Green cane harvesting and trash management. *Proceedings of the International Society of Sugar Cane Technologists*. 22 133-141.
- Donaldson RA. 2009. Season effects on the potential biomass and sucrose accumulation of some commercial cultivars of sugarcane. PhD thesis, University of KwaZulu-Natal, South Africa.
- DWAF (DEPARTMENT OF WATER AFFAIRS AND FORESTRY,SOUTH AFRICA) (2004) *National Water Resource Strategy*. (1st edn.). September 2004. Department of Water Affairs and Forestry, Pretoria, South Africa. 150 pp.
- Gosnell JM and Lonsdale JE (1997). Effect of irrigation management on sugarcane. Rhodesia sugarcane association, Chiredzi, Rhodesia.
- Gosnell JM. 1970. Optimum irrigation levels for cane under burnt and trashed conditions. *Proceedings of the South African Sugar Technologists' Association* 44: 121-130.
- Jenkins EPG. 2013. A review of the factors that determine the length of the milling season in South Africa. MSc thesis, University of KwaZulu-Natal. South Africa.
- Meyer E. 2005. Machinery Systems for Sugarcane Production in South Africa. MSc thesis, University of KwaZulu-Natal, Pietermaritzburg. South Africa.
- Morandini M, Figueroa R, Pérez Zamora F, Scandalariis J. 2005. The effects of green cane trash blanket on soil temperature, soil moisture and sugarcane growth. In: *Proceedings of the ISSCT Congress, 25*, Guatemala, Guatemala. pp. 231-236.
- Mourombo M, Takavarasha E, Wiseman J. (1997). Green cane harvesting at Mltwasine Estate, Zimbabwe. *Proceedings of the South African Sugar Technologists' Association* 71: 30-32.

- Núñez O, Spaans E. 2007. Evaluation of green-cane harvesting and crop management with trash-blanket. In: *Proceedings of the ISSCT Congress*, 26, Durban, Sudáfrica. pp 131-142.
- Olivier F, Singles A. 2003. Water use efficiency of irrigated sugarcane as affected by row spacing and variety. *Proceedings of the South African Sugar Technologists' Association 7*: 347-351.
- Olivier FC, Lecler NL, Singels A. 2009. Increasing water use efficiency of irrigated sugarcane by means of specific agronomic practices. WRC Report No. 1577/1/09, ISBN 978-1-77005-883-5. *Water Research Commission*, Pretoria, South Africa. pp 127.
- Olivier FC, Singels A. 2006. The effect of plant residue layers on water use and growth of irrigated sugarcane. *Proceedings of the South African Sugar Technologists' Association*. 80 178-181.
- Thompson GD, Wood RA. 1967. Wet and dry seasons and their effects on rain-fed sugar-cane in Natal. *Trop Agric Trin* 44(4): 297-307.
- Thompson GD. 1965. The effects of trash conservation on soil moisture and the sugar cane crop in Natal. *Proceedings of the 39th Congress of South African Sugar Technologists' Association*. pp. 143-156.
- Van Antwerpen R, Meyer JH, Thompson, G.D. 2006. The impact of trashing on yield response in the South African sugar industry: a summary of results from several BT trials. *Proceedings of the South African Sugar Technologist Association 80*: 130-135.
- Van Antwerpen R, Meyer JH, Turner PET. 2001. The effects of cane trash on yield and nutrition from the long-term field trial at Mount Edgecombe. *Proceedings of the South African Sugar Technologists' Association 75*:235-241.
- Van Antwerpen R, Meyer JH, Turner PET. 2001. The effects of cane trash on yield and nutrition from the long-term field trial at Mount Edgecombe. *Proceedings of the South African Sugar Technologists' Association 75*:235-241.
- Van Antwerpen R, Thorburn PJ, Horan H, Meyer JH, Bezuidenhout CN. 2002. The impact of trashing on soil carbon and nitrogen: ii: Implications for sugarcane production in South Africa. *Proceedings of the South African Sugar Technologists' Association 76*:269-280.

Viator HP and Wang JJ. 2011. Effects of residue management on yield after three production cycles of a long-term sugarcane field trial in Louisiana. *Journal of American Society of Sugar Cane Technologists*. 31:15-25.

Viator RP, Johnson RM, Boykin DL and Richard Jr. EP. 2009. Sugarcane post-harvest residue management in the temperate climate of Louisiana. *Crop Science*. 49: 1023-1028.

CHAPTER 6

GROWTH AND YIELD RESPONSES OF COMMERCIAL SUGARCANE CULTIVARS TO MULCHING IN THE MIDLANDS

Abstract

The benefits and disadvantages of mulching have been frequently reported to be highly dependent on climate. Many authors have reported the potential benefits of mulching under low rainfall conditions. However under cool and wet conditions, reductions in yield have also been reported. The KwaZulu-Natal (KZN) Midlands region is characterised by low temperatures, with frost occurrences being common in valley bottoms and research on effects of mulching in this region is limited. Furthermore, no quantitative information exists on the reaction of popular commercial cultivars to mulching in the Midlands region.

A field trial was established in 2008 at Glenside in the Midlands region. The trial comprised eight of the most popular cultivars in the Midlands region. The trial was planted as a 2 x 8 factorial strip-plot with four replicates, with burning vs. mulching as the main plots (strips) and cultivar as sub-plots. Cultivar responses to mulching were evaluated over a period of one summer ratoon grown for a 24-month period. Cane yields (TCANE), estimated recoverable crystal (ERC) percentage, ERC yields (TERC), and mulch yields were determined at harvest. The effects of mulching on stalk population dynamics, stalk height, soil temperatures, and soil water content were monitored during the growing season.

Cane and ERC yields were significantly ($P < 0.001$) reduced by mulching for most currently grown cultivars in the Midlands. However, only cultivars 94H004 (20%), N16 (22%), N37 (24%) and N48 (20%) had significant reductions in cane yield, while only cultivars 94H004 (22%), N37 (24%) and N48 (19%) had significant reduction in both cane and ERC yields. The ERC yield reduction under mulching was attributed to the reduction in cane yield, rather than the reduction in ERC percentage. The reduction of these yield components was attributed to higher soil water content and relatively low soil (and most probably also air) temperatures caused by the mulch blanket under cold climatic conditions. Final stalk population ($P = 0.899$) and stalk mass ($P = 0.534$) were not influenced by the mulch treatments. Stalk height on the other hand was significantly ($P = 0.006$) affected by the mulch treatments. Most cultivars had shorter stalks due to mulching, however only cultivar N37 showed significant reductions in stalk heights. All cultivars had reduced delayed emergence in response to mulching. This

delayed emergence can be attributed to the lower soil temperatures prevalent under the mulch blanket early in the season. Even though most cultivars showed a reduction in stalk population during the growing season, a change in treatment ranking occurred, presumably because of the compensating effect caused by a longer growing cycle. Stalk heights of cultivars N48, N37, 94H004 and N31 were constantly lower under mulching, but the differences between treatments were not significant. Cultivars N12, N37, N48 and N50 were found to be the highest mulch yielding cultivars and can be potentially used for energy co-generation. Most of the currently grown cultivars showed a reduction in cane yield and most yield components. Therefore, from the current results mulching is not recommended as the best management practice in the Midlands region. However, future work on mulching needs to involve testing these cultivars over a few more ratoons to confirm results.

6.1 Introduction

The South African sugar industry can be broadly divided into either rainfed or irrigated regions, with a total production area split of 75 and 25%, respectively. Within the rainfed region 17% of the total sugarcane production occurs in the Midlands of KwaZulu-Natal. The Midlands region is characterised by low temperatures with frost occurrences being common in valley bottoms (Ramburan et al. 2012). In the winter period the minimum air temperature can be as low as 6°C, which severely stunts sugarcane growth. The normal age at harvest is between 18 and 24 months, which gives the crop enough time to reach its full yield potential since the 12 month harvesting cycle is not economically viable for farmers. Current cane yields in the Midlands region are approximately 80 tons of cane per hectare per annum, with ERC of about 12 percent (Singles et al. 2014). However, cane yields can vary depending on the amount and distribution of rainfall received in that season and the length of the harvesting cycle.

Many authors have reported the potential benefits of mulching on factors such as cane yield (especially under low rainfall) (Van Antwerpen et al. 2001), reducing evaporation (Olivier and Singles 2006) and increasing soil organic matter (Blair 2000). Moreover, even though mulching has been reported to have no significant effect of yield in the irrigated regions, potential means to make it more beneficial (reducing irrigation) have been reported (Olivier et al. 2009). The advantages and disadvantages of mulching are highly dependent on climate. Viator and Wang (2011) reported that under cool and wet conditions of Louisiana mulching has been found to decrease yields in the ratoon crop. Furthermore, cool and wet conditions

prevalent during crop emergence are reported to be potentially detrimental to crop establishment (Viator et al. 2009). In environments with frost occurrences, as the crop ratoons after harvest it is killed due to frost events and remains dormant until temperatures rise above 18°C again (Mangelard and Mimurma 1972; Lingle 1999). Viator et al. (2005) reported if the mulch blanket is not removed before winter dormancy, stalk population is reduced. A review on mulch management by Ridge and Dick (1989) mentioned that in cooler environments there are concerns of poor ratooning ability on mulched cane harvested early in the season when soil temperatures are low. However, it has been shown that growth differences between burnt and mulched cane harvested early in the season diminishes after 100 days (Chapman et al. 2001).

The decision on whether to continue burning or adopt the practice of mulching in the South African sugar industry has been the subject of debate in the past few years. Research involving mulching has been conducted in the northern irrigated region (Olivier et al. 2009). Furthermore, coastal rain-fed areas of KwaZulu-Natal near Empangeni have an estimated sugarcane field burning rate of less than 70% (van Antwerpen et al. 2006), leaving the rest of the total area to be mulched at harvest. In contrast, research on effects of mulching in the Midlands region is limited. Currently, the Midlands region has about 26 cultivars that are permitted for planting. Yet none of these cultivars have been investigated for their response to mulching in the Midlands region. Viator et al. (2005) concluded that most currently grown cultivars in Louisiana (USA) do not tolerate the environmental conditions created by mulching. Furthermore, Hardman et al. (1985) reported that some cultivars in Australia had reduced speed of emergence and tillering because of the reduction in soil temperature caused by mulching. An understanding of the reaction of cultivars to mulching will allow for cultivar-specific recommendations and/or adjustments of current agronomic practices to maximise yields if farmers choose to adopt such practice in the Midlands region.

Therefore, the objectives of this study were to: (a) quantify effects of mulch vs. burnt conditions on yield and yield components of common commercial cultivars in the Midlands region of South Africa, (b) compare these cultivars under mulch vs. burnt conditions with respect to their growth, establishment, and population dynamics, (c) monitor the influence of mulching on factors such as soil water and temperature, and radiation interception in order to explain yield responses, and (d) quantify the amount of mulch material produced by the different commercial cultivars.

6.2 Materials and methods

A field experiment was established in October 2008 on a SASRI research farm located at Glenside in the KwaZulu-Natal Midlands (29°25'0''S 30°41'0''E). The trial consisted of eight sugarcane cultivars (seven commonly grown in the KZN Midlands and one unreleased variety). The varieties were either burnt or mulched at harvest and their agronomic performance was evaluated for a period of 24 months in the first ratoon crop. The details of cultivars, crop, trial design and plot dimensions, and treatment application are detailed in Chapter 3. For brevity, some key aspects of the methodology are mentioned below.

Weather data were collected during the growing season (ratoon) from an automatic weather station (AWS) situated at the experimental site. The weather variables collected were mean air temperature and rainfall (mm). The long term mean (LTM) monthly rainfall was also calculated to characterise the growing seasons in terms of rainfall.

Growth measurements were taken at two week intervals from 2 x 2 m sections which were randomly assigned to net rows prior to emergence. Details of methods used to determine population dynamics (stalk population and heights), final stalk population and the amount of incoming solar radiation are mentioned in Chapter 3. Growth measurements were taken from emergence up to canopy closure.

At harvest, sucrose samples were taken by cutting 12 stalks from the net rows. The samples were then sent to the SASRI mill room to determine the estimated recoverable crystal percent (ERC %). Cane yield in tons cane/ha (TCANE) was measured by hand-cutting and weighing the net plots with a mechanical grab apparatus fitted with a load cell. Tons ERC/ha (TERC), was calculated as a product of TCANE and ERC.

From each of the 12 stalks used for sucrose sampling, the components of mulch which included green leaves and dead brown leaves were separated into brown paper bags. These components were dried at 75 °C for approximately 72 hours. The samples were then weighed to calculate the total mulch yield (tons/ha) for each cultivar on a dry mass basis.

Soil water content was measured using soil moisture sensors (Decagon Device 10HS). The sensors were installed at 20-25 cm depths in selected burnt and mulch treatments. The readings were taken at two week intervals from selected burnt and mulch plots.

To help establish the general soil temperature condition under the mulch blanket, Hobo data loggers were installed. The devices were set to log temperatures every 15 minutes and were installed at a depth of 15-20 cm in selected mulched and burnt plots of the same cultivars.

All data collected from the trial was processed using Microsoft Office Excel and statistical analysis was done using analysis of variance (ANOVA) to establish main (cultivar and mulch) and interaction effects (cultivar x mulch). Comparison of means was performed using Fisher's protected LSD test at 5% significance difference. statistical analyses were done using GenStat Statistical Package version 14.

6.3 Results

6.3.1 Seasonal characteristics

In general, the first ratoon which grew from October 2010 up to October 2012 had an above average rainfall season (Figure 6.1). From the start of the growing season the monthly rainfall was above the long term mean (LTM) until the end of December 2010 when the crop was two months. On the fourth and fifth month after planting (January and February 2011), the monthly rainfall dropped below the LTM. From the crop age of five to ten months (six months period from Mar 2011 to Aug 2011) monthly rainfall was above the LTM. The highest rainfall received in the 2011 season (184 mm) was in December when the crop was 14 months of age. Monthly rainfall was below LTM during the period April-July 2012. From August 2012 up until the end of the growing season, monthly rainfall was above LTM.

The average air temperatures were relatively low throughout the growing season, the mean maximum air temperature for the season were 23 °C and mean minimum air temperature was 10 °C. The highest maximum air temperature were experienced in March 2011 (29 °C) and Feb 2012 (27 °C) when the crop was five and 16 months of age respectively. On the other hand, the lowest minimum temperatures of 4 °C and 7 °C were measured in July 2011 and July 2012 respectively.

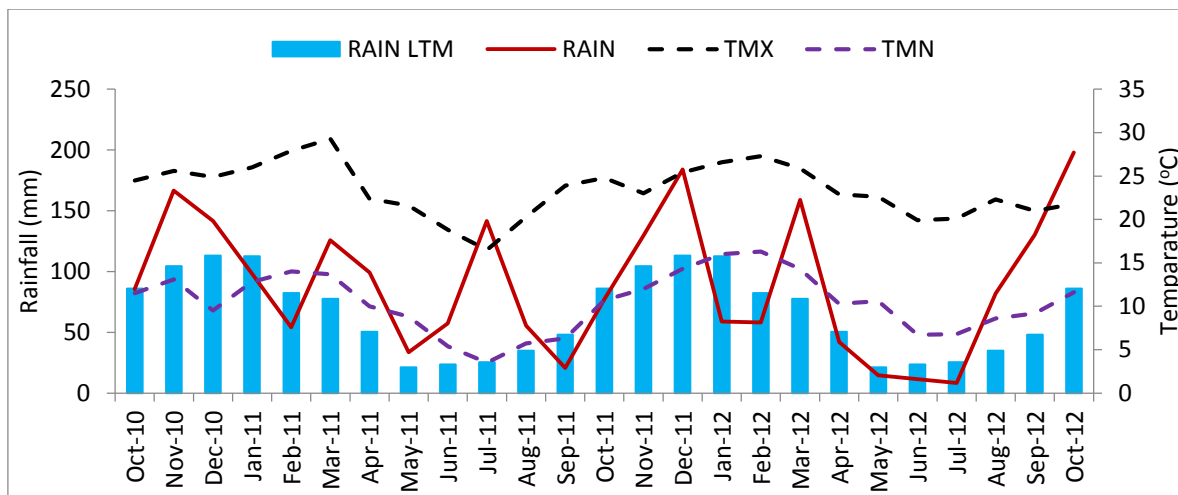


Figure 6.36 Monthly mean rainfall, long term mean (LTM) rainfall, and TMX (maximum temperatures), TMN (minimum temperatures) taken from an automatic weather station in the first ratoon crop at Glenside. (The x-axis are synchronised with the harvesting months).

6.3.2 Yield and yield components

The analysis of variance showed that the cultivar main effect was highly significant ($p < 0.001$) for all yield components (Table 6.1). The mulch treatment affect was only significant for cane yield, TERC and stalk heights. This meant that all the other yield components (ERC%, stalk population and stalk mass) did not have any pronounced reaction to the much treatment. The C x M interaction was not significant ($p > 0.05$) for all the yield components, meaning that all cultivars responded similarly to the mulch treatments.

Table 6.6 P values from the analysis of variance (ANOVA) for all yield components in the first ratoons for eight cultivars under burnt and mulched treatments at Glenside.

Source of variation	df	Cane yield (t/ha)	ERC%	TERC (t/ha)	Stalk population (ha ⁻¹)	Stalk heights (cm)	Stalk mass (g)
Cultivars	7	<.001	<.001	<.001	<.001	<.001	<.001
Mulch	1	<.001	0.226	0.06	0.899	0.006	0.534
C x M	7	0.158	0.424	0.119	0.553	0.239	0.69

In general, cane yields were reduced by mulching for all cultivars with the exception of cultivar N31, which had slightly improved cane yield (Figure 6.2a). However it was only cultivars 94H004 (20%), N16 (22%), N37 (24%) and N48 (20%) which had significant reductions in cane yield due to mulching.

The mulch treatments did not significantly affect ERC% for most cultivars (Figure 6.2b). However, most of the cultivars showed slight improvement in ERC%, except for cultivars N31 and 94H004 which showed a reduction due to mulching. Only cultivar N16 showed a significant improvement in ERC% of 7% due to mulching.

The responses of TERC were similar to responses of cane yield (Figure 6.2c). TERC was generally reduced by mulching for most cultivars, with the exception of cultivar N31, as was the case for cane yield. However, the only statistically significant reductions in TERC were observed for cultivars 94H004, N37 and N48, with 22%, 24% and 19% reductions respectively.

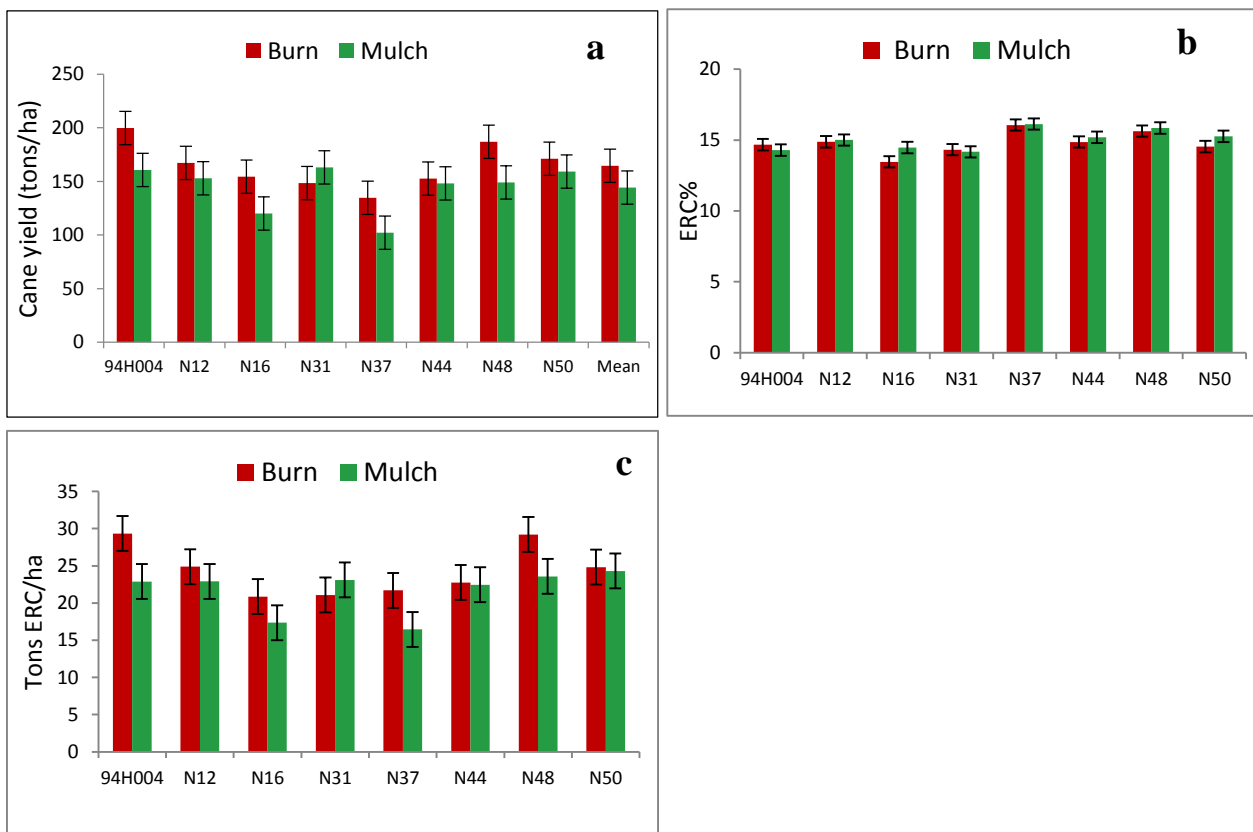


Figure 6.37 (a) Cane yields, (b) ERC% and (c) TERC for eight different cultivars under burn and trash treatments in the first ratoon crops at Glenside. Vertical bars represent least significant differences ($p < 0.05$).

There were variable cultivar responses to the mulch treatments with regards to the final stalk population (Figure 6.3a). Some cultivars (N50, N48, N44, N37 and N31) showed an improvement, while others (N12 and N16) showed a reduction in stalk population due to mulching. However, none of the improvements or reductions reached statistical significance for all of the cultivars. Cultivar 94H004 was heavily prone to lodging at the end of the growing season, therefore no data concerning final stalk population was salvaged. The large LSD values obtained are an indication of the variability in stalk population at harvest.

In general most cultivars showed a numerical reduction in final stalk height in response to mulching, with the exception of cultivar N37 (statistically significant reduction) (Figure 6.3b).

There were also variable cultivar responses to the mulch treatment with stalk mass (Figure 6.3c). Cultivars 94H004, N12, N16 and N50 showed numerical improvements, while cultivars N37, N44 and N48 had a numerical reduction in stalk mass. In general, there were no significant differences between the mulch and burnt treatment for all the cultivars.

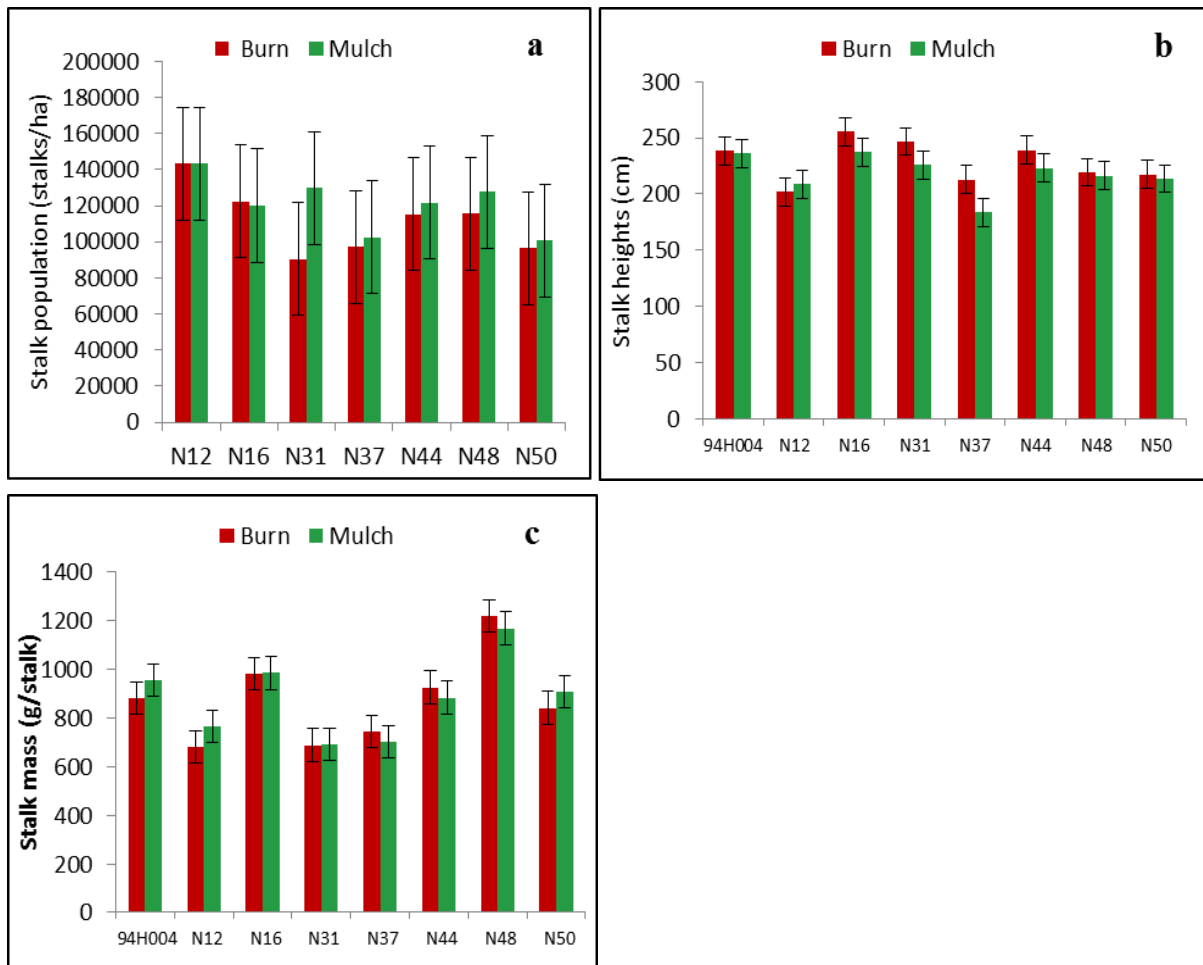


Figure 6.38 Final stalk populations (a), stalk heights (b) and stalk mass (c) for eight cultivars under burn and mulch treatments in the first ratoon crop at Glenside. Vertical bars represent least significant differences ($p < 0.05$).

6.3.3 Effect of mulching on canopy development

The growth pattern in response to mulching for cultivars N12 and N16 were similar (Figure 6.4a). However, N12 and N16 had a different growth pattern response to mulching as compared to cultivars 94H004, N31, N37, N44, N48 and N50 (Figure 6.4b) with regards to stalk population. For this reason cultivars were grouped into two groups, for each group of these cultivars the means were used. For brevity, cultivar N12 and N16 will be referred to as group 1 and cultivars 94H004, N31, N37, N44, N48 and N50 will be referred to as group 2. It must also be noted that graphs presented in this study, both for stalk population and height, are not plotted through to harvest. For group 1 (Figure 6.4a) mulching only significantly reduced stalk population for a short period at emergence, where after stalk populations between the burnt and mulch treatments were almost identical throughout the period of measurements. The mean

response for group 2 showed that mulching significantly reduced stalk population from emergence up to the peak tiller population. Even though after peak tiller population the differences were not significant, the burnt treatment consistently had a higher number of tillers throughout the period of measurements (Figure 6.4b).

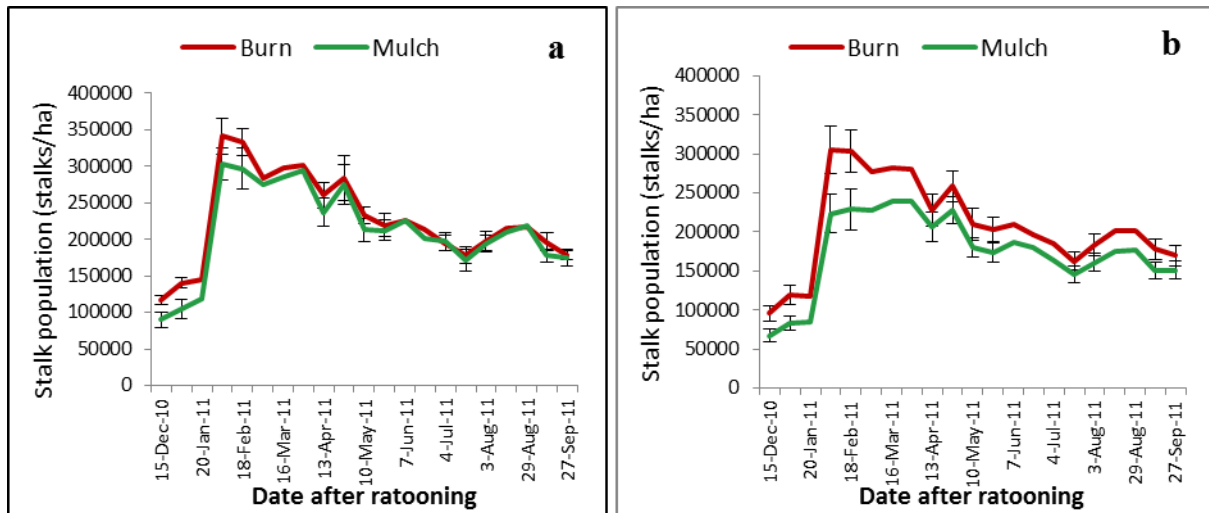


Figure 6.39 Stalk populations for (a) mean of cultivar N12 and N16 (group1) and (b) cultivars N50, N48, N44, N37, 94H004 and N31 (group2) at Glenside as affected burn and mulch conditions in the first ratoon for a period of 12 months.

With regards to stalk heights, the growth pattern in response to mulching for cultivars N50, N44, N16 and N12 were similar (Figure 6.5a). However, N50, N44, N16 and N12 had a different growth pattern response to mulching when compared to cultivars N48, N37, N31 and 94H004. Hence again groups were made for stalk heights, for each group of these cultivars the means were used. Again for brevity cultivars N50, N44, N16 and N12 will be referred to as group 1 and cultivars N48, N37, N31 and 94H004 will be referred to as group 2. The mean stalk heights between the burnt and the mulch treatment for group 1 were similar throughout the period of measurements (Figure 6.5a). However the mean for group 2 showed that stalks under the burnt treatment were consistently taller throughout the growing season, even though the differences were mostly not statistically significant (Figure 6.4b).

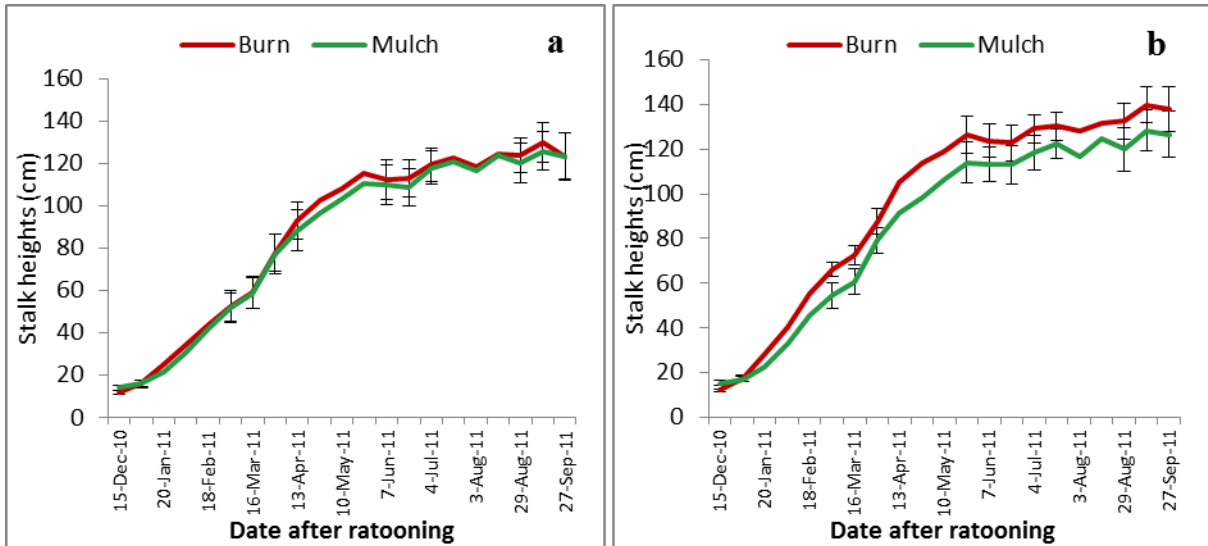


Figure 6.40 Stalk heights for (a) mean of cultivar N50, N16, N12 and N44 (group 1) and (b) cultivars N48, N37, 94H004 and N31 (group 2) at Glenside as affected burnt and mulched conditions in the first ratoon for a period of 12 months.

All cultivars showed a similar trend regarding fractional interception between the burnt and mulch treatments, therefore Figure 6.6 shows the mean response of all cultivars. Fractional interception was measured for a short period of time (January-April 2011, crop age of three to six months). Within that period the trend showed that the burnt treatment intercepted higher proportions of FiPAR, compare to the mulch treatment, but the difference between the treatments was not statistically significant (Figure 6.6). By April, however, the differences were declined and the treatments intercepted similar fractions of radiation.

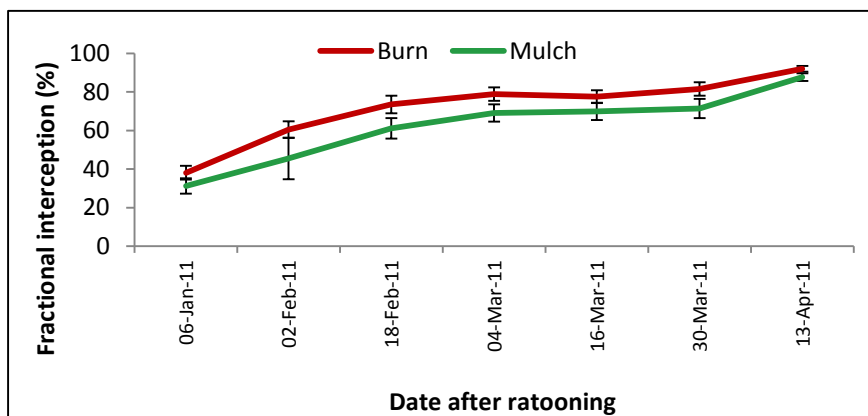


Figure 41.6 Fraction of intercepted photosynthetically active radiation (FiPAR) as affected by burn and trash treatment at the first ratoon for mean of all cultivars at Glenside.

6.3.4. Effects of mulching on soil water content

Differences in soil water content between the mulch and burnt treatment were not observed at the beginning of the measurement period until June 2011 (Figure 6.7). From June onwards the mulched plots had a higher soil water content compared with the burnt plots. These observations could be due to lower rainfall received during the winter period. Under such conditions the mulch blanket was able to maintain a higher soil water status. However, the increase in rainfall again in summer (November 2011) (Figure 6.1) reduced soil water content differences between the treatments (Figure 6.7).

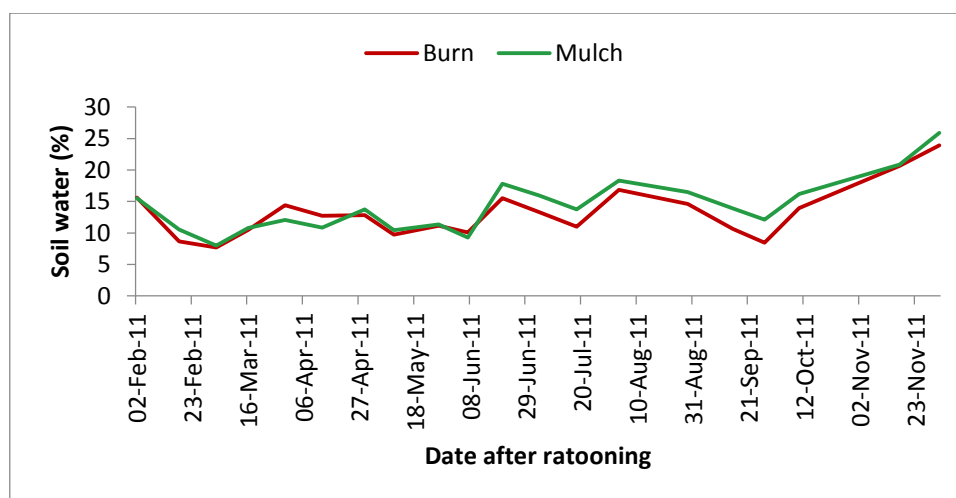


Figure 6.42 Changes in soil water content (in percentage) across the growing season as affected by burn and mulch treatment for the first ratoon crop at Glenside

Soil temperature differences between burnt and mulch treatments are shown for three periods of the growing season (Figure 6.8a). In the early parts of the season (June 2013- October 2013) the mulch treatment had lower soil temperatures compared to the burnt. Furthermore, diurnal soil temperature fluctuations were reduced by mulching throughout the early season. Mid-way through the season when the crop was reaching full canopy, temperature differences were reduced between the two treatments, especially at the end of the mid-season (November 2013- May 2014) where no differences were observed between the treatments (Figure 6.8b). Diurnal temperature fluctuations were also reduced for the burnt treatment and were similar to the mulch treatment at the end of the mid-season. In the later part of the season (June 2014- October 2014) no soil temperature differences were observed and diurnal fluctuations in soil temperature were similar for both treatments (Figure 6.8c). The reduced temperature

differences and diurnal temperature fluctuations at the end of the mid-season and throughout the late season were as a result of full canopy closure by the crop.

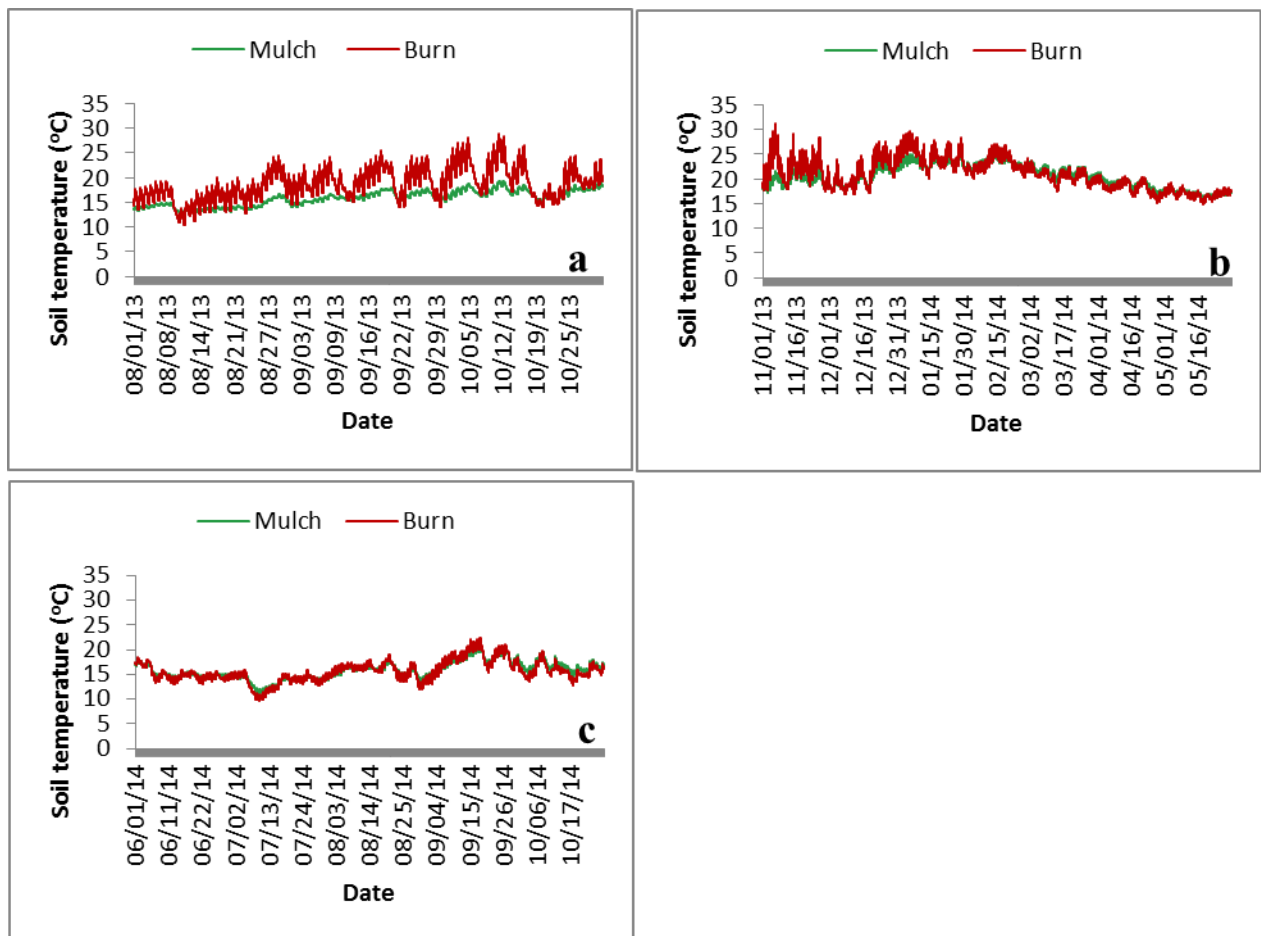


Figure 6. 43 Soil temperature regimes under trash and burn treatment on a first ratoon crop at Glenside. Temperatures were logged every 15 minutes at 15 cm depth during the (a) early season, (b) mid-season and (c) late season.

6.3.5 Residue production by cultivars

The total mulch yield as well as the components of mulch was different for each cultivar (Figure 6.9). Total mulch produced per cultivar ranged from as low as 13.4 t ha⁻¹ for cultivar N44 to as high as 27.6 t ha⁻¹ for cultivar N12. Cultivar N12 produced significantly higher mulch yields than most other cultivars. Most cultivars produced higher brown leaf mass as compared to the green leaves, with exceptions of cultivars 94H004 and N31 (higher green leaf mass). Cultivar 94H004 and N31 produced 46 and 16% more green leaf material than brown leaf material, respectively. On the other hand, brown leaf material ranged from as high as 36% to as low as 14% more than green for cultivars N37 and N12 respectively. Brown leaf production in relation

to the total mulch production ranged from 61% for cultivar N37 to 40% for cultivar 94H004. The mulch yield/cane yield ratio ranged from 18% for cultivar N37 to 9% for both cultivars N31 and N44. There was a positive but very weak correlation ($R^2 = 0.009$) between mulch and cane yield (data not presented), thus limiting the potential use of models to predict mulch yields in cane fields.

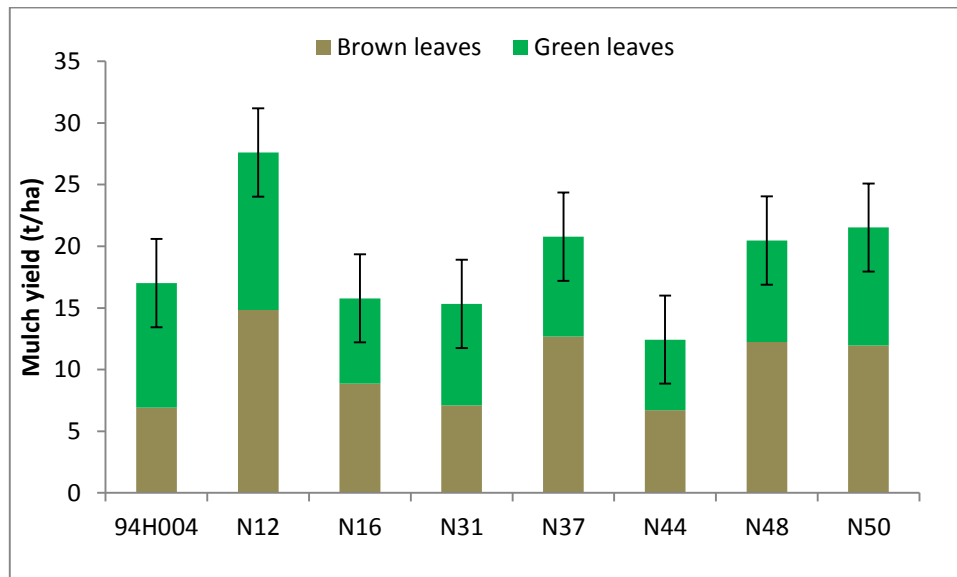


Figure 6.44 Residue yield estimates of eight cultivars at Glenside at the first ratoon. The total residue yield for each cultivar is composed of brown (dead leaves) and green (all green leaves including tops). The LSD bars represent differences in total mulch yield.

Discussion

Mulching significantly reduced cane and TERC for most currently grown cultivars in the Midlands (Table 6.1); this was further observed in Figure 6.2a and Figure 6.2c. The reductions in cane yield and TERC under the mulch treatment were most likely influenced by relatively low soil temperatures prevalent under the mulch blanket (Figure 6.8), particularly early in the growing season. In the cool and temperate climate of Louisiana (USA), Viator et al (2009) reported that mulching reduced cane and sugar yields in a low yield environment by 10.7 and 1.2 t/ha respectively. Under high yielding conditions mulching reduced cane and sugar yields by 14.3 and 1.4 t/ha, respectively. Furthermore, Viator and Wang (2011) also reported a significant mean cane and sugar yield reduction of 7.6 and 0.96 t/ha respectively as an average of 10 crops. Even though these findings agree with those obtained in the current study, it must

be noted that the Louisiana studies were conducted in the temperate region with a very short harvesting cycle. The cooler temperatures and above average rainfall received in the Midlands during the course of this experiment may have resembled those at Louisiana (Figure 6.1). Although mulching reduced cane and TERC (sugar yields) for most cultivars except for cultivar N31, significant cane and sugar yield reductions were only observed for cultivars 94H004, N37 and N48 (Figure 6.2a and 6.2c). The significant reductions in TERC (sugar yield) for these cultivars were not as a result of reduced ERC% (sugar content) but rather a reduction in the tonnage of cane. This was evident since ERC% was not significantly affected by the mulch treatments (Table 6.1) and this was consistent for all cultivars except N16 (Figure 6.2b). Although cultivar N16 had significantly lower cane yield (Figure 6.2a), it also had improved ERC% due to mulching (Figure 6.2b), hence TERC was not significantly reduced by mulching for that cultivar (Figure 6.2c).

Final stalk population and stalk mass were not influenced by the mulch treatments (Figure 6.3a and 6.3c). With respect to stalk population, this was consistent with the report by Viator and Wang (2011) in Louisiana. However, in their study they found that the burnt treatment had numerically higher number of stalks compared with the mulched treatment, while the opposite was true in this study. Nunez and Spaans (2007) also reported higher stalk population under burnt treatment for a 12 months crop in Ecuador. On the other hand the analysis of variance showed that stalk height was significantly ($P=0.006$) affected by the mulch treatments. Most cultivars had shorter stalks due to mulching, however only cultivar N37 had significant reductions in stalk heights.

All cultivars showed delayed emergence due to mulching (Figure 6.4a and 6.4b). This delayed emergence can be attributed to the lower soil temperatures prevalent under the mulch blanket early in the season (Figure 6.8a). These findings were in line with those reported by Viator et al. (2005) in the cool and wet conditions of Louisiana. Beater and Maud (1962); Woods (1991); Morandini et al. (2005) and Digonzelli et al. (2009) also found that mulching reduced soil temperatures in the first few centimetres of the profile, which can impair sugarcane emergence, initial growth and tillering. Furthermore, Torres and Villegas (1995) reported that under tropical environments the effects of mulching on tillering are temporary since they can be compensated for by the longer growing season. In the current study, cultivars in group 1 better compensated for tillering under mulching later in the season than cultivars in group 2 (Figure 6.4b). The radiation interception measured between Jan-Apr 2011 better corresponds with cultivars in group 2 whereby more stalks under burnt conditions meant higher radiation

interception compared to mulched cane (Figure 6.6). This meant that the burnt treatment developed canopy slightly faster than the mulch treatment. However, in both groups no significant differences were observed between burnt and mulched cane towards the end of the period of measurements for both stalk population and fractional interception. However, it must be noted that a cross over occurred in treatment ranking for most cultivars after the period where measurements were taken. This can be observed in the final stalk population (Figure 6.3a). This cross over further signifies the compensating effect caused by a longer growing cycle.

Generally, stalk height was not significantly affected by mulching for most cultivars during the period of measurements (Figure 6.5). However, some cultivars, especially those in group 2 (Figure 6.5b), had reduced stalk elongation rate. This was in contrast with the report from Olivier and Singles (2012) in their ratoon crop under irrigated conditions. In their study stalk under mulched conditions elongated faster than the burnt treatment after a thermal time of 1300 °Cd. A study by Morandini et al (2005) in Argentina showed that there were no significant differences in stalk heights between burnt and mulched cane.

The higher mulch yielding cultivars N12, N37, N48 and N50 can be potentially used for energy co-generation. Sugarcane can produce sufficient biomass to provide energy for its processing and leave a surplus (De Beer et al. 1996). On the other hand, a thick layer of mulch can impair regeneration of sugarcane ratoon crops (Donaldson 2009). A possibility exists in burning sugarcane and only retaining green leaves (tops) as mulch so as to avoid the retarding effects of a thick mulch layer.

Conclusions

Mulching generally reduced cane and ERC yields (TERC) in the Midlands region. This reduction was associated with higher soil water content, combined with lower soil temperatures. Furthermore, cooler temperatures and above average rainfall during the growing season contributed to the reduced cane and ERC yields. Mulching may have had positive effects on yields, had the rainfall during the growing season been lower. Even though mulching generally reduced cane yield for most cultivars, only cultivars 94H004, N37 and N48 had significant reductions in both cane and ERC yields. The reductions in TERC due to mulching were as a result of reduced cane yields rather than reduced ERC%.

Final stalk population and stalk mass were not significantly affected by mulch treatments for all currently grown cultivars in the Midlands. On the other hand, stalk heights were generally reduced by mulching for most cultivars. Lower soil temperatures under the mulch blanket early in the growing season were found to delay the emergence for all cultivars. However, the reduced tillering under mulching was short lived since most cultivars were able to compensate because of the long growing season.

The results of this study showed that mulching has detrimental effects on yield and yield components of all currently grown cultivars in the Midlands region. However, the study needs to be replicated for more than one summer ratoon and in a winter harvesting cycle in order to have concluding evidence on the effect of mulching in the Midlands. As the study has shown, some cultivars suffered more detrimental effects on yield and other yield components than others, which signifies cultivar differences in tolerance to mulched conditions. These differences were even observed during the growing season for stalk population and heights. It is therefore recommended that breeding efforts have to be made for cultivars that could better tolerate mulched conditions if this management practice is to be used in the Midlands region.

REFERENCES

- Beater B, Moud R. 1962. The effect of mulch on soil temperature in the sugar belt of Natal. *Proceedings of the International Society of Sugar Cane Technologists* 11: 378-380.
- Blair N, 2000. Impact of cultivation and sugarcane green trash management on carbon fractions and aggregate stability for a Chromic Luvisol in Queensland, Australia. *Soil and Tillage Research* 55: 183 - 191.
- Chapman LS, Larsen PL, Jackson J. 2001. Mulch conservation cane yield in the Mackay district. *Proceedings of the Australian Society Sugar Cane Technologist* 23: 176- 184.
- De Beer AG, Hudson C, Meyer E, Seigmund B. 1996. Green cane harvesting and mulch management. *International Society Sugar Cane Technologists (ISSCT)*: 133 - 141.
- Digonzelli PA, Fernández de Ullivarri J, Romero E, Giardina J, Alonso L, Casen S, Tonatto J, Leggio Neme M, Scandaliaris J. 2009. Assessment of two sugarcane management systems: with or without post-green-cane-harvest residue retention. In: *Proceedings. ISSCT Agronomy Workshop*, 8, Uberlandia, Brasil. pp 27-28.
- Donaldson RA. 2009. Season effects on the potential biomass and sucrose accumulation of some commercial cultivars of sugarcane. PhD thesis, University of KwaZulu-Natal, South Africa.
- Hardman JR, Tilley LGW, Glanville T. 1985. Agronomic and economic aspects of various farming systems for sugarcane in the Bundaberg district. *Proceedings of the Australian Society Sugar Cane Technologist* 7: 47-153.
- Lingle SE. 1999. Sugarcane. p. 287–310. In D.L. Smith and C. Hamel (ed.) *Crop yield, physiology, and processes*. Springer, Berlin.
- Mongelard JC, and Mimurma LM. 1972. Growth studies of the sugarcane plant. II. Some effects of root temperature and gibberellic acid and their interactions on growth. *Crop Science*. 12:52–58.
- Morandini M, Figueroa R, Pérez Zamora F, Scandaliaris J. 2005. The effects of green cane mulch blanket on soil temperature, soil moisture and sugarcane growth. In: *Proceedings of the ISSCT Congress*, 25, Guatemala, Guatemala. pp. 231-236.

- Núñez O, Spaans E. 2007. Evaluation of green-cane harvesting and crop management with trash-blanket. In: Proceedings of the ISSCT Congress, 26, Durban, Sudáfrica. pp 131-142.
- Olivier FC, Lecler NL, Singels A. 2009. Increasing water use efficiency of irrigated sugarcane by means of specific agronomic practices. WRC Report No. 1577/1/09, ISBN 978-1-77005-883-5. Water Research Commission, Pretoria, South Africa. pp 127.
- Olivier FC, Singels A. 2006. The effect of plant residue layers on water use and growth of irrigated sugarcane. *Proceedings of the South African Sugar Technologists' Association*. 80 178-181.
- Ramburan S, Zhou M, Labuschagne MT, 2012. Investigating test site similarity, trait relations and causes of genotype \times environment interactions of sugarcane in the Midlands region of South Africa. *Field Crops Research*. 129, 71-80.
- Ridge DR, Dick RG. 1989. The adoption of green cane harvesting and trash blanketing in Australia. *Proceedings of the International Society of Sugar Cane Technologists*. 20 1034-1041.
- Singels A, Leslie GW, McFarlene SA, Schoeman J, and Gabriel A, 2014. South African sugarcane production in 2013/14: A record breaking season. *Proceedings of the South African Sugar Technologists' Association* 87: 1-22.
- Torres JS, Villegas F. 1995. Green cane management under heavy mulch conditions. *Proceedings of the International Society of Sugar Cane Technologists*. 22: 142-148.
- Van Antwerpen R, Meyer JH, Thompson, G.D. 2006. The impact of mulching on yield response in the South African sugar industry: a summary of results from several BT trials. *Proceedings of the South African Sugar Technologist Association* 80: 130-135.
- Van Antwerpen R, Meyer JH, Turner PET. 2001. The effects of cane mulch on yield and nutrition from the long-term field trial at Mount Edgecombe. *Proceedings of the South African Sugar Technologists' Association* 75:235-241.
- Viator HP, Wang JJ. 2011. Effects of residue management on yield after three production cycle of a long-term sugarcane field trial in Louisiana. *Journal American Society of Sugar Cane Technologists* 31: 15-25.

Viator RP, Johnson RM, Boykin DL and Richard Jr. EP. 2009. Sugarcane post-harvest residue management in the temperate climate of Louisiana. *Crop Science*. 49: 1023-1028.

Viator RP, Johnson RM, Richard Jr, EP. 2005. Challenges of post-harvest residue management in the Louisiana sugarcane industry. *Proceedings of the International Society of Sugar Cane Technologists*. 25: 238-244.

Wood AW. 1991. Management of crop residues following green cane harvesting of sugarcane in north Queensland. *Soil and Tillage Research* 20: 69 - 85.

CHAPTER 7

GENERAL DISCUSSION AND CONCLUSIONS

At harvest sugarcane can either be burnt (to facilitate harvest) or mulched, however, it is well known that the majority of cane growers burn before harvesting. Reasons for the lack of uptake of mulching as routine practice include increased costs, reduction in harvest efficiency of cane cutters, increased transport and maintenance required by machinery, and increased accident risks for manual sugarcane cutters. However, studies have shown that having a mulch blanket on the field can change the local production environment; this includes soil water relations and temperature, radiation interception and weed competition (Wynne and van Antwerpen, 2005). These factors in turn can affect the growth and population dynamics of the crop during the growing season. The South African sugarcane industry has a wide range of cultivars that are bred for specific production regions. These cultivars differ considerably in their agronomic characteristics and their reactions to management practices. Although mulching is a recommended practice, some growers have reported that certain cultivars show negative growth and yield responses to mulching. Most studies on mulching have been specific to certain cultivars and were only conducted for a single sugarcane production region. The current study was aimed at investigating how popular cultivars respond to mulching in their commercial production environments in terms of their germination, population dynamics and yielding ability. The study was also aimed at quantifying the amount of mulch material produced by these cultivars, since very little information is currently known about this aspect. This would be important for future decision making concerning energy co-generation.

Results from this study showed that mulching had variable effects at all three locations. Cane and ERC yields were significantly improved in the coastal rainfed regions, significantly reduced for some cultivars (94H004, N37 and N38) in the Midlands and was not affected in the irrigated region under mulched conditions. The amount of available soil water seemed to have played a big role in the outcomes of cane and ERC yields specifically in the coastal rainfed region. At Empangeni under low rainfall conditions mulching was able to conserve soil water content, hence cane and ERC yields were improved. In the second ratoon, however the yield responses to mulching were reduced because of the above LTM rainfall. Under similar tropical conditions in the long term trial at Mount Edgecombe, Van Antwerpen et al. (2001) also recorded a decrease in responses to mulching with increasing rainfall. The best yield responses

to mulching under rainfed conditions are associated with periods of below average rainfall (Thompson 1965; Van Antwerpen et al. 2006). In contrast, the results from the Midlands and irrigated region showed no added benefits from mulching. In the Midlands, cold conditions associated with above LTM rainfall contributed to reduced cane and ERC yields. One of the many benefits to mulching is its ability to reduce evaporation, thereby conserving soil water under the mulch blanket (Olivier and Singles 2012). However, under cold conditions, as observed in the Midlands, evapotranspiration is reduced, therefore the preceding benefit of mulching is of little use. The reduction in cane yield in the Midlands was in agreement with the findings by Viator and Wong (2011) under cool and wet temperate conditions of Louisiana, which resembled those of the current study in the Midlands. However, it should be noted that the harvesting cycle in Louisiana is much shorter (nine months). Hence studies in Louisiana attribute the significant reduction in yield to the inability of their current cultivars to recover from conditions created by the mulching. This is in contrast to the long (24 months) growing cycle practised for the trial in Midlands. The long and persistent unfavourable conditions exacerbated by mulching throughout the season did not allow recovery for most of the cultivars.

Under irrigated conditions, the amount of irrigation water that was used to irrigate both treatments (burnt and mulch) was calculated as per requirements of the burnt treatment. Since mulched cane would require less water, this implies that both treatments did not experience stress conditions because of water limitations. However, the mulched treatment might have experienced saturated or even water logged conditions at times. This was most probably the main reason why mean numerical reductions, both in cane and ERC yields, under mulching were observed. This reduction in cane yield was in agreement with that reported by Gosnell (1970). In their study they reported that at 100% irrigation of A- pan evaporation the mulched treatment reduced cane yield by 8 t h^{-1} compared to the burn treatment. Furthermore, reports from semi-arid regions showed that mulching under full irrigation resulted in a substantial yield depression (Gosnell and Lonsdale 1977). Other authors (Gosnell 1970; Olivier et al. 2009) also observed similar yield advantages for the burn treatment under unadjusted irrigation scheduling such as one in the current study. With such observations it becomes clear that a possibility exist to reduce irrigation which can lead to savings in irrigation water (and electricity), using mulching in irrigated regions. Olivia et al. (2009) recommended that the frequency of irrigation should be adjusted to suit either mulched or burn conditions, especially prior to the development of full canopy.

ERC yields for all three agronomic regions were largely influenced by cane yield rather than ERC%. Cane yield is a function of mean cane mass and final stalk population. Therefore it could be expected that as one of the variables is affected (increased or decreased) by mulching it would have a direct influence on cane yield. Stalk population for summer ratoons, both in the coastal and Midlands region, were not significantly affected by mulching. A study by Digonzelli et al. (2011) also reported that there were no significant differences in stalk population between the burn and the mulch treatment of a 2006/2007 crop harvested in summer. From the results presented it is clear that stalk population did not play a significant role in the improvement or reduction of cane yield in summer ratoon in the coastal rainfed and Midlands regions, respectively. Furthermore, the same study by Digonzelli et al. (2011) reported that the 2007/2008 crop harvested in winter had significantly improved final stalk population. Similarly, in the current study at the coastal rainfed region the winter crop had significantly improved stalk population due to mulching. Hence the more pronounced improvement in cane yield in the winter crop at the coastal rainfed region could be partially due to improved stalk population. Reasons for the improvement under winter harvesting cycle are unclear, but may be attributed to improved soil water conditions during a low rainfall period (winter). In the irrigated region, stalk population showed a reduction due to mulching. The reductions in stalk population are presumably due to over irrigation under mulched conditions, which might have caused waterlogging. Hossain et al. (2010) reported that excessive water causes water stagnation in the field, creating oxygen stress conditions in the root zone, which reduces growth and yield of sugarcane. Gosnell (1970) also showed reduced stalk population in the mulched treatment under irrigated conditions in Zimbabwe.

Mean stalk mass is another factor to consider when talking about cane yield and is further determined by components such as stalk height and stalk diameter. Unfortunately in all three trials stalk diameter was not measured. However, the effect of mulch on stalk mass and height would have direct effects on, cane yield, provided that other factors (stalk population) are kept constant. Stalk elongation and height have been shown to be highly sensitive (negatively affected) by water stress (Inman-Bamber and Smith 2005; Olivier and Singles 2012). In the current study, it was therefore not surprising that stalk heights and mass were generally improved in the coastal rainfed region for all ratoons as a result of higher soil water under the mulch blanket. Furthermore, the irrigated and Midlands regions showed no significant differences in stalk heights, seemingly because cane under both treatments was not under water stress conditions. Domaingue (1996) also reported that stalk height are more severely reduced

by water stress under rainfed conditions. Mean stalk mass in the irrigated region was however improved by mulching, since no improvement in stalk height was observed, this could mean stalk diameter or density was improved by mulching, resulting in heavier stalks. However, for the irrigated region this did not result in improved cane yield since stalk population seemed to have played a bigger role in reducing cane yield. It can be confidently stated that the influence of mulching on the local growing environment in all three sugarcane agronomic regions affect the final yield and possibly profitability.

In order to fully understand the effects that the mulch treatments (burn and mulch) have on sugarcane cultivars, it was important to study their growth and development during the growing season. In all three sugarcane agronomic regions mulching significantly delayed emergence and initial tillering. This delay was attributed to lower soil temperatures under the mulch blanket at the beginning of the growing season and to some extent, the physical barrier exerted by the mulch blanket. At the coastal rainfed and irrigated regions the magnitude of these reductions differed from one season to the next but most cultivars had similar responses. In the winter ratoons the reductions in initial tillering were amplified and prolonged, probably because of the combination of lower soil temperature for a longer period of time and higher soil water under the mulch blanket. In the Midlands region, a group of cultivars (N50, N48, N44, N37, 94H004 and N31) expressed the reduction in tillering more than the other (N12 and N16). However, it must be noted that measurements were only taken for half of the growing season. During the last half of the growing season when measurements were not taken, a cross over in the ranking between burnt and mulch treatments must have occurred. This is apparent since all the cultivars that displayed a greater reduction in tillering during the period of measurements had improved final stalk population due to mulching, even though it was not significant (Figure 6.3b). The numerical improvements in final stalk population due to mulching in the Midlands proved to be due to a longer growing cycle. Perhaps similar improvement in final stalk population would also be observed in the coastal and irrigated regions under a growing cycle longer than 12 months. In all three sugarcane agronomic regions it was observed that differences in stalk population between burn and mulch treatments declined as the season progressed.

As mentioned earlier, stalk elongation is more affected by soil water content and rainfall amount and distribution. It is therefore expected that the treatment with a more favourable soil water balance would result in faster stalk elongation rates, as was observed for the coastal

rained region under mulching. What was also interesting to note in the coastal rainfed region was that under high rainfall conditions, as was observed in the second ratoon (Figure 4.1b), no significant differences in stalk heights were seen during the growing season (Figure 4.9). This could be attributed to adequate soil water under both treatments. Similarly, in the irrigated region no significant differences were observed in any of the measured ratoons since irrigation water was sufficient to alleviate any water stress. In the Midlands region, however, there were also no significant differences observed, but there were some numerical reduction in stalk elongation under mulching for some cultivars.

Romero et al. (2009) reported that mulch yields are influenced by several factors such as cultivar, yield levels, crop age, management variability and differences in harvesting systems and harvesting efficiency. Their observations were in agreement with what was found in this study. In the current experiments it was found that cultivars in each site produced different quantities of mulch, the average production level of mulch also differed from one site to the next. The Midlands region was found to be the highest mulch producing region, with cultivar N12 producing as high as 27.6 t ha^{-1} . The coastal rainfed region was the second highest mulch producing region, with cultivar N47 producing as much as 20 t ha^{-1} . The irrigated region had the least mulch production, with both cultivar N41 and N46 producing 18 t ha^{-1} . The higher mulch production in the Midlands was probably because of the higher cane yield of 154 t ha^{-1} (grand mean of all cultivars) which could be expected for a longer harvesting cycle. However, it was expected that the irrigated region would produce higher mulch yields as compared to the coastal rainfed region, since the mean production level across ratoons and across cultivars was as high as 104 t ha^{-1} , as compared to 49 t ha^{-1} measured for the coastal rainfed region. The shift from expected results could be due to a number of reasons, including cultivar differences in these two regions. This could also be due to experimental error due to a large number of samples being processed. It was also observed that mulch yields decreased with crop age but this situation was more apparent at the coastal rainfed region than in the irrigated regions. This can be due to water stress conditions experienced in the rainfed region. It was also observed that mulch production levels decreased drastically in the winter ratoon for both rainfed (average of 8.6 t ha^{-1} across cultivars) and irrigated regions (average of 7.9 t ha^{-1} across cultivars). However it is unclear if the decrease was only caused by crop age, which reduces production levels or harvesting cycle also played a role in the reduction. It should be noted that estimated figures for mulch production presented in this study might be an over estimation of the actual figures expected in actual practice. This is because the method used to quantify much yields

was very thorough in removing residues from stalk, which does not necessarily happen in practice.

One of the shortcomings of this study was that only one summer ratoon was harvested in the Midlands region due to a longer harvesting cycle. The results would have been more conclusive if more ratoons could have been harvested in order to observe trends between cultivars for the different components under a different season. For instance, if the following season was a drier season it would have been interesting to see if yield and yield components react any different to mulching. In the irrigated region, adjusting irrigation for the mulch treatment would have added more value to the study in order to validate if there would be significant improvements. A separate study, however, is required to test the performance of these cultivars under levels of irrigation adjusted for mulching. In this study, however, the idea was to investigate cultivar performance under mulching using cultural practices generally used by local farmers. A greater focus on cultivar differences in response to mulching could have been placed in this study if cultivars did not show similar response with regards to most of the yield variables measured (see Table 4.1, 5.1 and 6.1 C x M interaction).

Mulching affects the radiation balance due to modification in thermal conductivities and reflection coefficients and, as a consequence, it interferes in all other energy balance components. This therefore means it has the potential to also alter air temperature within the sugarcane canopy. Measurements of air temperature in future studies with mulching are therefore necessary, as in this study it was not done because of resource limitations. During the night air temperatures decline; Gilbert et al. (2010) reported that air temperatures in the mulch treatment were consistently 2-3°C lower than in the burnt treatment. Lower air temperatures for a longer duration can significantly reduce stalk elongation in sugarcane if they can cause freezing of plant tissue. This information could have been of great significance in this study, especially in the Midlands region, to explain the reduction in stalk height under mulching since air temperatures are greatly reduced at night.

Future/ongoing work in this study will involve harvesting and analysing the winter ratoon in the Midlands region. Furthermore, the study will also look at the economic feasibility of mulching in all three agronomic regions. This will take in to account the improvements (where observed) that each cultivar has in relation to production costs (especially harvesting and transport costs) incurred because of mulching. A follow up study is recommended to illustrate

the economic implications of not scheduling irrigation accordingly when mulching. Lastly, soil and leaf nutrient status will be analysed in order to quantify the potential benefits of mulching in terms of nutrients left in the field.

REFERENCES

- Digonzelli PA, Romero ER, Alonso L, de Ullivarri FJ, Quinteros HR, Fajre S. 2011. Assessing a sustainable sugarcane production system in Tucumán, Argentina. Part 1: Dynamics of sugarcane harvest residue (trash) decomposition. *Revista Industrial y Agrícola de Tucumán* 88: 1-12.
- Domaigne R. 1996. Family and varietal adaptation of sugarcane to dry conditions and relevance to selection procedures. Proceedings of the 21st international society of sugar cane technologists congress, Bangkok. Pp 418-435.
- Gilbert RA, Kingston G, Morgan K, Rice RW, Baucum L, Shine JM, Subiros JF. 2010. Effect of harvest method on microclimate and Sugarcane yield in Florida and Costa Rica. *Proceedings of the International Society of Sugar Cane Technologists* 27:1-8.
- GOSNELL JM, LONSDALE JE. 1977. Effects of irrigation level and trash management on sugarcane. *Agronomy*: 1565-1586.
- Gosnell JM. 1970. Optimum irrigation levels for cane under burnt and trashed conditions. *Proceedings of the South African Sugar Technologists' Association* 44: 121-130.
- Hossain KK, Itoh RD, Yoshimura G, Tokuda G, Oku H, Cohen MF, Yamasaki H. 2010. Effects of nitric oxide scavengers on thermos inhibition of seed germination in *Arabidopsis thaliana*. *Russian Journal of Plant Physiology* 57:222–232
- Inman-Bamber NG, SMITH DM. 2005 Water relations in sugarcane and response to water deficits. *Field Crops Research*, Amsterdam 92(2): 185-202.
- Olivier FC, Lecler NL, Singels A. 2009. Increasing water use efficiency of irrigated sugarcane by means of specific agronomic practices. WRC Report No. 1577/1/09, ISBN 978-1-77005-883-5. *Water Research Commission*, Pretoria, South Africa. pp 127.
- Olivier FC, Singels A. 2012. Effect of crop residue layer on evapotranspiration, growth and yield of irrigated sugarcane. *Water research commission*, Pretoria, South Africa 38. 77-86.
- Romero ER, Scandalariis J, Digonzelli P A, Alonso LG, Leggio F, Giardina JA, Casen SD, Tonatto M J, de Ullivarri JF. 2009. Effect of variety and cane yield on sugarcane potential trash. *Revista industrial y agrícola de Tucumán* 86 (1): 9-13.

- Thompson GD. 1965. The effects of trash conservation on soil moisture and the sugar cane crop in Natal. *Proceedings of the 39th Congress of South African Sugar Technologists' Association*. pp. 143-156.
- Van Antwerpen R, Meyer JH, Thompson, G.D. 2006. The impact of trashing on yield response in the South African sugar industry: a summary of results from several BT trials. *Proceedings of the South African Sugar Technologist Association* 80: 130-135.
- Van Antwerpen R, Meyer JH, Turner PET. 2001. The effects of cane trash on yield and nutrition from the long-term field trial at Mount Edgecombe. *Proceedings of the South African Sugar Technologists' Association* 75:235-241.
- Viator HP, Wang JJ. 2011. Effects of residue management on yield after three production cycle of a long-term sugarcane field trial in Louisiana. *Journal American Society of Sugar Cane Technologists* 31: 15-25.
- Wynne AT, van Antwerpen R. 2004. Factors affecting the economics of trashing. *Proceedings of the South African Sugar Technologists' Association* 78: 207-214.