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DOCTORAL THESIS

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With the title:

Developing container protocol for screening sugarcane (*Sacchurum officinarum* L) varieties for tolerance to water-deficit stress

FACULTY OF SCIENCE, AGRICULTURE AND ENGINEERING, DEPARTMENT OF AGRICULTURE

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Period of study: 2017 – 2021

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Candidate

I acknowledge that I have read and understood the University's policies and rules applicable to postgraduate research, and I certify that I have, to the best of my knowledge and belief, complied with their requirements.

I declare that this doctoral dissertation is the product of my own work and effort. I have, to the best of my knowledge and belief, acknowledged all sources of information in line with normal academic conventions.

I further certify that this research is original and that the material submitted for examination has not been submitted, either in whole or in part, for a degree at this or any other university.

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I am satisfied that I have given the candidate the necessary supervision in respect of this PhD research and that it meets the University’s requirements in respect of postgraduate research dissertation.

I have read and approved the final version of this doctoral dissertation and it is submitted with my consent.

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SUMMARY

In Zimbabwe, sugarcane (*Sacchurum officinarum* L) is an important crop grown for sucrose, ethanol and other by-products such as molasses, bagasse and filter cake. Drought due to climate change is projected to negatively reduce the production of sugarcane. The effects of water-deficit stress due to climate change can be mitigated by growing water-deficit stress tolerant sugarcane varieties. There is limited information on drought tolerant genotypes among the 14 released sugarcane varieties in the Zimbabwe Sugarcane Industry. Screening of these varieties can be effectively done in containers as it is rapid and economic. It has been noted that plants grown in containers under natural environmental conditions show symptoms of stress. Consequently, it was prudent to first develop a protocol that minimises the stress inherently associated with growing plants in a container. Sources of stress for container-grown sugarcane plants include the rate and frequency of applying irrigation water, growth medium, fertiliser rates and size of the container used. After obtaining the protocol that minimised stresses associated with these sources, the varieties were screened on their tolerance to water-deficit stress.

Five experiments were done at the Zimbabwe Sugar Association Experiment Station (ZSAES) located in Chiredzi. The first experiment tested seven rates of applying irrigation water for sugarcane plants grown in container (35 cm top diameter, 23 cm bottom diameter and 27.5 cm height). The water application rates tested were 0.25, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 litres per container per day. The growth media used in this experiment were pine bark (6-8mm) + vermiculite (1:1 v/v) and ZSAES soil medium comprised of a mixture of top soil: composted cattle manure: sand (5:2:2 v/v). The study showed that water application rates greater than 2.5 L per container per day increased stem height, number of tillers anddry matter of sugarcane plants in the ZSAES soil medium over pine bark + vermiculite. However, reduced germination of cane setts and root dry matter was observed in plants grown in the ZSAES soil medium.

The second experiment assessed the suitability of four media for growing sugarcane plants in containers. The media tested were filter cake only, filter cake + pine bark, pig manure + pine bark, and the ZSAES soil medium. Growing plants in pig manure + pine bark produced more tillers, shoot and root dry mass, green leaf area and number of leaves and leaf nutrient adequacy than the other media tested although stem height was suppressed.

The third experiment assessed the suitability of five blend fertiliser rates for growing sugarcane plants in containers. The rates tested were 312.5mg/l, 937.5mg/l, 1562.5mg/l, and 2187.5mg/l of Triple 16 blend fertilizer (16% N, 16% P_2O_5 and 16% K_2O) and Hoagland nutrient solution per container (control). The study revealed that the application of 937.5mg/l Triple 16 blend fertiliser fortnightly until 56 days after planting (DAP) resulted in more tillering but, also reduced stem height in all the four media tested. This was deemed adequate nutrition for sugarcane plants.

The fourth experiment tested the interactions of pot sizes and three growth media for suitability for growing sugarcane plants in containers. The three sizes of containers tested in the experiment were respectively small (25.5 cm deep x 31.3 cm diameter), medium (45 cm deep x 54 cm diameter) and large (90 cm deep x 54 cm diameter). The three media used were filter cake, filter cake+ pine bark and the ZSAES soil medium. Filter cake + pine bark in large containers produced sugarcane plants with thicker and taller stems and heavier total plant dry matter than the other treatments.

The fifth experiment tested all 14 commercial sugarcane varieties in Zimbabwe for their tolerance to water-deficit stress by growing the varieties in two levels of irrigation viz well-watered (100%) and water stress (30% of daily water volume applications). The varieties tested were ZN1, ZN2, ZN3, ZN4, ZN5, ZN6, ZN7, ZN8, ZN9, ZN10, CP72-1312, NCo376, N14 and CP 72-2086. All things considered, sugarcane varieties that can be grown by cane famers when faced with drought instigated by climate change are NCo376, ZN1, ZN8, ZN10 and N14.

Key words: sugarcane, container, water application rate, growth medium, blend fertiliser rate, pot size and water-deficit stress.

DEDICATION

This research work is dedicated to my wife Beatrice and my children, Makatendeka Racheal, Matidaishe Cheryl and Munenyasha Joyful Chandiposha.

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ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
CRD	Completely Randomised Design
DAP	Days After Planting sugarcane setts
EC	Electrical conductivity
LSD	Least Significant Difference
RWC	Relative Water Content
SED	Standard Error Difference of means
SPAD	Soil and Plant Analyzer Development
TPDM	Total Plant Dry matter
ZSAES	Zimbabwe Sugar Association Experiment Station

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background and justification

In Zimbabwe, sugarcane is produced in the South Eastern Lowveld region of the country. The area is characterised by low altitude (430 m), high mean air temperatures ranging from 16 ^{o}C during winter (May, June and July) to over 26 ^{o}C in summer (August to April) and low average annual rainfall of 625 mm (Clowes and Breakwell, 1998). The crop is grown mostly under irrigation on privately owned estates and farms (USDA, 2012). The country's two major privately owned sugarcane estates, Hippo Valley Estates and Triangle Estates, produce about three million tonnes of sugarcane per annum on 28,494 hectares while smaller indigenous sugarcane farms produce about 490,000 tonnes of cane per annum on 15,880 hectares (USDA, 2012).

Whereas the potential yield is estimated at 90 tonnes per hectare, the average cane yields among small indigenous farmers is approximately 54 tonnes per hectare. In contrast, the current average cane yields for Hippo Valley and Triangle Estates is around 83 tonnes per hectare while the average cane to sugar ratio is 8.0 (Scoones et al., 2017). The large yield gap between the smaller indigenous farms and the two Estates is mainly due to poor crop management, lack of resources and old ratoons of cane on indigenous farms among other challenges (Chidoko and Chimwai, 2011;USDA, 2012). The same factors also explain the large gap between the average yields of the indigenous farms and potential yield. Furthermore, the current economic hardships in Zimbabwe have resulted in poor financing of indigenous farmers, leading to under-capitalisation and under-utilisation of land. In partial mitigation of the financial problems faced by the indigenous farmers, Hippo Valley and Triangle have set up a US$20 million revolving loan facility to help the farmers (USDA, 2012). Scoones et al. (2017) reported that the production among outgrowers have since risen to 86 tonnes per hectare due to major investment in replanting sugar areas and improvement in management of labour.

Neverthless, in Zimbabwe, sugarcane (*Sacchurum officinarum* L) is an important crop grown for sucrose, ethanol and other by-products such as molasses, bagasse and filter cake (Clowes and Breakwell, 1998). Not only is the sucrose from sugarcane processing used in tea by many people globally, it is also used in manufacturing in the bakery industry, for instance (Sahin et al., 2019). Whereas molasses is used to feed livestock and to make ethanol, bagasse is used in the generation of electricity to power households and industries, including sugarcane mills, while filter cake is used as inorganic fertiliser in field and horticultural crops (de Castro et al., 2018). The crop contributes substantially to the economies and calorie component of the diets of many developing countries such as Zimbabwe, Swaziland, South Africa and others (Abdel-Rahman and Ahmed, 2008; Knox et al., 2010). In addition, Zimbabwe's sugarcane industry employs 25,000 people and indirectly 125,000 people. Also, exports of sugar bring to the country a substantial amount of foreign currency. Zimbabwe exported about 207 240 and 160 662 metric tonnes of sugar produced respectively in the 2014/15 and 2015/16 seasons to notably Botswana, the European Union and the United States (USDA, 2016). In 2014, overall Tongaat Hulett made a profit of US$30.6 million from its Zimbabwe operations (Scoones et al., 2017). According to the Zimbabwe Annual Action Programme (2009), sugarcane contributed about 1.4 % of total gross domestic product in 2005.

In spite of the economic importance of sugarcane to Zimbabwe, the viability of the industry is being threatened by climate change and variability caused by anthropogenic factors and other natural processes (Marin et al., 2013). Globally, climate change is projected to increase temperatures by a margin in the range of 1.5 to 5 ^{o}C by 2030 when compared to the average temperature of the year 2000 (Trenberth et al., 2007; UNFCCC, 2007). In Zimbabwe, it is anticipated that climate change will result in more frequent droughts (Brown et al., 2012), leading to reduction in the volume of water in the reservoirs, dams and rivers. Less availability of irrigation water will negatively impact sugarcane production in Zimbabwe, since the crop is mainly grown under irrigation (Chandiposha, 2013). Reduced irrigation of sugarcane, which needs between 10,000 and 14,000 m^3 of water per hectare, is likely to cause water deficit stress in sugarcane plants (Zhao and Li., 2015). Water-deficit stress affects critical physiological processes such as photosynthesis and ultimately curtails both the cane and sugar yields (Inman-Bamber, 2004; Knox et al., 2010). In the 2015/16 season, cane yields in Zimbabwe were lower than usual due to reduced volumes of water available for irrigation in the Manyuchi, Mutirikwi, Manjirenji and Siya dams (USDA, 2016).

One way of addressing water-deficit stress in sugarcane is to use drought tolerant varieties but, that calls for the evaluation and selection of varieties tolerant to inadequacy of water (Inman-Bamber et al., 2012). Advantages of using sugarcane varieties with tolerance to water stress are that higher yields will be attained under drought conditions, also less irrigation water is used and save the cost of irrigation (Ferreira et al., 2017; Santos et al., 2019). The most cost effective and quickest approach to evaluating the tolerance of sugarcane varieties to water-deficit stress involves growing them in containers under natural environmental conditions. However, previous attempts to grow sugarcane plants in containers under natural environment at the Zimbabwe Sugar Association Experiment Station (ZSAES) resulted in growth, which manifested as short internodes and stalks, reduced number of tillers and restricted green leaf area (Plate 1) (unpublished data). The source of the stress on sugarcane plants grown in containers is not clearly understood. However, the stress is suspected to be inadequate application of irrigation water (unpublished data). Water-deficit stress in sugarcane leads particularly to stunted growth as well as reduced tillers and leaf area (Vasantha et al., 2005; Begcy et al., 2012). Another source of plant stress in containers can be due to poor growth media. An inappropriate growth medium can impede root growth through poor aeration and low retention of water and nutrients (Majsztrik et al., 2011; Majsztrik et al., 2017). Furthermore, over-application of fertilisers in containers may lead to nutrient toxicities or imbalanced nutrients, causing nutrient stress to plants (Ridge, 2013). Alternatively, inadequate application of nutrients can lead to poor growth. Nutrient deficiency caused by leaching can also contribute to poor plant growth in containers since the plants are irrigated frequently and the soil volume for rooting is limited. The size of the container in which plants are grown can also cause poor growth *per se* due to restricted root volume (Poorter et al., 2012a). Ultimately, the height and diameter of the container has an influence on plant growth since it dictates the volume or amount of substrate, and thus, nutrient and water availability in the container (Luna et al., 2009; Poorter et al., 2012a).

The major focus of the present research was to develop an appropriate container system comprising a suitable water application rate, optimum growth medium, fertiliser rate and container size for sugarcane plants. Subsequently, the system would be used for screening sugarcane varieties released in the Zimbabwe sugarcane industry for their tolerance to water-deficit stress in anticipation of climate change-induced droughts.

Plate 1: A sugarcane stalk in a container at the Zimbabwe Sugar Association Experiment Station showing short internodes at the base due to stress.

1.2 Problem statement

In Southern Africa, it is projected that climate change will entail longer and more frequent droughts, causing water-deficit stress in crops (Brown et al., 2012). Drought due to climate change is projected to negatively reduce the production of many crops, including sugarcane. The reduction of sugarcane production in Zimbabwe would cause massive job losses and economic depression as the country depends heavily on its sugarcane industry. Zimbabwe Sugarcane industry has also been exporting sugar to the region and abroad, generating hard earned foreign currency. For example, in 2012–13, over 200,000 tonnes of raw sugar was exported to the EU (Scoones, 2017). Also, the sugarcane industry produces ethanol, which is blended with petrol, thereby reducing the imports of fossil fuels and saving foreign currency, for example in 2017, Zimbabwe saved US$ 26.5 million representing 2.65 % import bill (Gwenzi, 2018). Thus, whereas any reduction in sugarcane production would exacerbate Zimbabwe’s economic crisis. Longer and more frequent climate change-induced droughts would cause reductions in sugarcane production, leading to serious foreign currency losses and ever-diminishing prospects for economic recovery. Fortunately, the devastating effects of climate change on sugarcane production can be countered by growing drought tolerant varieties (Hemaprabha et al., 2004; Silva et al., 2008; Rodrigues et al., 2009; Jangpromma et al., 2010; Medeiros et al., 2013). The 14 varieties of sugarcane released in Zimbabwe to date have not been evaluated for tolerance to water-deficit stress. Whereas the use of containers would greatly facilitate the accomplishment of this task, a container system that minimises problems related to container size, growth medium, as well as fertiliser and irrigation regime is yet to be developed. This is despite it having been noted that sugarcane grown in containers under natural environment shows symptoms of stress (unpublished data). Indeed, most research on containerised production has been conducted in the horticulture industry and very little is known about its application to the sugarcane production (Carlson and Endean, 1976; Kharkina et al. 1999). Water application frequency in container-grown crop production ranges from multiple times per day to once every few days depending on the production system, growing season, and environmental conditions, such as aerial temperature and rainfall (Majsztrik et al., 2017). Irrigation is applied more in the in containerized production than in the field because of lower plant available water within containers filled with soilless substrates, which are more porous and have limited root volumes (Owen and Altland, 2008). In addition, lower rates of fertiliser and water on per hectare basis are applied in the field when compared to production in containers because soil matrices in the field are more chemically and water buffered (Bailey et al., 1999). Therefore, it is clear that the amount of water or nutrients required by sugarcane plants grown in containers is different from field conditions.

1.3 Aim

This study sought to develop a protocol that would minimize stress in sugarcane plants grown in containers and to use the protocol to assess the tolerance of the 14 sugarcane varieties released in Zimbabwe to water-deficit stress. The information generated in this study is to be used by researchers who would want to use rapid and cost effective methods to test hypotheses in sugarcane research. Also the output of this study is possibly going to improve or sustain sugarcane yields and profit of farmers who may be planning to select Zimbabwe sugarcane varieties following prediction of drought.

1.4 Objectives

1.4.1 To test the suitability of selected irrigation and fertiliser application regimes, growing media, and container size for the growth of sugarcane.

1.4.2 To screen 14 sugarcane varieties released in Zimbabwe for their tolerance to water-deficit stress using a container-based system.

1.5 Hypotheses

1.5.1 There is an appropriate protocol comprising growth medium, irrigation and fertiliser application regimes and container size, which minimises stress to sugarcane plants grown in containers.

1.5.2 Using an appropriate container-based protocol is likely to show that there is diversity in tolerance to drought among the sugarcane varieties released in Zimbabwe, which can be successfully assessed.

CHAPTER 2
LITERATURE REVIEW

2.1 Water application rate for sugarcane plants grown in containers

Currently, in the sugarcane industry, the irrigation of plants in containers is based on visual assessment of growth medium and plants. This culture has led to over or under application of water in container-grown sugarcane (Majsztrik et al., 2011). Over application of irrigation water in container-grown sugarcane has been associated with leaching of nutrients and the creation of water loggedconditions, leading to poor plant growth as a result of restricted oxygen supply (Manik et al., 2019). Over application of water in containers, especially in soil-less medium, may also cause denitrification (Wang et al., 2017). Denitrification is a process where NO_3^- and NO_2^- disintegrate into nitrogen oxide or nitrogen gases from the medium. Denitrification in containers can be reduced by using denitrification inhibitors, moderate rates of slow release fertilisers and improved irrigation management (Majsztrik et al., 2011).

The under-application of irrigation water in containers can lead to water-deficit stress in sugarcane plants. One of the most sensitive parameters to water stress in plant growth is photosynthesis. Photosynthetic potential is seldom achieved in many crop species under water stress and other unfavourable environmental conditions (t al., 2007). In sugarcane, water-deficit stress has been found to affect many of the photosynthesis-related physiological processes, including radiation capture, stomatal conductance, and electron transport (Qing et al., 2001; Ferreira et al., 2017).

Adaptive physiological traits of sugarcane in response to water stress include early closure of stoma and reduction in leaf area which is achieved by either leaf rolling or leaf shedding (Inman-Bamber and Smith,2005; (Kariniki and Sahoo, 2019). Early closure of stoma and leaf rolling are reversible processes that reduce carbon dioxide uptake and transpiration when sugarcane is under water stress and these processes resume quickly with increased water content or reduced atmospheric demand for water. Early stomatal closure limits increase in dry mass (Inman-Bamber and De Jager, 1988) but, improves the survival chances of plants under water-deficit stress.

Another physiological trait that is exhibited by sugarcane when exposed to water stress is stalk senescence and, eventually, reduction in plant population, which may warrant the need for replanting (Inman- Bamber et al., 2012; Kariniki and Sahoo, 2019). However, stalk senescence is only significant under very severe water stress (Inman- Bamber, 2004). Long-term to moderate water stress will reduce growth more than photosynthesis, thus increasing sucrose content although cane yields will be low (Inman-Bamber and De Jager, 1988).

Water stress has also been found to reduce chlorophyll content, probably as a result of photo-inhibition and photo-bleaching (Long et al., 1994; Lima-Melo et al., 2019). Also, leaf temperature has been reported to increase with water stress (Silva et al., 2007). The increase in leaf temperature is explained by the closure of stomata which reduce transpiration (Jones, 2004). Thus, whilst stomatal closure can deter the development of lethal water-deficit, it can result in lethal temperatures under warm and sunny conditions (Silva et al., 2007).

The effects of water stress on plant growth vary according to growth stages (Silva et al., 2007). The main growth stages of sugarcane are germination, tillering, grand growth and maturity (Gascho and Shih, 1983). Of these, the tillering and grand growth stages are the most sensitive to water stress, since 70 to 80% of cane yield is produced during these phases (Ramesh, 2000).

2.2 Medium for sugarcane plants grown in containers

Until the problem of perched water table at the base of the containers was noticed, native top soil had been used as medium for growing plants in containers (Spomer, 1990; Schnelle and Henderson, 1991). The problem associated with native soils was poor drainage, which resulted in limited oxygen supply to the roots, leading to the creation of conditions conducive to disease development (Majsztrik et al., 2011). As an alternative, farmers started to use soil-less media to improve drainage in containers. Soil-less media became popular among growers of ornamental plants owing to its low weight, low cost and good physical and chemical properties (Wright and Niemiera, 1987; Raviv and Lieth, 2008). The good properties of soil-less media include favourable bulk density, air-filled porosity, water holding capacity, particle size, cation and anion exchange capacities, pH, wettability after drying, and longevity of medium (Raviv and Lieth, 2008). The soil-less media materials that have been used include composted pine bark, vermiculite, filter cake, bagasse, sawdust, peat, coconut coir and rockwool (Majsztrik et al., 2011). However, the porous nature of soil-less media is conducive to high percolation of water and leaching of mineral elements from the container, especially in cases where water and fertiliser are not well managed (Majsztrik et al., 2011). Soil-less media also has low anion and cation exchange capacities when compared to soils and this exacerbatesthe leaching of nutrients (Bilderback et al., 2007). It is difficult to come up with a single substrate with optimum physical and chemical properties. Nevertheless, substrate mixture can help to reach a compromise which can offer better physical and chemical characteristics to achieve optimal plant growth in containers. Examples of container media can be drawn from University of California (UC) mixtures and the Cornell peat-lite mixtures developed from 1950 to the 1970s (Hanan, 1998). However, these substrate mixtures were tailor-made for the growth of specific vegetable and ornamental plants. Moreover, the same materials are not readily available in Zimbabwe. Therefore, there is need to test substrate mixtures with locally available materials for the growth of sugarcane plants in containers. Currently, in the Zimbabwe sugarcane industry, the locally available soil-less substrate include filter cake, bagasse, pinebark and vermiculite (unpublished data).

2.2.1 Physical and chemical properties of filter cake

Filter cake is a by-product of sugarcane processing that is formed as a result of filtration of cane juice. In addition to having a high Cation Exchange Capacity (CEC), filter cake contains high levels of nitrogen, calcium, phosphorus, potassium, organic matter and water (Prado et al., 2013; Korndörfer and Anderson, 1997). However, the chemical composition of this material mainly depends on sugarcane variety, age of cane at harvest, season of harvest, method used in juice clarification and other factors. Filter cake has a very low C/N ratio when compared to other organic products (Prado et al., 2013). The low C/N ratio (14) of filter cake is the reason why substantial ammonia N is lost during compositing (Meunchang et al., 2005). Filter cake can be used as fertiliser in sugarcane fields, use as fertiliser is a safe method of disposal of this waste product (Pedro et al., 2010).

2.2.2 Physical and chemical properties of bagasse

Bagasse is a fibrous organic by-product from the sugarcane after crushing to extract the juice (Mokhena et al., 2017).It consists of two carbohydrate compounds, which are cellulose and hemicelluloses, as well as lignin (Santana and Teixeira, 1993). Lignin is a phenolic compound which offers resistance to enzyme attack and decomposition (Laser et al. 2002; Zhang and Lynd, 2004; Himmel et al., 2007; Taherzadeh and Karimi, 2008). This is also the reason why bagasse has high C/N ratio (100), which helps to reduce the volatisation of nitrogen during decomposition.

Bagasse initially offers very high porosity in a soil-less mix medium. However, the pore space tends to decrease very fast as the bagasse decomposes after addition of water and fertilisers. Therefore, when bagasse is used alone or in substrate mix, it should only be used in small containers and for limited time (Ingram et al., 1993).

2.2.3 Physical and chemical properties of pine bark

The chemical constitution of pine bark is influenced by tree species and environment (Bollen, 1969). Pine bark generally contains high amounts of phosphorus and potassium (Tucker, 1995). It has adequate manganese and copper, but very low calcium and zinc (Buamscha et al., 2007). The pH of pine bark is also generally low in the range of 4.0 to 4.5. Consequently, pine bark can only be used as substrate in containers after liming (Rippy and Nelson, 2007). The CEC for milled pine bark is generally high, approximately 96.6 meq/L (Nash and Pokorny, 1990). Altland et al. (2014) found that the CEC for pine bark varied with particle size and not pH, so that coarse particles generally had lower CEC than finer pine bark.

Whilst pine bark has high aeration, it is known to have very low water holding capacity compared to soil, and therefore needs frequent irrigation of container-grown plants (Owen et al., 2008). Furthermore, pine bark is difficult to rewet once the water holding capacity is lower than 35 % (Ingram et al., 1993). In order to increase its water retention, pine bark is amended with other materials, such as expanded clay, zeolite, arcillite and other inorganic components (Reed, 1996; Handreck and Black, 2002; Owen et al., 2008).

2.2.4 Physical and chemical properties of vermiculite

Vermiculite is an Al-Fe-Mg silicate which expands when heated. The substrate is mainly composed of potassium, calcium and magnesium. Vermiculite cannot be used alone due to some non-essential elements such as lithium and barium resident on the exchange sites (Spomer et al., 1997; Raviv et al., 2002). According to Ingram et al. (1993), the pH of vermiculite is in the range 6.0 to 8.9, which is good for container-grown plants. In contrast, Spomer et al. (1997) noted that vermiculite used for insulation should never be used as substrate for container-grown plants since it has compounds such as asbestos which are toxic to crops.

The vermiculite substrate initially has a very high water holding capacity, three to four times its weight, however, is lost over time (Raviv et al., 2002). Another advantage of vermiculite is that it is very light and the bulk density is in the range of 0.1 to 0.9 g/cm^3 (Raviv et al., 2002). However, the physical attributes of vermiculite are lost when it is rewetted over and over again. The challenge of losing physical characteristics is also apparent where vermiculite is used in substrate mixes within large containers since pressure is built at the base (Ingram et al., 1993).

2.2.5 Chemical and Physical properties of pig manure

Pig manure is made up of liquid and solid fractions. The liquid fraction of pig manure is composed of urine and water, which contains nitrogenous compounds (such as nitrates, ammonia and ammonium ions) and organic matter (Bertora et al., 2008). Most of the nitrogen content in pig manure is in the inorganic form and decreases with time. For example, slurry that has been stored for three months will lose about 40% nitrogen (Prapaspongsa, 2010; Kowalski et al., 2013). The solid fraction of pig manure is in the form of faeces, which contain mainly inorganic phosphoric compounds (Lens et al., 2004). Choudhary et al. (1995) reported that pig manure applied to soil increased nitrogen, phosphorus, potassium, magnesium, calcium and sodium. However, chemical constituents of pig manure vary according to breed, age and size of the animals and feeding method, among other factors (Sa′nchez and Gonza′lez, 2005; Kowalski et al., 2013). According to Choudhary et al. (1995), heavy use of pig manure in soil may cause increased leaching of nitrites, magnesium and phosphorus. High rates of pig manure release more available forms of nitrogen and phosphorus than required by plants, culminating in heavy losses of these elements to the environment. Over application of pig manure may also cause ions such as sodium, potassium and ammonium to displace calcium and magnesium ions from exchange sites, causing increased leaching in the soil (King et al., 1985).

Pig manure, just like other organic fertilisers, increases the organic component in a substrate used for crop production (Comin et al., 2013). Increased organic content in media increases porosity, aggregation, infiltration and water holding capacities (Ribeiro et al. 2007; Mosaddeghi et al. 2009). High organic content in media reduces bulk density and crusting of the surface, thus improving emergence of crops (Haynes and Naidu, 1998). However, Comin et al. (2013) reported that when applied in no tillage system, pig manure, in contrast to pig litter, did not cause any changes to the physical attributes of soil, such as aggregation and aggregate stability.

2.3 Fertiliser regime for sugarcane plants grown in containers

Nutrient management ofplants grown in containers is more problematic than in the field, because in the former there is high frequency of irrigation due to limited root volume (Lea Cox and Ross, 2001). Irrigation of plants in containers is, therefore, very excessive and this reduces the efficiencies of water and nutrient use by plants with exception of drip irrigation (Bauerle et al., 2002; Bilderback 2002; Ristvey et al., 2004; Ross and Lea Cox, 2004; Majsztrik et al., 2011). The efficiency of nutrient use by plants grown in containers can be increased by applying less fertiliser. For example, Cabrera (2003) reported higher N use efficiency after applying 60 mg L^{-1} Nin *Ilex opaca* (Hedge holly) as compared to N rates of up to 300 mg L^{-1}. Higher rates of fertiliser not only reduce nutrient uptake efficiency but, result in excessive leaching with no significant benefit in the growth of the plants (Majsztrik et al., 2011; Ku and Hershey, 1997). Majsztrik et al. (2011) warn that the current nutrient management practices in containers by growers of applying a constant rate of fertiliser regularly, irrespective of plant growth stage, is wasteful since there is no match with plant nutrient requirements. In Zimbabwe, depending on the soil type, sugarcane under field conditions requires 110 to 160 kg/ha nitrogen, 80 kg/ha phosphorus and up to 330 kg/ha potassium in extreme cases of deficiency (Clowes and Breakwell, 1998). The amount of fertiliser required in containers is expected to be much higher than the figures reported for field conditions because of higher irrigation frequency and severely limited root volume in containers.

To avoid fertiliser wastage, controlled release fertilisers (CRF), also known as slow release fertilisers (SRF), are usually applied on the surface of media as top dressing or mixed into the substrate in the containers before planting. The release rates of SRF are directly affected by temperature of growth medium (Huett and Gogel, 2000; Du et al., 2006). Thus, SRF tend to release nutrients faster during summer, leading to an increase in salt content as well as leaching of nutrients. Each SRF has an optimal release temperature. Merhaut et al. (2006) reported that for every 10 ^{o}C increment above the optimum temperature results in a release rate increment in the order of 15 to 200%. Other than temperature, another factor affecting the release rate of SRF is the method of applying the fertiliser. It has been shown that surface applied SRF may release nutrients at slower rates when incorporated into the growth medium (Broschat, 2005).

2.4 Container size for sugarcane plants grown in containers during formative phase

Container size is a function of substrate volume, height, diameter, shape and other factors (Luna et al., 2009). Yang et al. (2010) reported that a smaller pot volume resulted in reduced plant height and tillers of sorghum. This severely limited volume has been reported to increase the Root: Shoot ratio of plants grown in containers (Zhu et al., 2006; Yang et al., 2010). Small containers have been reported to decrease root size, but increase root density, which causes the roots to compete among each other for nutrients, space, water and other requirements (Yang et al., 2010). The restricted volume in containers is closely associated with poor N uptake and assimilation even when nutrients are sufficiently applied (Whitefield et al., 1996; Ronchi et al., 2006; Zhu et al., 2006; Yang et al., 2007; Yang et al., 2010). Sugarcane plants are likely to suffer from nutrient deficiency when grown in small containers since the crop requires more nitrogen, phosphorus and potassium when compared to most field crops. Poor N uptake and assimilation in small pots could be due to limited oxygen to roots, which leads to restricted shoot growth (Shi et al., 2007).

Container height delays the formation of a firm root plug (Landis et al., 2014). The height of a container also affects the amount of freely drained substrate in a container. Tall containers have a higher proportion of freely drained medium than shorter containers (Poorter et al., 2012a). When irrigation water is applied to the container, it moves downward by gravity until it reaches the bottom and creates a saturated zone (Landis et al., 2014). This saturation zone is proportionally greater in containers with a limited height resulting in poor aeration (Luna et al., 2009). Sugarcane plants, just like many other crops, require sufficient oxygen in the container for the roots to grow normally (Manik et al., 2019).

The diameter of a container dictates the type of plant that should be grown. Containers with larger diameters should be used for broad leaved tree shrubs and herbaceous plants so that irrigation water can penetrate dense foliage and reach the substrate (Luna et al., 2009). Being in the grass family, sugarcane plants typically produce many tillers around the primary plant, and therefore require containers with a large diameter (Poorter et al., 2012a).

2.5 Tolerance to water-deficit stress among sugarcane varieties

Water-deficit stress causes substantial loss of sugar and cane yields (Hemaprabha et al., 2004; Khaled et al., 2018). The frequency of drought in Zimbabwe is projected to increase in the future due to climate change (IPCC, 2007). The negative effects of water-deficit stress can be reduced by developing sugarcane varieties that are tolerant to these adverse conditions (Hemaprabha et al., 2004; Silva et al., 2008; Rodrigues et al., 2009; Jangpromma et al., 2010; Medeiros et al., 2013; Ferreira et al., 2017). In this regard, it is important to understand the diversity in tolerance of sugarcane genotypes and the processes that govern it.

Water stress deficit affects the physiological, biochemical and morphological processes of the sugarcane plant. Consequently, the physiological characteristics of sugarcane can be used to screen genotypes for tolerance to water-deficit stress (Hemaprabha et al., 2004; Silva et al., 2008; Rodrigues et al., 2009; Jangpromma et al., 2010; Medeiros et al., 2013; Ferreira et al., 2017). One of the physiological responses of plants to water-deficit stress is stomata closing. Stomatal closure due to water-deficit stress has a direct adverse influence on photosynthesis due to limited carbon dioxide diffusion into the plant (Silva et al., 2013; Haworth et al. 2016). Sugarcane varieties vary in their ability to maintain non-stomatal limitation on photosynthetic rate during moderate stress (Silva et al., 2007; Centritto et al., 2009; Galmes et al., 2011; Ferreira et al., 2017). Varieties that maintain non-stomatal limitation on photosynthetic rate during moderate stress are said to be tolerant of water-deficit stress (Ferreira et al., 2017). In contrast, other sugarcane varieties that are tolerant of water-deficit stress partially close their stoma to save water, and at the same time continue to fix carbon dioxide (Yordanov et al., 2000; Lawlor and Tezara, 2009; Ferreira et al., 2017). Although, the reduction of stomatal conductance in leaves due to water-deficit stress may reduce transpiration rate and increase leaf temperature with negative consequences (Azevedo et al., 2004; Liberato et al., 2006; Haworth et al., 2016).

Other parameters indicative of the effects of water-deficit stress on the physiological characteristics of sugarcane genotypes are Soil and Plant Analyzer Development (SPAD) index and chlorophyll content (Silva et al., 2011; Reyes et al., 2020). Sugarcane varieties with SPAD index values under 40 when subjected to water-deficit stress are not drought tolerant (Silva et al., 2011), because they are deficient in chlorophyll, and, therefore, have low photosynthetic rates (Torres et al., 2005). Similarly, Jangpromma et al. (2010) reported that drought resistant sugarcane varieties have high chlorophyll content. Water-deficit stress reduces chlorophyll content in sugarcane plants (Cha-um and Kirdmanee, 2009; Jaleel et al., 2009; Jangpromma et al., 2010; Ferreira et al., 2017) by causing oxidative damage (Medeiros et al., 2013). However, water-deficit causes plants to produce more antioxidants such as carotenoids and flavonoids and antioxidant enzymes such as peroxidases and catalases as a way of protecting the cells (Medeiros et al., 2013). The differences in ability to produce these enzymes may relate to differences in tolerance to drought between varieties.

Relative water content (RWC) is also a parameter indicative of tolerance to water-deficit stress by sugarcane genotypes as it shows the degree to which tissues and cells are hydrated (Silva et al., 2013; Ferreira et al., 2017). Sugarcane varieties tolerant to drought maintain high relative water content with increasing levels of water-deficit stress by accumulating osmolytes that reduce the water potential of the cells and concentration of water in the cells (Abid et al., 2018). Sugarcane varieties with an average RWC of below 80% were said to be sensitive to water-deficit stress (Graca et al., 2010; Silva et al., 2011).

There is a strong positive relationship between free proline content found in the roots and leaves of sugarcane plants and water-deficit stress (Queiroz et al., 2008; Cha-um and Kirdmanee, 2009; Medeiros et al., 2013). When plants are water-deficit stressed, their initial defence mechanism is to produce free proline to increase the osmotic potential of the cells (Iskandar et al., 2011) as a cytoplasmic compatible osmoticum/solute (Ahmad et al., 1979) that also protects the cell from water-deficit damage (Ashraf and Fooland, 2007). The significance of proline produced during water-deficits to water-stressed cells is to participate in osmotic adjustment (Kavi et al., 2005), membrane stability, reduction of oxygen radicals and protection of cell organelles (Ashraf and Fooland, 2007; Silva et al., 2013).

2.6 Conclusion

The frequency of drought in Zimbabwe is projected to increase in the future due to climate change. The negative effects of water-deficit stress can be reduced by developing sugarcane varieties that are tolerant to these adverse conditions. The physiological, morphological and biochemical characteristics of sugarcane can be used to screen genotypes for tolerance to water-deficit stress. The most cost effective and quickest approach to evaluating the tolerance of sugarcane varieties to water-deficit stress involves growing them in containers under natural environmental conditions. A review of literature shows that there is no information on the optimum water application rate, suitable medium, appropriate fertiliser rate and container size that can be used to grow sugarcane in containers with minimized stress. This study intends to develop a container protocol for screening sugarcane varieties for tolerance to water-deficit stress.

CHAPTER 3

TESTING THE SUITABILITY OF SELECTED WATER APPLICATION RATES FOR GROWING SUGARCANE PLANTS IN A CONTAINER WITH SOIL-LESS OR ZSAES SOIL MEDIUM

3.1 Abstract

The daily amount of water required by sugarcane plants grown in containers is not known and this has resulted in over and under irrigation, causing stress to the crop. An experiment was done at the Zimbabwe Sugar Association Experiment Station (ZSAES) from October 2015 to March 2016 with the objectives to determine the effect of water application rate on the growth performance and leaf nutrient concentrations of sugarcane plants grown in different media. The experiment was set using a 2 x 7 factorial arrangement in Completely Randomised Design (CRD) with 3 replications. The first factor was media with two levels namelysoil-less medium (composted pine bark + vermiculite) and ZSAES soil medium (five parts of top soil, two parts of river sand and composted cattle manure by volume). The second factor was water application rate with the following levels: 0.25; 0.5; 1.0; 1.5; 2.0; 2.5and 3.0 L per container per day. The germination of cane setts was 53 % lower in the ZSAES soil medium than in the soil-less medium due to restricted drainage. The number of tillers per container, stem height, green leaf area, above ground dry matter and total plant dry matter were higher in the ZSAES soil medium with water application rate ≥2.5 L per container per day. Leaf N, P, K and Mg for plants grown in the ZSAES soil were above optimal threshold for plant growth. Calcium was the only leaf nutrient in the ZSAES soil medium which was below optimal threshold of 0.15%. Nutrient contents in leaves of sugarcane plants either decreased or remained fairly close to each other as the water application rates increased. Noticeably, the nutrient content in leaves of plants applied 0.25 L per container had greater K (1.90%), N (2.5%) and Mg (0.21%) compared to the optimal threshold levels. The water application rate suitable for growing sugarcane in containers is ≥2.5 L per container per day using ZSAES soil medium.

Key words: sugarcane, media, water application rate, containers, plant growth and leaf nutrients.

3.2 Introduction and background

Water is one of the most limiting factors in sugarcane production both under rain-fed and irrigated conditions (Hemaprabha et al., 2004; Inman-Bamber, 2004; Basnayake et al., 2012). Sugarcane crop losses due to water stresses can be astronomical (Inman-Bamber et al., 2012; Khaled et al., 2018). Therefore, enough water is required for the crop to realize its full potential of cane and sugar yields (Wiedenfeld, 1995). A considerable amount of research has been done in the past on the effects of water stress on sugarcane growth and yield in the field, however, these studies are costly and time consuming (Wiedenfeld, 1995; Bell et al., 2000; Ramesh and Mahadevaswamy, 2000; Wiedenfeld and Enciso, 2008; Endres et al., 2010). Alternatively, water related studies can be done in containers in controlled environments (Graça et al., 2010; Medeiros et al., 2013). However, the application of the results in the field may result in different outcomes due to varying environmental conditions with those of greenhouses (Bell et al., 2000). To overcome this, sugarcane can be grown in containers under natural conditions instead of controlled environments such as greenhouses and growth chambers. Also containerized production in the open is less costly since there is no artificial control of the environment. Currently, there is limited information on the amount of water that should be applied to sugarcane plants grown in containers under natural environment. At the Zimbabwe Sugar Association Experiment Station (ZSAES), sugarcane grown in containers in the open is irrigated without measuring the amount of water. It has shown symptoms of stress when compared to thatgrown in the fields and this may be due to under- or over- application of irrigation water (Plate 1) (unpublished data).

Under application of water in sugarcane grown in containers may result in water-deficit related stress (Basnayake et al., 2012; Inman-Bamber et al., 2012; Zingaretti et al., 2012). Water-deficit stress affects sugarcane plants differently according to the stage of development. Gascho and Shih (1983) reported that sugarcane has four developmental stages namely, germination, tillering, grand growth and maturity. Of these, the most critical developmental stages of sugarcane sensitive to water stress are tillering and grand growth, collectively known as the formative phase (Ramesh and Mahadevaswamy, 2000; Zingaretti et al., 2012). Water-deficit stress during the formative phase causes many physiological changes to the plant. The first physiological sign of water stress is the closure of stomata to avoid more water loss due to transpiration (Rachmilevitch et al., 2006). Closure of stomata reduces the CO_2 diffusion into the plant and therefore decreases the photosynthetic rate (Taiz and

Zeiger, 2006; Graça et al., 2010). However, it is not only the stomatal factors which reduce photosynthetic rate under water stress. It has been reported that non-stomatal factors, such as low activity of photosynthetic enzymes, decreased ATP amount, reduced nitrate assimilation, early senescence and changes to the leaf morphology, can also reduce photosynthesis under water-deficit stress (Ghannoum, 2009). Other major signs of water stress, besides reduction of stomata and photosynthetic rate in sugarcane plants, are reduction of leaf area and root growth. Leaf temperature of sugarcane also tends to increase due to reduced foliar transpiration as a result of stomatal closure (Graça et al., 2010).

Over application of water in containers causes water logging stress conditions that have serious adverse effects on growth of sugarcane plants.Water logging causes soil microbes and roots to rapidly consume the remaining oxygen in the waterlogged soil, causing roots to use inefficient anaerobic fermentation to generate ATP required by the plant (Sasidharan and Voesenek, 2015). Finally, all carbohydrate reserves available are used, and this reduce transport of water and nutrients affecting shoot function (Sasidharan and Voesenek, 2015). The initial physiological effects of water logging conditions on sugarcane are similar to those of water stress and include stomatal closure, low transpiration and photosynthetic rate (Insausti et al., 2001; Striker et al., 2005; Mollard et al., 2008; Mollard et al., 2010). Flooding also causes symptoms such as wilting, senescence, and death of plants (Sasidharan and Voesenek, 2015). Plants develop adaptive traits to improve aeration, these include the formation of a suberin barrier in the root that prevents radial loss of oxygen (Shiono et al., 2011), increased formation of air spaces (aerenchyma) (Takahashi et al., 2014), and formation of aerenchyma-rich adventitious roots. The volatile ethylene and reactive oxygen species in all flooded plant cells triggers the development of aerenchymatous adventitious roots that replace older roots to improve shoot- root gas diffusion (Kozlowski and Pallardy, 1984; Voesenek and Sasidharan, 2013; Takahashi et al., 2014; Sasidharan and Voesenek, 2015). The production of these aerenchyma-rich adventitious roots is limited, and, as a result, flooding conditions result in increases in plant height and shoot biomass above water level (Naidoo and Mundree, 1993).

The media used in containerized production determine the amount of water and nutrients retained and in turn affect the plant growth of sugarcane (Majsztrik et al., 2011; Majsztrik et al., 2017). Soil-less media, such as vermiculite or pine bark, tend to be highly porous, which, on one hand, increases the amount of water and nutrients lost though the drainage holes (Majsztrik et al., 2011) but, on the other, enables the plant to get sufficient oxygen for growth. Media with soil or sand have high bulk densities and relatively lower porosities when compared to soil-less media (Bilderback et al., 2007). Low porosity of soil medium enables it to hold more water and nutrients, thereby enhancing plant growth. However, limited porosity coupled with high bulk density in soil-based media may result in compaction in the pot and poor aeration of roots.

3.3 Aim

To test the suitability of selected water application rates for growing sugarcane plants in containers with soil-less or ZSAES media.

3.4 Specific objectives

3.4.1 To determine the effect of water application rate (0.25; 0.5; 1.0; 1.5; 2.0; 2.5 and 3.0 L per container per day) on the (germination percent and rate, stem height, number of tillers, leaf temperature, leaf SPAD index, green leaf area, number of leaves, dry matter of above and below ground parts of plants) of sugarcane grown in different media (pine bark + vermiculite) and ZSAES soil medium).

3.4.2 To assess the effect of water application rate (0.25; 0.5; 1.0; 1.5; 2.0; 2.5 and 3.0 Lper container per day) on leaf nutrient concentrations (N, P, K, Mg and Ca percent) of sugarcane grown in different media (pine bark + vermiculite) and ZSAES soil medium).

3.5 Hypotheses

3.5.1 The water application rate suitable for growth performance of sugarcane plants varies from one growth medium to another.

3.5.2 The water application rate has an effect on leaf nutrient concentrations of sugarcane plants grown in different growth media.

3.6 Materials and methods

3.6.1 Site description

The study was done at the Zimbabwe Sugar Association Experiment Station (ZSAES) located in the South Eastern Lowveld of Zimbabwe ($21^{o}01$'S: $28^{o}38$'N; 430 m above sea level). The area experiences an average rainfall of 625 mm per annum, much of which falls in summer (October to March). The mean air temperatures range from 16^{o}C in June to July to 26^{o}C in October to January.

3.6.2 Experimental design and treatments

A 2 x 7 factorial experiment was used in Completely Randomised Design with 3 replications. The first factor was media consisting of two levels: pine bark (6-8 mm) + vermiculite (1:1 v/v) and ZSAES soil medium comprised of a mixture of top soil: composted cattle manure: sand (5:2:2 v/v). The second factor was water application rate consisting of 7 levels: 0.25; 0.5; 1.0; 1.5; 2.0; 2.5 and 3.0 L per container per day applied once per day between 0900 and 1200 hours.

3.6.3 Plant culture

The plastic containers used for growing sugarcane plants measured 35 cm top diameter, 23 cm bottom diameter and 27.5 cm height. They were filled with growth media to within 7.5 cm from the brim leaving space for irrigation water. Prior to planting, the pine bark + vermiculite mediumwas saturated with water for 72 hours by plugging the drainage holes.The ZSAES soil medium was only saturated for 24 hours prior to planting without plugging drainage holes. Sugarcane setts of ZN8 variety (10 months old) were cut at the base from S2 field using cane knives which were sterilized by immersing them for 5 minutes in diluted Propan-2-ol or isopropanol (JEYES fluid) (0.5 L JEYES fluid per 10 L of water).Three internodes from the base and top of the stalk were discarded using a cane knife (Okapi, South Africa). One eyed setts were cut from the remaining stalk before dipping them for 5 minutes in Triadimenol (Shavit) (1ml Shavit / 1000 mlof water) to prevent ratoon stunting disease. Five ‘one’ eyed setts of sugarcane variety ZN8 were then planted on 26 October 2015, five cm deep in the medium in each container. ZN8 variety is known to be sensitive to water-deficit stress, which is manifested by wilting of leaves and stunted growth. The water application treatments were commenced a day after planting. When the emergence of sugarcane plants in containers was complete, the plants were thinned 27 days after planting, leaving one healthy plant in each pot.

A modified Hoagland solution was applied to the media four weeks after planting and weekly thereafter until the end of the experiment. Hoagland modified solution was made according to Hoagland and Arnon, (1950) and comprised the following salts: KNO_3, $Ca(NO_3)_2{\bullet}4H_2O$, $MgSO_4{\bullet}7H_2O$, KH_2PO_4, Fe-EDTA, H_3BO_3, $CuSO_4{\bullet}5H_2O$, $ZnSO_4{\bullet}7H_2O$, $MnCl_2{\bullet}4H_2O$, $Na_2MoO_4{\bullet}2H_2O$. The 100 percent nutrient solution was applied after irrigation at a rate of one litre per container by applying 250 ml per day over four days inclusive of the water treatments. Irrigation using raw water was done between 0900 and 1200 hours. Rain shelters were drawn to cover the containers temporarily whenever it rained. Weeds were pulled out of the pots by hand to keep the pots weed free throughout the experimental period.

3.6.4 *Measurements*

Chemical and physical analyses of the media were done using methods shown in Table 1 prior to planting of sugarcane plants in containers

Table 1: Method and instruments used in chemical and physical analyses of media

Parameter	**Method and instrumentsused**
pH ($CaCl_2$)	Rayment and Higginson (1992) Mettler Toledo Multiparameter
Electrical conductivity (uS/cm)	Water method 1:5 (Rayment and Higginson (1992)
Phosphorus (ppm)	Ion exchange resin method (Saunders and Metelerkamp, 1962)
Potassium (ppm)	Ammonium acetate method (McKeague, 1978) and Varian SpectAA50
Calcium (ppm)	Ammonium acetate method (McKeague, 1978) and Varian SpectAA50
Magnesium (ppm)	Ammonium acetate method (McKeague, 1978) and Varian SpectAA50
Sodium (ppm)	Ammonium acetate method (McKeague, 1978) and Varian SpectAA50
Bulk density	Core method (Al-Shammary et al., 2018)

Average seasonal air temperature, evaporation and rainfall data were collected from an automated weather station which was located approximately 100m from the experimental site. The approximate amount of water draining through the drainage holes of the plastic container and collected in the plastic dishes underneath was measured at 0700 hours daily before irrigation. The number of sugarcane plants that emerged from the setts divided by the number of setts planted was recorded at 27 DAP as germination percent. Germination rate was estimated using a modified Timson's index of germination velocity (∑G/t), where G is the percentage of germination at one-day intervals and t is the total germination period (Khan and Ungar, 1984). The heights (cm) of the primary tillers were measured at 52 DAP, at weekly interval up to 107 DAP. The height was taken from the base of the plant at the surface of the medium to the apex using a metre rule. Number of tillers were counted once at 107 DAP. During the experiment, samples of leaves showing the top visible dewlap from primary tillers were analysed for N, P, K, Mg and Ca percent (Table 2).

Table 2: Methods used in chemical analysis of elements in sugarcane leaves

Parameter	**Method**
Nitrogen percent	Kjedahl digestion method (Persson et al., 2008)
Phosphorus percent	Vanado-molydo phosphate method (Bray and Kurtz, 1945)
Potassium percent	EDTA method (Derderian, 1961)
Magnesium percent	EDTA method (Derderian, 1961)
Calcium percent	EDTA method (Derderian, 1961)

Leaf temperature was measured between 0600 and 0900 hours on leaves showing the top visible dewlap from primary tillers at 149 DAP using handheld infrared thermometer (6:1 optics, Manchester, United Kingdom). SPAD index was measuredon leaves showing the top visible dewlaps from primary tillers at 149 DAP, respectively using a chlorophyll meter (Minolta SPAD-502, Minolta Co., Osaka, Japan) between 0600 and 0900 hours. At termination of the experiment, the primary tillers and all other subsequent tillers were excised at the base to separate shoot and roots. The shoots were further separated into green leaves, trash, sheaths, tops and stems. All green leaves were plucked from the shoot and counted. Green leaf area was measured on all green leaves at 150 DAP using a leaf area meter (Delta-T Devices Ltd., Burwell, Cambridge, UK). The stem diameter was measured at the base of primary tillers usingDial calliper 150 mm (Ultra Präzision, Glattbach, Germany). The roots were washed with water to remove any media particles. Washed roots and separated parts of shoots were placed in a forced air oven at 105 ^{o}C for 48 hours and weighed to determine root, green leaves, trash, sheaths, tops and stems and total plant dry matter.

3.6.5 Data analysis

Prior to analysis, data was tested for conformity to assumptions of Analysis of Variance (ANOVA) and an appropriate square root or log transformation was done. The data was subjected to Fisher's Analysis of Variance using Genstat statistical software (Genstat 14^{th} edition, VSN International Ltd., Hemel Hempstead, UK). The treatment means were separated using ±SED (standard error difference) or Least Significant Difference test at 5% level (Steel and Torie, 1984). Regression analysis were done using MS Excel 2010 version.

3.7 Results

3.7.1 Chemical and physical analyses of media

The pH ($CaCl_2$) of vermiculite + pine bark (soil-less medium) was slightly more acidic than that for the ZSAES soil medium (Table 3). The electrical conductivity of the ZSAES soil medium was higher than that of the soil-less medium. Phosphorus and potassium concentrations in the ZSAES soil medium were respectively, 27 and eight times those of the soil-less medium (Table 3). However, calcium and magnesium concentrations in the soil-less mediumwere respectively 16% and 209% higher than the ZSAES soil medium. In contrast, the sodium concentration was 74% higher in the ZSAES soil medium than it was in the soil-less medium.

Table 3: Chemical and physical analyses of media used in the experiment

Parameter	**soil-less medium**	**ZSAES soil medium**
pH ($CaCl_2$)	5.26	7.39
Electrical conductivity (uS/cm)	39	1472
Phosphorus (ppm)	59	1601
Potassium (ppm)	314.7	2122.5
Calcium (ppm)	3073	2642
Magnesium (ppm)	1557	504
Sodium (ppm	64.6	253.3
Bulk density (g/cm^3)	0.37	1.44

3.7.2 Seasonal air temperature, evaporation and rainfall

The average monthly air temperatures increased from 27 ^{o}C in October 2015 to 29 ^{o}C in December 2015 before declining to 27 ^{o}C in March 2016 (Figure 1). The highest rainfall was received between November 2015 (70 mm) and January 2016 (105 mm) (Figure 1) but, this had no impact on sugarcane growth, since the plants were covered by rain shelters when it rained. Monthly evaporation rates were in excess of 9 mm per day (Figure 1).

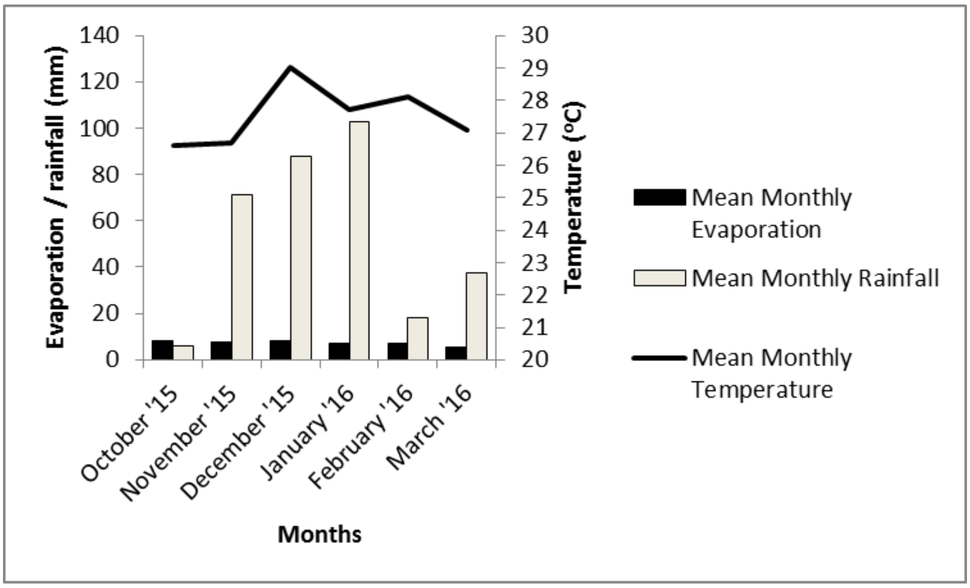

Figure 1: Average monthly temperature (ºC), rainfall (mm) and evaporation (mm) at ZSAES during the experimental period (October 2015 to March 2016)

3.7.3 Water loss through drainage from the container

Water loss through drainage from the bottom of the containers was higher for the soil-less medium than it was for the ZSAES soil medium (Figure 2). The amount of water that drained through the bottom of the containers was proportional to the quantity of water applied.

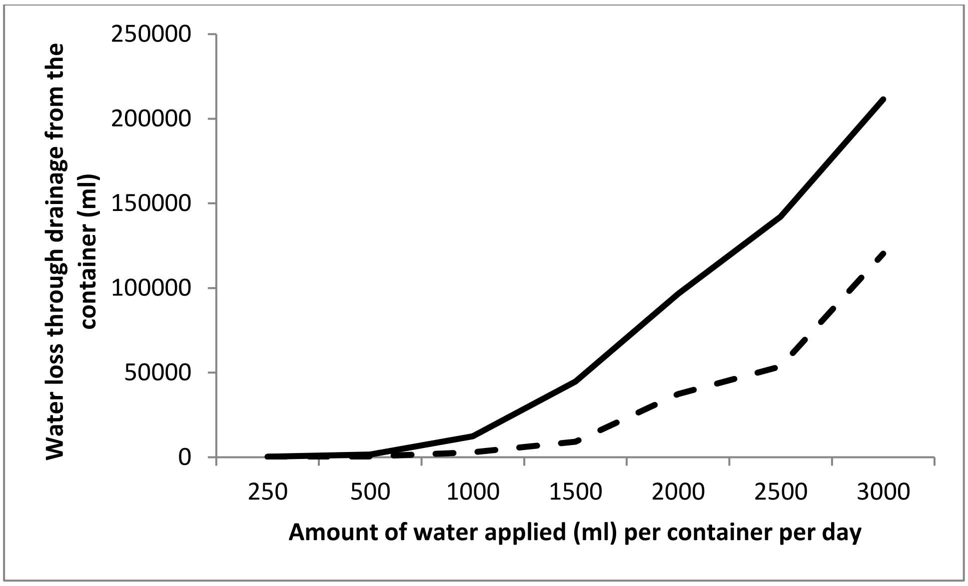

Figure 2: Total amount of water that drained from each container as affected by water application rate and growth media (soil less (——) and ZSAES soil medium (– –) used for sugarcane during the experimental period (150 days)

3.7.4 Germination percent and rate of cane setts

There was no statistical difference between water application rates on germination percent and rate of sugarcane setts in the containers. However, there was higher germination percent and rate of sugarcane setts grown in soil-less medium than for ZSAES soil medium (Table 4).

Table 4: The germination percent of sugarcane setts grown in ZSAES soil and soil-less media averaged across water application rates and measured at 21 days after planting

	Germination percent	**Germination rate**
ZSAES soil medium	62.9a	34.0a
Pine bark + vermiculite	96.2b	66.9b
P value	<0.001	<0.001
CV%	32	30.4
LSD	16.09	9.69

3.7.5 Sugarcane stemheight of primary tiller

There was interaction between media and water application rate on stem height of primary tillers at all sampling times (52 DAP to 107 DAP) (Table 5). At 107 DAP, water application rates of 0.25 L and 1.0 L per container, the stem height of sugarcane plants grown in soil-less medium were taller than in the ZSAES soil medium (Figure 3). In contrast, the stem height of sugarcane plants grown in all media was similar at 1.5 L and 2.0 L water application rates (Figure 3). Also, the stem height of sugarcane plants grown in the ZSAES soil medium was taller than soil-less medium that were applied ≥2.5 L of water per container per day (Figure 3). Stem heights of primary tillers were strongly and positively related (82.31%) to water application rates (Figure 4).

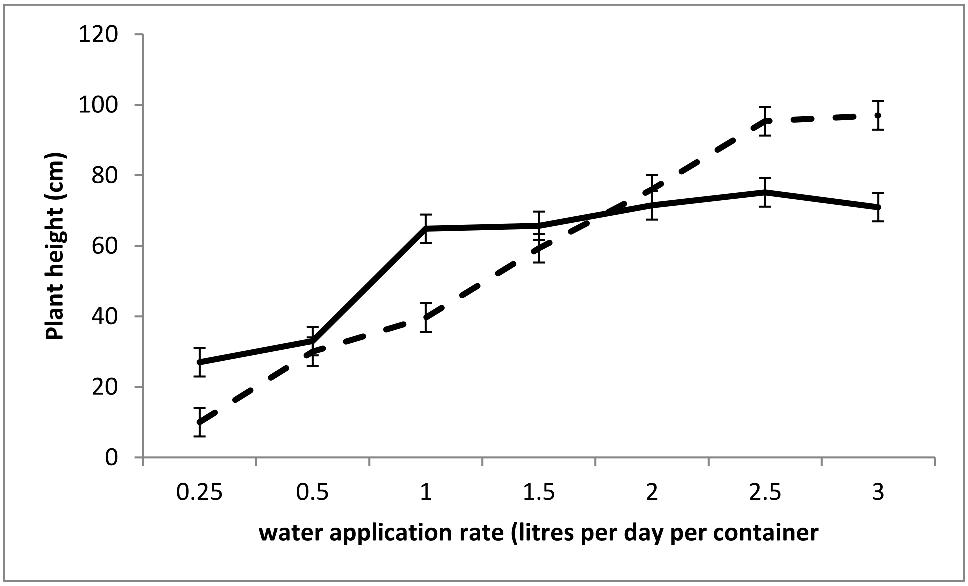

Figure 3: The stem height of primary tillers grown in soil-less (——) and ZSAES soil medium (– –) applied 0.25 L, 0.5 L, 1.0 L, 1.5 L, 2.0 L, 2.5 L and 3.0 L of water per container per day, measured at 107 DAP (level of significance *)**

Table 5: Stem height (cm) of primary tillers of ZN8 sugarcane variety grown in two different growth media (soil-less and ZSAES soil media) applied 0.25 L, 0.5 L, 1.0 L, 1.5 L, 2.0 L, 2.5 L and 3.0 L of water per container per day, measured from 52 to 107 DAP

Water	**52 DAP**		**66 DAP**		**73 DAP**		**86 DAP**		**107 DAP**	
Rate	Soil-less	ZSAES soil	Soil-less	ZSAES soil	Soil-less	ZSAES soil	Soil-less	ZSAES soil	Soil-less	ZSAES soil
0.25 L/day	14.67	8.67	23.00	10.00	25.33	10.00	26.00	10.00	27.00	10.00
0.5 L/day	17.00	16.67	27.00	20.67	28.33	23.67	30.00	25.00	33.00	30.00
1.0 L/day	17.67	24.83	29.00	32.17	33.83	32.50	43.67	32.83	64.83	39.67
1.5 L/day	17.83	23.83	29.17	34.67	32.67	39.17	42.67	45.33	65.67	59.33
2.0 L/day	17.00	17.33	28.00	32.67	31.50	36.50	44.17	49.33	71.50	76.00
2.5 L/day	17.00	20.33	27.67	32.00	33.17	40.00	47.33	59.50	75.17	95.33
3.0 L/day	15.67	21.67	25.50	33.67	31.00	43.50	46.00	62.00	71.00	97.00
P value	<0.001	<0.001	<0.001	<0.001		<0.001				
CV (%)	18.2		11.4		10.6		9.5		8.5	

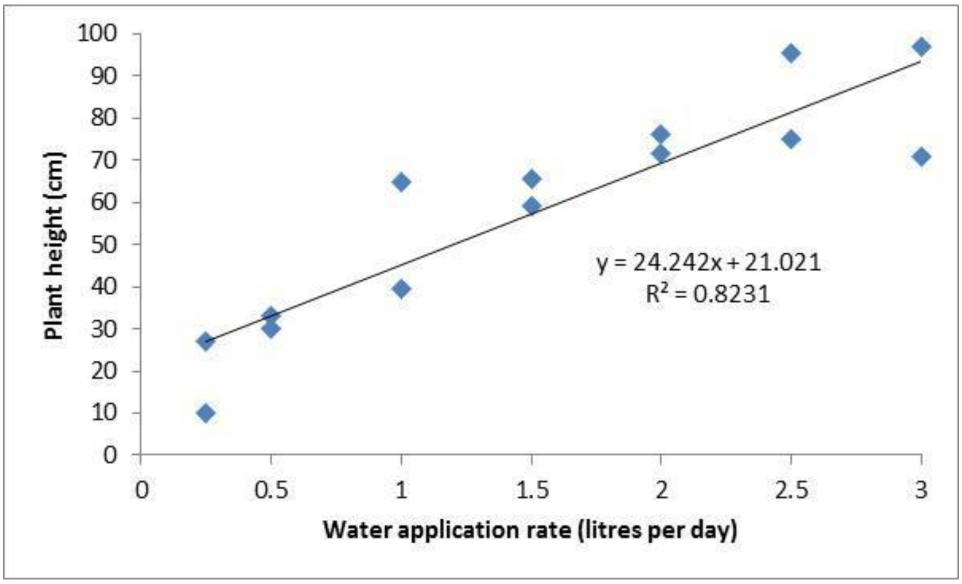

Figure 4: Relationship between plant height and water application rate averaged across mediaof ZN8 sugarcane variety grown in containers

3.7.6 Number of tillers per container

There was interaction between media and water application rate on number of sugarcane tillers per container at 107 DAP. At water application rate of 0.25 L per container, the number of tillers per container in soil-less medium were more than in the ZSAES soil medium (Figure 5). In contrast, at water application ≥0.5 L of water per container per day, the number of tillers per container of sugarcane plants grown in the ZSAES soil medium were more than in soil-less medium (Figure 5).

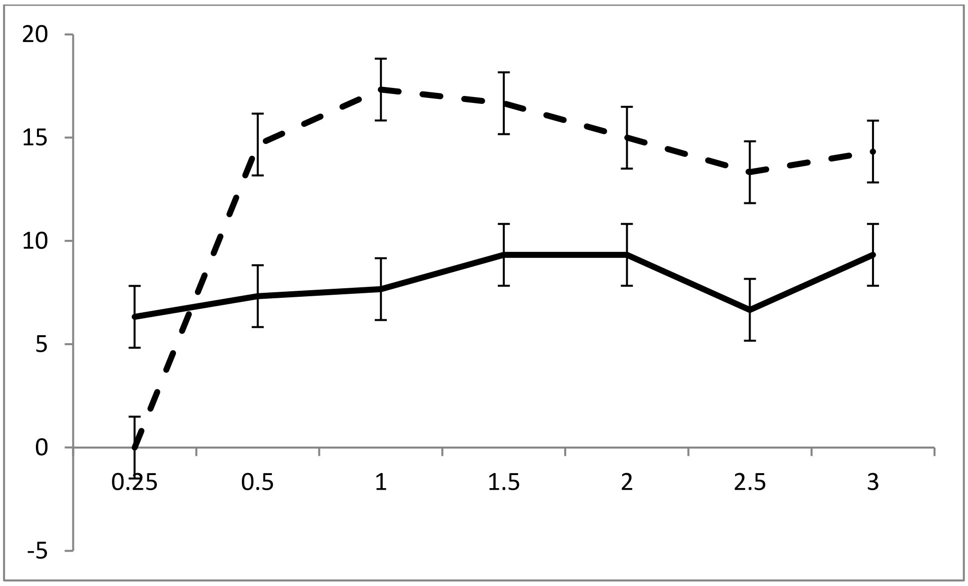

Figure 5: Number of sugarcane tillers per container grown in soil-less (——) and ZSAES soil medium (– –) applied 0.25 L, 0.5 L, 1.0 L, 1.5 L, 2.0 L, 2.5 L and 3.0 L of water per container per day, measured at 107 DAP (level of significance *)**

3.7.7 Leaf temperature of the TVD leaves of primary tillers

There was a significant interaction between growth media and water application rate on leaf temperature (Figure 6). Leaf temperature did not differ at the lowest water application rate for soil-less and the ZSAES soil media but was higher for the ZSAES soil medium than soil-less medium at water application of 0.5 to one litre per container per day (Figure 6). Leaf temperature was similar for the plants grown in the soil-less and ZSAES soil media when 1.5 L per container per was applied. Leaf temperature decreased with increase in water application rate for the ZSAES soil medium but remained constant for the soil-less medium as water application rate was increased above 1.5 L per container per day (Figure 6).

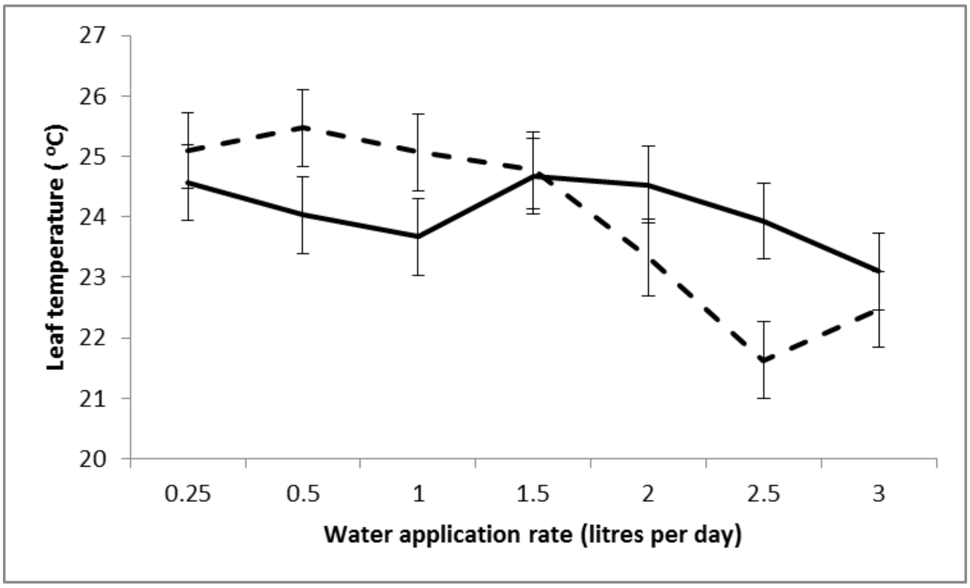

Figure 6: Leaf temperature of the TVD leaves of primary tillers grown in containers with soil-less (———) and ZSAES soil (▬ ▬) media, irrigated different water application rates and measured at 149 DAP (level of significance **)

3.7.8 SPAD index of the TVD leaves of primary tillers

There was a significant interaction of growth media and water application rate on the SPAD index of the TVD leaves of primary tillers (Figure 7). The SPAD index was 40 times higher in the soil-less medium than the ZSAES soil medium at the lowest water application rate of 0.25 L per container per day (Figure 7). However, at water application rates ≥0.5 L per day except 1.5 L per day, the SPAD index of the plants grown in the ZSAES soil medium was the same to that of plants grown in the soil-less medium (Figure 7).

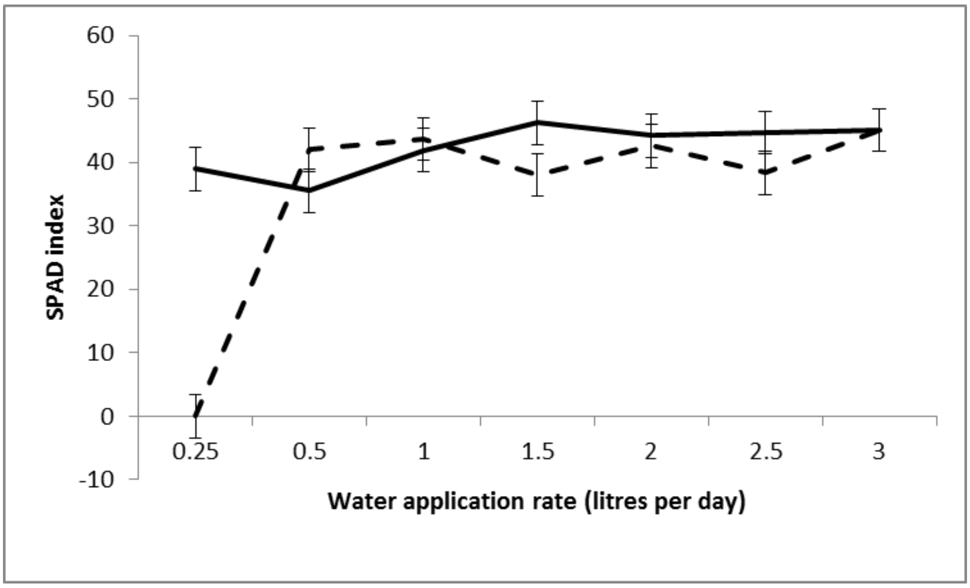

Figure 7: SPAD index of the TVD leaves of primary tiller grown in the soil-less (—) and ZSAES soil (- -) media, irrigated different water application rates and measured at 149 DAP (level of significance *)**

3.7.9 Green leaf area and number of green leaves

There was significant difference in water application rates on the green leaf area (Table 6). Water application rate ≥2.0 L per container per day had greater green leaf area than water application <2.0 L per container per day (Table 6). Also, there was significant difference in water application rates on the number of green leaves per container per day (Table 6). Water application rate ≥0.5 L per container per day had equal number of leaves per container and more than 0.25 L per container per day.

The green leaf area and the number of leaves per container were fewerwhen plants were applied 0.25 Lof water per day per container; these increased as the water application rate increased and tended to plateau at water application rates ≥2.0 L per day per container. The green leaf area and number of leaves were highest in plants grown in the ZSAES soil medium than in plants grown in the soil less medium (Table 6).

Table 6: Number of green leaves and green leaf area of cane grown in containers with soil-less andZSAES soil media, irrigated different application water rates and measured at 150 DAP

Water application rate (L)	Log (x+1000000) Green Leaf area (mm^2)	Log (x+100) Number of green leaves
0.25	6.059^{a} (161204)	2.1002^{a} (29.2)
0.5	6.089^{ab} (226632)	2.1879^{b} (55.3)
1.0	6.136^{bc} (373239)	2.2182^{b} (66.8)
1.5	6.143^{cd} (394687)	2.2140^{b} (64.8)
2.0	6.187^{de} (554636)	2.2278^{b} (70.7)
2.5	6.196^{e} (581440)	2.2274^{b} (70.2)
3.0	6.194^{e} (573039)	2.2355^{b} (73.3)
P value	<0.001	0.001
LSD	0.04754	0.06088
Medium		
ZSAES soil medium	6.1717^{a} (508907)	2.2436^{a} (78.2)
Soil-less	6.1122^{b} (309626)	2.1595^{b} (44.7)
P value	<0.001	<0.001
LSD	0.02541	0.03254
CV (%)	0.7	2.3

Means followed by the same letter, within a column, do not differ significantly at the 5% level. Figures in brackets are the original means

3.7.10 Dry matterof sugarcane tillers

3.7.10.1 Dry matter of green leaves

There was interaction between media and water application rate on dry matter of green leaves at 150 DAP. At water application rate of ≤0.5 L per container, the dry matter of green leaves in soil-less medium and the ZSAES soil medium was equal and the least (Figure 8). In contrast, as the rate of water application increased above 0.5 L per container per day, the dry matter of the green leaves increased to a maximum, but was much greater in the ZSAES soil medium than it was in the soil-less medium (Figure 8).

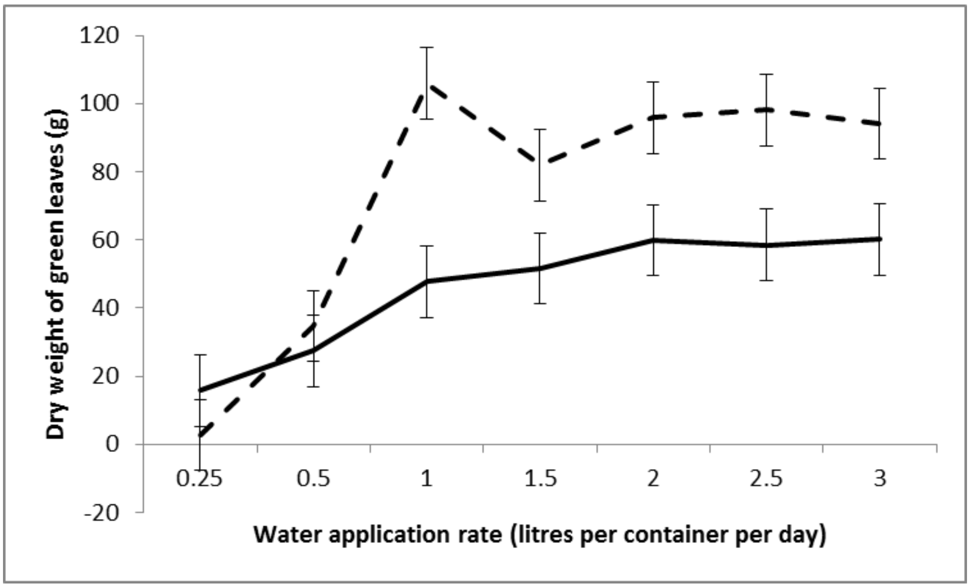

Figure 8: Dry matter of green leaves of plants grown in the soil-less (——) and ZSAES soil (— —) media, irrigated different water application rates and measured at 150 DAP (level of significance **)

3.7.10.2 Above-ground dry matter

The interaction between media and water application rate on above-ground dry matter was significant (Figure 9). At water application rate of ≤1.0 L per container, the above-ground dry matter in soil-less medium and the ZSAES soil medium was equal and the least (Figure 9). In contrast, as the rate of water application increased above 1.0 L per container per day, above-ground dry matter increased to a maximum, but was much greater in the ZSAES soil medium than it was in the soil-less medium (Figure 9). The above-ground biomass increased to a maximum at ≥2.5 L of water per container per day in the ZSAES soil medium.

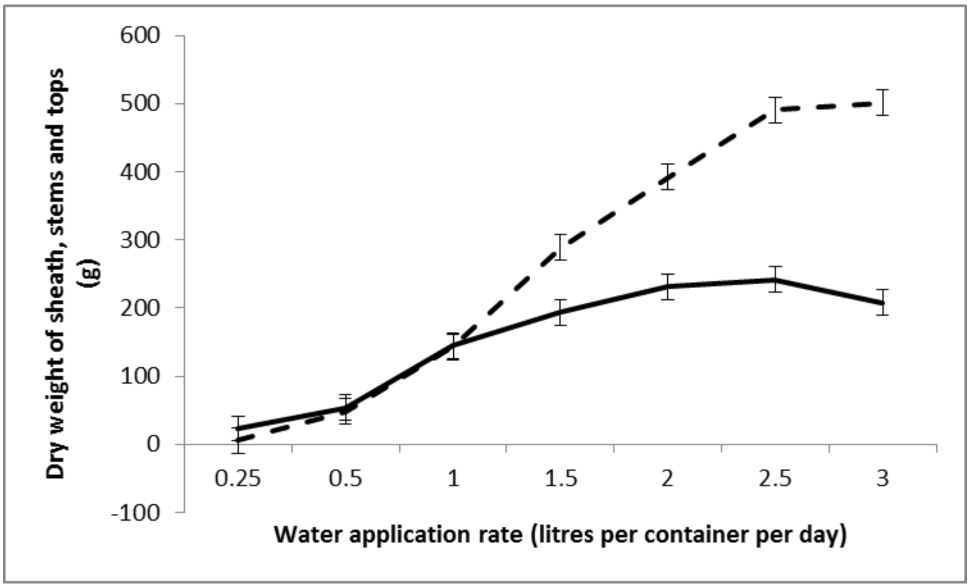

Figure 9: Above ground dry matter of sugarcane plants grown soil-less (━━) and ZSAES soil (━ ━) media, irrigated different water application rates and measured at 150 DAP (level of significance *)**

3.7.10.3 Dry matter of trash

There was interaction between media and water application rate on dry matter of trash at 150 DAP. The dry matter of trash from sugarcane plants in the treatments from 0.25 to 1.0 L per container per day was low and equal for both the ZSAES soil medium and the soil-less medium (Figure 10). However, increasing the water application rate from 1.5 to 3.0 L per container per day resulted in heavierdry matter of trash from sugarcane plants grown in the ZSAES soil medium compared to those in the soil-less medium (Figure 10).

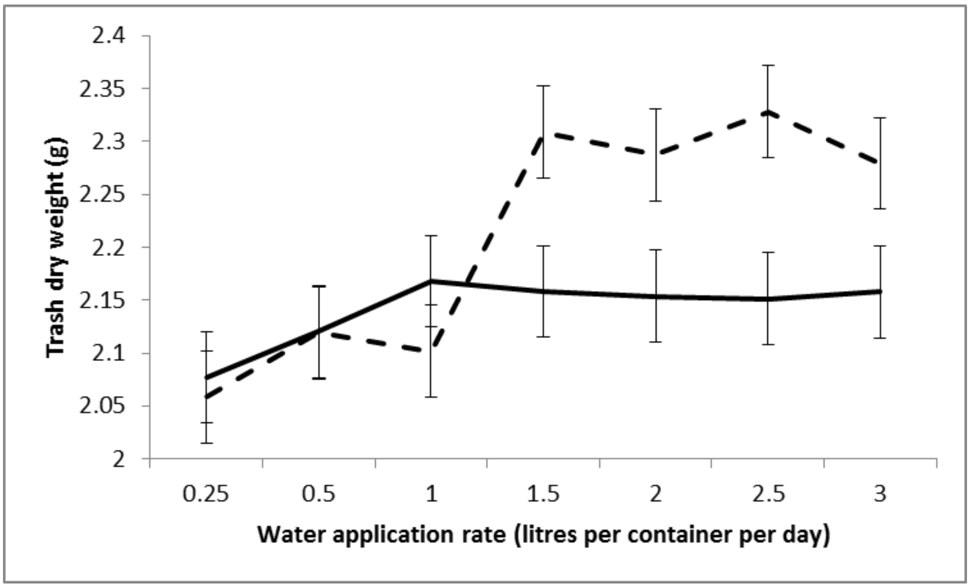

Figure 10: Dry matter of trash dry matter of sugarcane plants grown in the soil-less (—) and ZSAES soil (– –) media, irrigated different water application rates and measured at 150 DAP (level of significance *)**

3.7.10.4 Root dry matter

The interaction between media and water application rate on root dry matter was significant (Figure 11).The root dry matter of the sugarcane plants was similar for the two media between 0.25 and 1.0 L per day. The plants growing in the ZSAES soil medium accumulated more root dry matter than those in the soil-less medium with water application rate at >1.0 L per container per day (Figure 11). Furthermore, the root dry matter declined at water application rates >2.5 L per container per day in the ZSAES soil medium.

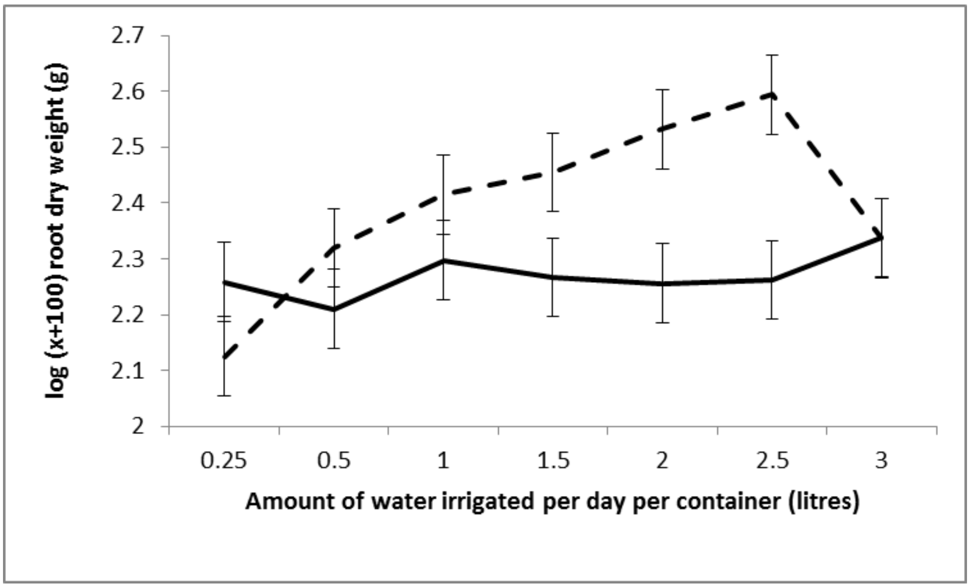

Figure 11: Root dry matter of sugarcane plants grown in containers with the soil-less (——) and ZSAES soil (– –) media, irrigated different water application rates and measured at 150 DAP (level of significance **)

3.7.10.5 Total dry matter of sugarcane plants

There was interaction between media and water application rate on total dry matter of sugarcane plants at 150 DAP. The total plant dry matter (TPDM) of sugarcane plants irrigated with 0.25 to 1.0 L per container per day was low and equal in both the ZSAES soil medium and the soil-less medium (Figure 12). In both media, TPDM increased with increasing water application rates to a maximum at 2.5 L per container per day. The increase was significantly greater in the ZSAES soil medium compared to the soil-less medium at water application rates from 1.5 to 3.0 L per container per day (Figure 12). The differences in TPDM between the two media as the water application rates increased (Figure 12). The relationship between TPDM and plant height showed a strong positive relationship (Figure 13).

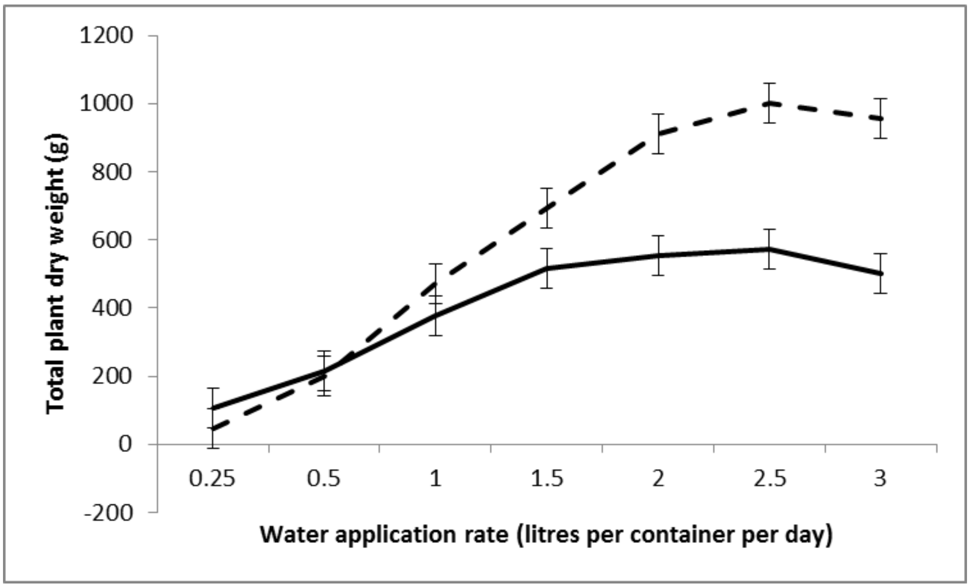

Figure 12: TPDM of sugarcane plants irrigated different water application rates in the soil-less (——) and ZSAES soil (– –) media measured at 150 DAP. Narrow bars represent ±SED (standard error of difference of the means) (level of significance *)**

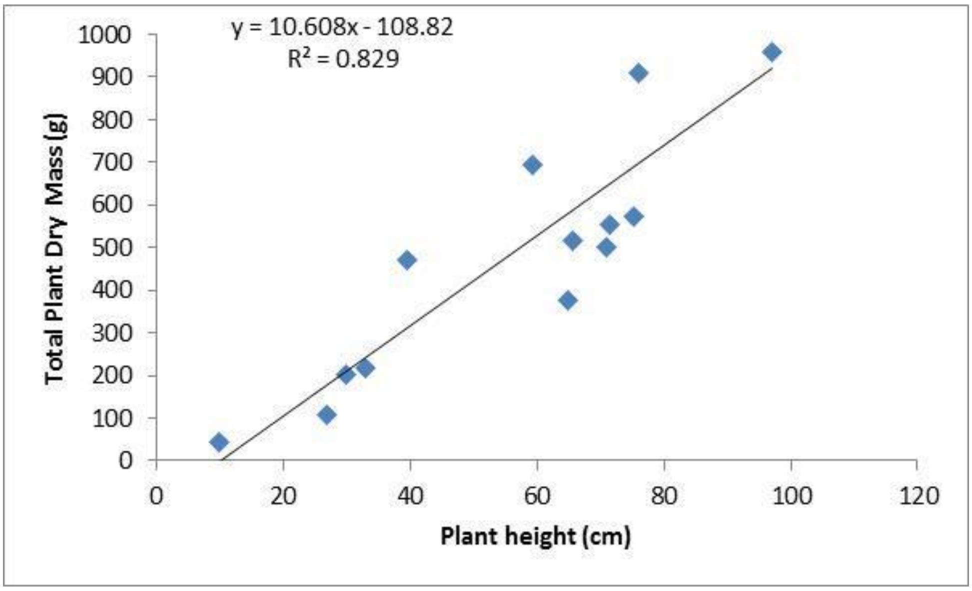

Figure 13: Relationship between total plant dry matter and plant height of plants that were grown in containers and irrigated different water application rates averaged across soil-less and ZSAES soil media

3.7.11 Foliar leaf analyses

3.7.11.1 Leaf nitrogen content

There was interaction between media and water application rate on leaf nitrogen content at 150 DAP. Leaf nitrogen content was higher in plants grown in the ZSAES soil medium than plants grown in the soil-less medium at low water application rate of 0.25 L per container per day (Figure 14). In both media, the leaf nitrogen content decreased markedly at watering rates ≥0.5 L per container per day compared to the 0.25 L per day per container (Figure 14). Nonetheless, the leaf nitrogen content did not change significantly as the water application rate was increased from 0.5 to 3.0 L per day per pot (Figure 14).

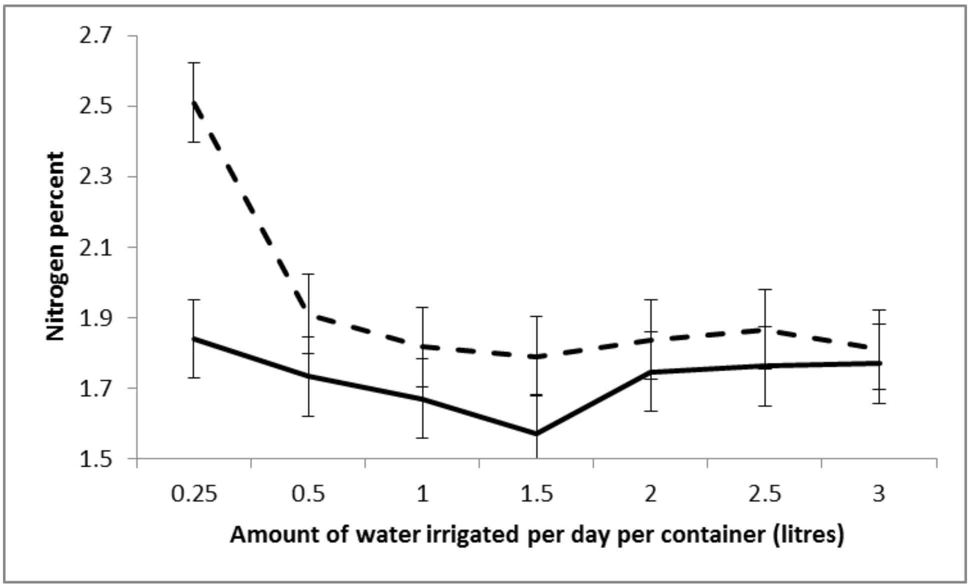

Figure 14: Leaf nitrogen percent of the TVD leaves of primary tiller irrigated different water application rates and grown in the soil-less (—) and ZSAES soil (- -) media measured at 150 DAP (level of significance *)

3.7.11.2 Leaf phosphorus content

There was interaction between media and water application rate on leaf P content at 150 DAP. The leaf phosphorus percent was highest in the lowest water application rate of 0.25 L per container per day in both media (Figure 15) and decreased when the water application rate was 0.5L per day. However, water application rate >0.5 L per day, the leaf phosphorous percent increased linearly with increasing water application rate of ≥0.5L per day in the

ZSAES soil medium. In contrast, leaf phosphorus content did not significantly change with increasing water application rate of ≥0.5L per day in the soil-less medium.

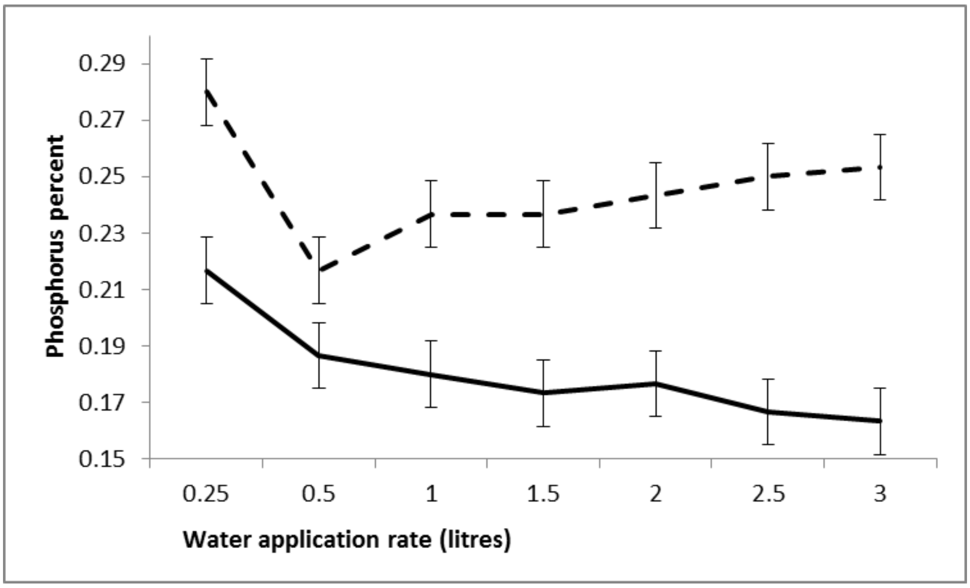

Figure 15: Leaf phosphorus percent of the TVD leaves of primary tiller irrigated different water application rates and grown in the soil-less (——) and ZSAES soil (- -) media measured at 150 DAP (level of significance *)

3.7.11.3 Leaf potassium content

The interaction between media and water application rate on leaf potassium was significant at 150 DAP (Figure 16). Plants in both the ZSAES soil and soil-less media had the same leaf potassium content when irrigated with 0.25 L per day (Figure 16). The leaf potassium concentration of plants grown in the ZSAES soil medium increased markedly in plants irrigated with 0.5L of water per container per day. Further increases in water application rate caused a decline in leaf potassium content of the plants grown in the ZSAES soil medium, the greatest decline being observed in the ≥2.0 L application rate (Figure 16). By contrast, leaf potassium of plants grown in the soil-less medium declined at water application rates from 0.25 to 1.0L per day. There was no significant difference in leaf potassium for plants grown in soil-less medium that was applied ≥ 1.0 L per day. The relationship between leaf potassium and water application rate (Figure 17A) or plant height showed a strong negative relationship (Figure 17B).

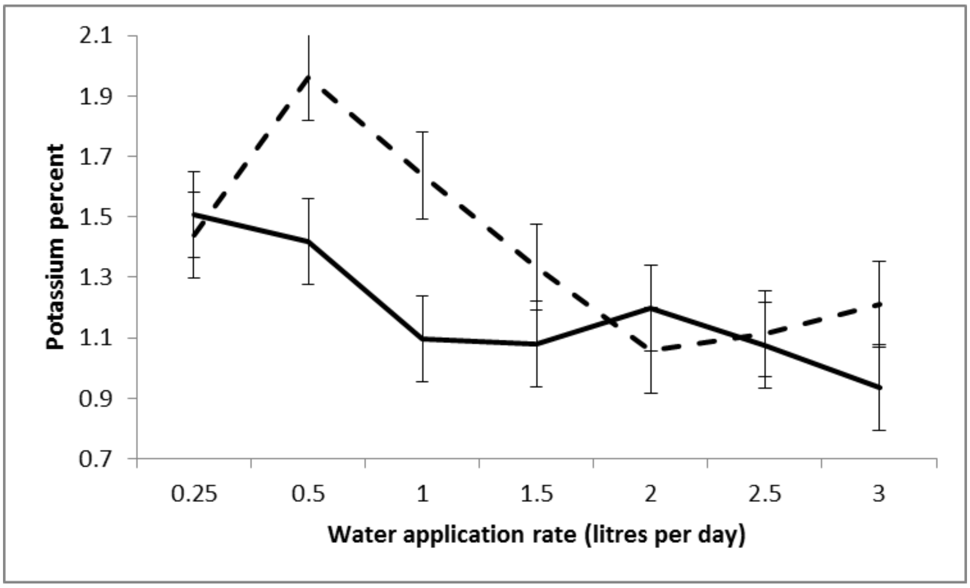

Figure 16: Leaf potassium percent of the TVD leaves of primary tiller irrigated different water application rates and grown in the soil-less (——) and ZSAES soil (– –) media measured at 150 DAP (level of significance **)

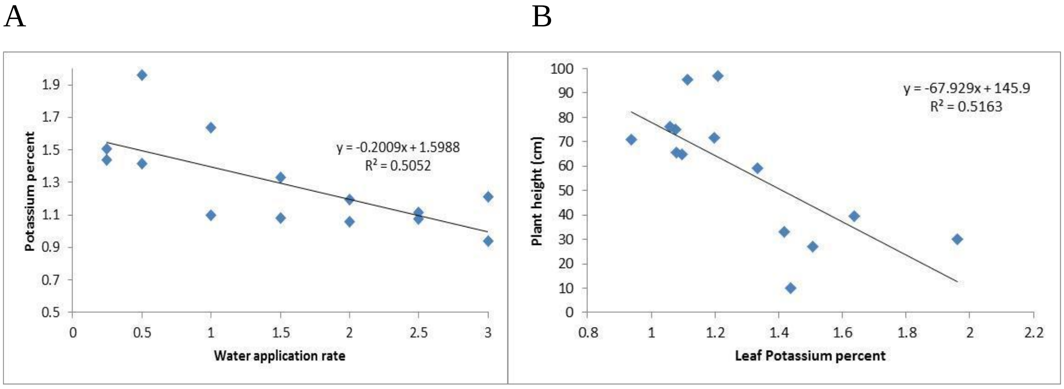

Figure 17: Relationships between leaf potassium percent and water application rate (A), plant height and leaf potassium percent (B) averaged across soil-less and ZSAES soil media

3.7.11.4 Leaf magnesium percent

There was no interaction between water application rate and media on leaf magnesium percent. The main effects of water application rates and media on leaf magnesium percent were significantly different (Table 7). Irrigating 0.25 L per container per day resulted in highest leaf magnesium content followed by 0.5 L per container per day (Table 7). However, leaf magnesium content was highly insensitive to increasing water application rate from 1.0

to 3.0 L per container. There was higher leaf magnesium content for sugarcane plants grown in soil-less medium than in the ZSAES soil medium (Table 7). The relationship between leaf magnesium versus TPDM (Figure 18A) or plant height showed a strong negative relationshipand (Figure 18B). Similarly, the relationship between leaf Mg versus root dry matter (Figure 18C) or water application rate showed a highly negative relationship (Figure 18D).

Table 7: Magnesium percent of the TVD leaves of primary tiller irrigated different water application rates and grown in the soil-less and ZSAES soil media measured at 150 DAP

Water application rate (L)	Magnesium percent
0.25	0.2066^{a}
0.5	0.1750^{b}
1.0	0.1317^{c}
1.5	0.1150^{c}
2.0	0.1283^{c}
2.5	0.1350^{c}
3.0	0.1233^{c}
P value	<0.001
LSD	0.02020
Media	
ZSAES soil medium	0.1390^{a}
Pinebark and Vermiculite	0.1510^{b}
P value	0.032
LSD	0.01080
CV (%)	28.6

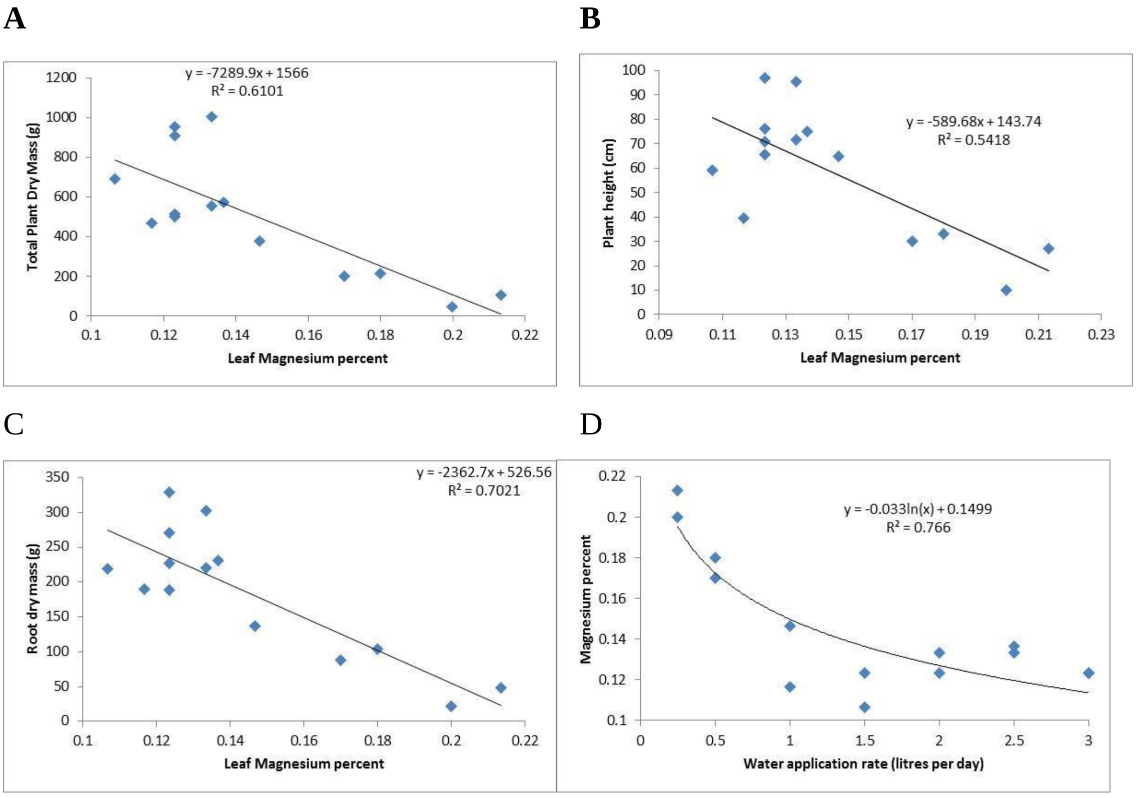

Figure 18: Relationships between TPDM and leaf Mg percent (A) plant height and leaf Mg percent (B), root dry mass and leaf Mg percent (C), water application rate and leaf Mg percent (D) averaged across soil-less and ZSAES soil media

3.7.11.4 Leaf calcium content

There was an interaction between water application rate and media on calcium percent (Figure 19). Leaf calcium concentration was higher in plants that were irrigated 0.25 L and 3.0 L per day per container grown in the ZSAES soil medium thanin soil-less medium. There was no significant difference in leaf calcium percent for plants grown in soil-less and the ZSAES soil media that were applied 0.5 L, 1.5 L and 2.5 L per day per container.At water application rate of 1.0 L per container per day, the leaf calcium content of the plants grown in the soil-less medium was more than that of plants grown in the ZSAES soil medium (Figure 19).

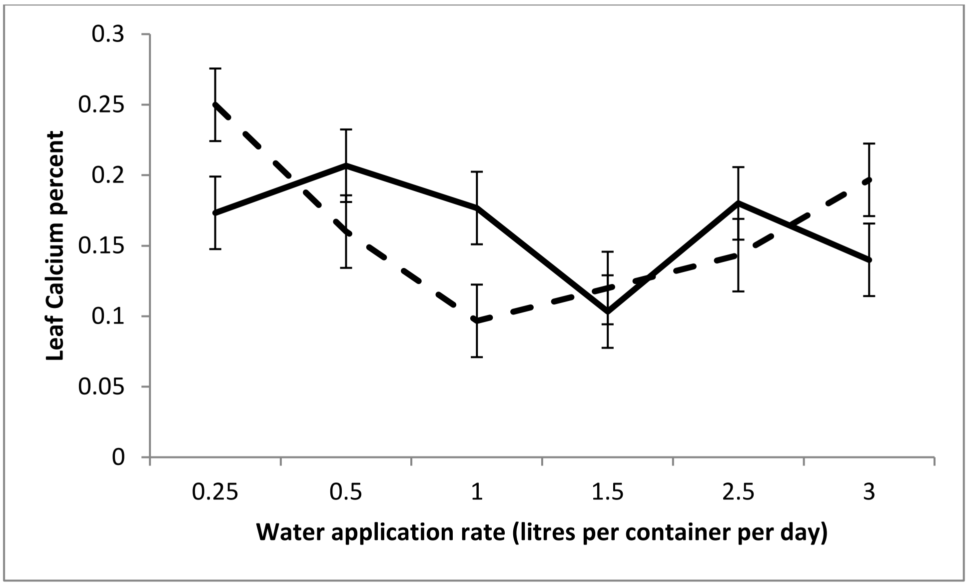

Figure 19: Leaf calcium percent of the TVD leaves of primary tiller irrigated different water application rates and grown in the soil-less (——) and ZSAES soil (– –) media measured at 150 DAP (level of significance **)

3.8 Discussion

3.8.1 Interactions of growth media and water application rate on germination and plant growth

One of the important aspects of a growth medium is to provide a favourable air-water environment in which both air and water are adequately available in the root-zone (Majsztrik et al., 2011). The ZSAES soil medium had a higher bulk density than the soil-less medium (Table 3). Medium with high bulk density has restricted porosity and water logging problems which increase with more watering (Raviv and Lieth, 2008; Majsztrik et al., 2011). Soil-less medium had higher water drainage compared with the ZSAES soil medium (Figure 2). The differences between the two media increased as the water application rate increased. The high retention of water in the ZSAES soil medium, especially at higher water application rates, resulted in water logging conditions. The deleterious effects of restricted drainage and overwatering were highly conspicuous in the germination of the cane setts for the ZSAES soilmedium (62.9 %) than soil-less medium (96.2 %) (Table 4). In addition, the germination rate of cane setts grown in soil-less was much higher than in the ZSAES soil medium (Table 4). According to Smit (2010), germination of cane setts was above 90% for the fertilised seed lots in the 30 ºC environment. The germination of cane setts is known to be adversely affected by inadequate aeration (Inman-Bamber and Smith, 2005), which explains the lower germination percent and rate of the cane setts in the ZSAESsoil medium which has restricted drainage, than in the soil-less medium. Ridge (2013) revealed that besides excessive soil moisture, germination of buds is sensitive to temperature. Although in this experiment, temperature of the media was not measured, temperature differences may have resulted in variances in germination of setts between ZSAES soil medium and soil-less medium. In Chapter 6 of this study showed that ZSAES soil medium had lower temperature than soil-less media (Figure 64 and 65). Smit (2010) reported that germination of cane setts increased with temperature. Temperature affects the production of gibberellins that are responsible for breaking dormancy (Finch-Savage and Leubner-Metzger, 2006). Also temperature affects the production of enzymes that is invoved in complex reactions during germination (Finch-Savage andLeubner-Metzger, 2006).

However, despite the adverse effects of restricted aeration in the ZSAES soil medium and its exacerbations with increased water application rate. Not only were stem height (Figure. 3), tillering (Figure. 5), green leaf area (Table 6), above ground plant weight (Figure 9) and total plant dry matter (Figure 12) higher in ZSAES soil medium than in the soil-less medium, but they also increased with increasing water application rate. This indicated that there were other factors at play that controlled these parameters, making the ZSAES soil medium more favourable for plant growth than the soil-less medium. As sugarcane plants grew beyond germination, they require more water for plant growth (Clowes and Breakwell, 1998). ZSAES soil medium retained more water than soil-less medium (Figure 2) and this may explain better growth in ZSAES soil medium than soil-less medium. The decrease in leaf temperature with increasing water application rate was more pronounced in the ZSAES soil medium than soil-less (Figure 6). High leaf temperature of sugarcane plants is indicative of less tolerance to water-deficit stress (Silva et al., 2007). However, adverse effects of water application rates >2.5 L per containerper day and restricted aeration in the ZSAES soil medium were observed in the dry matter of sugarcane plant roots (Figure 11). Understandably, roots are the organs in direct contact with water logging conditions and, therefore, would be the first to be affected by oxygen starvation (Tamang and Fukao, 2015).

Reduced plant biomass at water application rates >2.5 L per container per day in the ZSAES soil medium may be caused by other factors such as nutrition and container space that were limiting. As sugarcane plants grow, they require more N and K for biomass accumulation (Ridge, 2013). However, in this experiment, the leaf N and K for plants grown in the ZSAES soil medium with high water application rate was above the optimal threshold (SASRI, 2013).The limited space of containers may have impeded the root growth which reduced biomass accumulation of sugarcane plants (Yang et al., 2010).Nonetheless, water application rates >2.5 L per container per daylinearly increased stem elongation of plants in the ZSAES soil medium (Figure 3). Soil moisture is a critical factor in stem elongation over other factors such as mineral nutrition and root space (Zhao et al., 2013).

3.8.2 Interactions of growth medium and water application rate on tissue N, P, K, Ca and Mg concentrations

Container-grown plants are dependent on a relatively small volume of growing medium and therefore cannot mine the soil far and wide for nutrients and water (Poorter et al., 2012a). As a result, the degree to which the growth medium meets the nutrient requirements of the plants partly depends on the watering regime. Watering regime affects nutrient losses through leaching, and on the fertilisation program as it affects the replacement of the nutrient lost (Barrett et al., 2016). Between the two media tested in this experiment, the inherently lower pH, P and K in the soil-less medium (Table 3) were expected to restrict the growth of plants in that medium. This was mitigated by the application of a Hoagland nutrient solution, which should have reduced the differences in the nutrient availability between the two media tested. However, despite the supply of the nutrients via the Hoagland solution, the soil-less medium still had poorer growth than the soil-based ZSAESsoil medium (Figure 3 and Figure 5). Even though the reason for the difference in plant growth between the two media could not be discerned from the experiment, this outcome possibly points to variation in total available nutrients namely inherent in the media (Table 3) plus applied via the Hoagland Solution.

The effects of water application rate on the contents of the primary mineral nutrients in the leaves were most marked for K, which decreased with increasing water application rate in both media (Figure 16). Nitrogen and P showed a marked decrease only when the water application rate was increased from 0.25 to 0.5 L per pot per day. The values remained fairly close to each other as the water application rates increased. Thus, the application of the Hoagland solution adequately offset the loss of these nutrients from the soil through leaching. The tendency for leaf N, P and K content to be higher in the lowest water application rate (Figure 14; Figure 15 and Figure 16) could be explained by lack of dilution due to severely restricted plant growth in this treatment (Figure 3). The nutrient content in leaves of plants with low water application rate had excess K (1.90 %) and high N (2.5 %) and Mg (0.21 %) compared to the optimal threshold levels (SASRI, 2013). The decreasing leaf K with increasing water application cannot be explained by leaching, especially for the ZSAES soil medium because of water logging conditions that occurred at higher water application rates. However, the decrease in leaf K may have not been consequential to the growth of the plants as the leaf K level remained above optimal (1.05%) for plant growth (SASRI, 2013; Ridge, 2013). Sufficiency of leaf potassium in the ZSAES soil medium may be explained by high potassium inherently in this medium when compared to soil-less (Table 3). Potassium acts as an enzyme activator in the plantmetabolism such as in photosynthesis and translocation of sucrose from leaves to storage tissues in stalks (Medina et al., 2013). Also potassium is important in the hydration and osmotic concentration within stomata guard cells (Kwong, 2002)

A point to note is that the leaf P content of plants grown in the ZSAES soil medium increased whereas that for the soil-less medium decreased with increasing water application rate (Figure 15). This scenario suggests that the absence, due to leaching, of colloidal material to retain the P in the growth medium for plant uptake was probably a factor in the soil-less medium (Barrett et al., 2016). The leaf P in the plants grown in the soil-less medium increasingly became deficient until it was less than the optimal threshold of 0.19 % (SASRI, 2013) in plants with increasing water application rate (Figure 15). In addition, phosphorus content inherently in soil-less medium was 27 times lower than in ZSAES soil medium. Low leaf P may have been the cause of lower response of the plant dry matter to increasing water application rate in soil-less medium (Figure 12). This suggests that the P application rate should be increased beyond what was used in this study if soil-less medium is used for container-grown plants. Whereas, in the ZSAES soil medium, leaf P increased as water application rate increased. However, there was a decline in the leaf N (Figure 14) and K content (Figure 16)in the ZSAES soil medium with increasing water application rate, yet the decreases were associated with increase in plant growth (Figure 3). The leaf N and K for plants grown in the ZSAES soil medium with high water application rate was, however, still greater than the optimal threshold of 1.7 % and 1.05 %, respectively, suggesting Hoagland nutrient solution was adequate to supply N and K in this medium (SASRI, 2013). Leaf N content in plants grown in the soil-less medium was below the threshold when water was applied at a rate >0.5 L per container. Leaf K in this soil-less medium was sufficient with values >1.05 % (SASRI, 2013) across all water application rates except 3 Lper container.

Irrespective of water application rate used in this experiment, leaf Mg in both media tested wassufficient since it was greater than the optimal threshold of 0.08 % (SASRI, 2013). Leaf Ca was deficient (below optimal threshold of 0.15 %) in plants grown in the ZSAES soil medium with increasing water application rate (Figure 19). Leaf Ca was sufficient in soil-less medium in spite of water application used except 1.5 and 3.0 L per container per day. This may be partly explained by 16 % higher calcium content inherently in the soil-less medium than the ZSAES soil medium (Table 3). Also there was more plant growth in the ZSAES soil medium at high water application rates when compared to soil-less medium that would have led to competition between tillers for Ca.

3.9 Conclusions

The most suitable water application rate for greater growth performance of sugarcane was ≥2.5 L per container per day in the ZSAES soil medium since it resulted in more tillers per container, higher stem height,more green leaf area,above ground dry matter and total plant dry matter. In addition, sugarcane applied high water application rates had leaf N, P, K and Mg above optimal threshold levels except leaf Ca. However, the germination of cane setts was 53 % lower in the ZSAES soil medium than in the soil-less medium due to restricted drainage.

CHAPTER 4

ASSESSING MEDIA FOR SUITABILITY OF GROWING SUGARCANE PLANTS IN CONTAINERS

4.1 Abstract

There is limited knowledge available on the optimum medium that can be used for growing sugarcane plants in containers. A Completely Randomised Design (CRD) consisting of four levels of media and three sugarcane varieties in a factorial arrangement with three replications was used to assess media for suitability of growing sugarcane plants in a container at the Zimbabwe Sugar Association Experiment Station (ZSAES). The objectives were to test four media on the growth performance and leaf nutrient concentrations of three sugarcane varieties. The four media levels were filter cake only, pine bark + filter cake, pig manure + pine bark and ZSAES soil medium. The three sugarcane varieties used were a low stalk population variety ZN7, a medium stalk population variety ZN8 and a high stalk population variety ZN10. The germination of cane setts planted in ZSAES soil medium was 66 % while the other media had germination of above 80 %. Stem elongation for plants grown in pig manure + pine bark was suppressed by 30 % but number of green leaves, green leaf shoot and root biomass was higher than other media. Plants grown in pig manure + pine bark had adequate leaf calcium, potassium, magnesium, nitrogen and phosphorus concentrations making the medium more suitable when compared to the other media tested. Potassium was not adequate in plants grown in the filter cake + pine bark or filter cake only. The differences between varieties in plant growth was only observed in number of tillers with ZN7 maintaining a low tiller production when compared to ZN8 and ZN10. In leaf nutrition, all varieties attained leaf nutrient concentrations above the critical levels except potassium which was only adequate in variety ZN8.

Key words: soil-less, sugarcane, container, medium, stress.

4.2 Introduction

Considerable research has been done on sugarcane physiology in containers (Smith et al., 2005; Zhao et al., 2010; Queroz et al., 2011; Graça et al., 2010; Zhao et al., 2014). The major benefit of doing research on sugarcane in containers as compared to the field is that the environment is controlled and this reduces variability caused by non-treatment factors (Kawaletz et al., 2014). Another benefit of container experiments is that physiological traits are accurately measured without disturbing plant communities (Kohout et al., 2011). However, growing sugarcane in containers has its own challenges. The container used may induce some stresses on the crop. Jones (2016) reported that plants grown in controlled environments were more sensitive to stress than those grown in the field.

It has been observed at the Zimbabwe Sugar Association Experiment Station (ZSAES) that sugarcane grown in containers had uncharacteristically shorter internodes than sugarcane grown under field conditions (unpublished data). Reduced internode length in sugarcane plants is a sign of stress caused by the container or atmospheric environment (Bonnett et al., 2006). The internodes of sugarcane plants should be elongated to allow a great amount of sucrose produced by leaves to be loaded in the vacuoles of the parenchyma cells within the internodes (Oregeron, 2012). Short sugarcane internodes are a result of poor growth of the plant. One factor that may affect the growth of sugarcane plants in containers is the growth medium. Growth media used in containerised production vary in water holding capacity, texture, pH, anion and cation exchange capacities, porosity and fertility (Raviv and Lieth, 2008).

There is limited information on the appropriate medium for growing sugarcane in containers (Carlile and Coules, 2009). Media used in containers for growing plants includes materials as diverse as sand, pine bark, natural soil, composted sugarcane filter cake, vermiculite and peat (Raviv et al., 2002; Majsztrik et al., 2011). According to Argo (1998a and 1998b), the physical and chemical properties of the medium are mainly determined by particle size and composition of the substrate. While fine textured media have high water retention capacity, they also have poor aeration. In contrast, coarse textured media have large pores that improve aeration. However, coarse textured media does not retain sufficient water and nutrients (Spomer et al., 1997). Whereas there is no ideal medium for containerised production, substrates can be mixed in order to obtain optimal plant growth (Majsztrik et al., 2011). Media mixes that have been developed commercially for vegetable and flower nursery are Cornell peat-lite mixes (Boodley and Sheldrake, 1977). Cornell peat-lite mixes contain sphagnum peat moss and vermiculite or perlite as the main substrates. The ratios of the substrates in the media mix vary depending on plant species, although one part peat moss to one part vermiculite to one part perlite moss is commonly used (Boodley and Sheldrake, 1977). A media mix developed specifically for sugarcane plants grown in containers can potentially reduce stress in the crop.

In Zimbabwe, the sugarcane industry has been using the ZSAES soil medium for growing sugarcane plants in containers. The ZSAES soil medium comprises five parts of top soil, two parts of river sand and two parts of composted cattle manure (unpublished data). To produce ZSAES soil medium, large quantities of top soil are required and continuous mining of this natural resource causes environmental damage (Geissen et al., 2013). In addition, feed and health related factors has resulted in high mortality of cattle of up to 17 % in Zimbabwe and this has led to reduced volumes of cattle manure required in the composition of the ZSAES soil medium (Nkomboni et al., 2014). Therefore, an alternative sustainable medium for growing sugarcane plants in containers needs to be developed.

For sugarcane plants to grow well, the roots need to respire and take up water and nutrients from the medium mix. Therefore, an ideal medium mix should retain enough oxygen and water for absorption by the roots. Micro pores of the medium retain waterwhilst macro pores increase aeration and drainage (Drzal et al., 1999). Therefore, a suitable media mix should provide a balance of micro pores and macro pores for optimal plant growth (Raviv et al., 2002). Too many micro pores cause the medium to have poor drainage and saturation at the bottom (Spomer et al., 1997). Perching of water at the bottom of the container creates water logging conditions, depriving the roots of much needed oxygen for respiration. Abundant macro pores in the media not only facilitate entry of air into the container but also increased free drainage, thus causing most of the water and nutrients to be lost through leaching (Raviv et al., 2002).

The medium is the source of nutrients which are drawn by the plant and used in biomass accumulation (da Silva et al., 2018). Plant cane of sugarcane, generally, require nutrients in the following order K > N > Ca > Mg > S > P (Franco et al., 2007; da Silva et al., 2018). The leaf nutrient concentrations are used to determine sufficiency or deficiency of specific nutrient (Muchovej et al., 2006). The medium used to grow sugarcane plants may exhibits constraints such as low fertility, poor drainage, acidity, sodicity and salinity which may reduce the availability of nutrients for uptake, thereby causing deficiency of certain nutrients (Ridge, 2013).

In the Zimbabwe sugarcane industry, there are a total of 14 commercially released varieties. These varieties are divided broadly into high (140000), medium (120000) and low (80000) stalk populations (Clowes and breakwell, 1998). Sugarcane varieties differ in stem elongation, their ability to tiller, dry matter partitioning and cane yields (Freire et al., 2010; Zhou and Shoko, 2011; Costa et al, 2016; Alam et al., 2017). This is partly due to differences between sugarcane varieties on their demands for nutrients, water, light and other factors (Marchiori et al, 2010; Calheiros et al., 2011; de Oliveira et al., 2017).Therefore, sugarcane varieties are likely to differ when grown in different media in a container.

4.3 Aim

4.3.1 To assess growth media for suitability for growing sugarcane plants in a container.

4.4 Specific objectives

4.4.1 To test four media namely filter cake only, filter cake + pine bark, pig manure + pine bark and ZSAES soil medium (control) on the growth performance (germination percent, stem height, number of tillers, SPAD index, green leaf area, number of leaves, dry matter of above and below ground parts of plants) of ZN7, ZN8 and ZN10 sugarcane varieties in December 2016 to April 2017.

4.4.2 To test four media namely filter cake only, filter cake + pine bark, pig manure + pine bark andZSAES soil medium (control) on leaf nutrient concentrations (N, P, K, Mg and Ca percent) of sugarcane plants of ZN7, ZN8 and ZN10 sugarcane varieties in December 2016 to April 2017.

4.5 Hypotheses

4.5.1 The growth media has an effect on growth performance (germination percent, stem height, number of tillers, SPAD index, green leaf area, number of leaves, dry matter of above and below ground parts of plants) of ZN7, ZN8 and ZN10 sugarcane varieties.

4.5.2 The growth media has an effect on leaf nutrient concentrations (N, P, K, Mg and Ca percent) of sugarcane plants of ZN7, ZN8 and ZN10 sugarcane varieties.

4.6 Materials and methods

4.6.1 Trial site

The study was done in an open area at the ZSAES from December 2016 to April 2017. The Station, which lies between 21^{o}01'S and 28^{o}38'N is located in Chiredzi in south eastern Lowveld of Zimbabwe. The altitude of the area is 430 metres above sea level (masl) and it receives an average rainfall of 625 mm per annum, predominantly from October to March (summer months). The summer months are also characterised by higher Class A evaporation of approximately 2000 mm per year. Mean ambient temperatures range from 26 ^{o}C in summer to 16 ^{o}C in winter.

4.6.2 Design and treatments

A Completely Randomised Design (CRD) consisting of four levels of media in factorial combinations with three sugarcane varieties and three replications was used. The four media levels used in the experiment are shown in Table 8. The three varieties of sugarcane used were ZN7 (low stalk population), ZN8 (medium stalk population) and ZN10 (high stalk population).

Table 8: Media (filter cake only, filter cake + pine bark, pig manure + pine bark and ZSAES soil medium (control) and their componentsused to assess for suitability of growing sugarcane plants in a container

Media	**Components of media by volume**
Filter cake only (soil-less)	100% composted filter cake
Pine bark + filter cake (soil-less)	50% composted filter cake + 50% composted pine bark
Pine bark + pig manure (soil-less)	50 % composted pine bark + 50 % composted pig manure
ZSAES soil medium (control)	topsoil : river sand : cattle manure using a ratio of 5 : 2: 2 (v/v).

4.6.3 Media preparation and description of the container

The soil-less media mixes were made by mixing the substrates in the ratio of 1:1 of their volumes. The media mixes were prepared by spreading the components on a large plastic sheet and mixing them thoroughly. The containers used for growing sugarcane plants measured 35 cm top diameter, 23 cm bottom diameter and 27.5 cm height. They were filled with growth media to within 7.5 cm from the brim leaving space for irrigation water. The containers had six holes (1.0 cm diameter) at the base for drainage. Prior to planting, all soil-lessmedia were saturated by plugging the drainage holes for 72 hours. The ZSAES soil medium was only saturated for 24 hours prior to planting without plugging drainage holes.

4.6.4 Planting and fertilisation

Sugarcane setts of ZN7, ZN8 and ZN10 varieties (12 months old) were cut at the base from S4 field using cane knives which were sterilized by immersing them for 5 minutes in diluted Propan-2-ol or isopropanol (JEYES fluid) (0.5 LJEYES fluid per 10 L of water). Three internodes from the base and top of the stalk were discarded using a cane knife. One eyed setts were cut from the remaining stalk before dipping them for five minutes in Triadimenol (Shavit) (1ml Shavit / 1000 ml of water) to prevent ratoon stunting disease. Five 'one' eyed setts of sugarcane were then planted 40 mm deep on 26 December 2016 at the surface of the medium in each container. After emerging, the primary plants were thinned to one plant per container. Each container was fertilized using 250 ml Hoagland modified solution (Hoagland and Arnon, 1950) of 100 % strength from a day after planting and, thereafter, every other day until the end of the experiment.

4.6.5 Pest control and irrigation

Weeds were pulled out of the containers by hand from planting to harvesting. Fipronil (Regent) at the rate of 135 ml Regent /15 L of water was sprayed at the base of the containers and around the experimental site to control termites. The plants were irrigated by the same amount of water starting with 1 litre per day per container during the first month, increasing to 1.5 and 2.5 litres per day per container respectively in the second and third months. In the fourth month, the plants were irrigated with 3.0 L per day per container till the end of the experiment.

4.6.6 Measurements and data analysis

Prior to planting, samples of each media used in the experiment were analysed using methods presented in Table 1 of Chapter 3. Mean seasonal evaporation, air temperature, and rainfall data were collected from an automated weather station which was located approximately 100m from the experimental site. Total volume of water that drained from the container was measured by placing plastic dishes underneath and measuring collected water every day at 0700 hours before irrigation from planting to the end of the experiment. The number of sugarcane plants that emerged from the setts divided by the number of setts planted was recorded at 15 DAP as germination percent. Germination rate was estimated using a modified Timson's index of germination velocity ($\sum G/t$), where G is the percentage of germination at one-day intervals and t is the total germination period (Khan and Ungar, 1984). Germination percent and ratewere recorded before the plants were thinned, leaving one plant per container. Plant height was measured two weeks after emergence and, thereafter, fortnightly till the end of the experiment. Plant height was measured from the surface of the medium in the containerto the apex of the plant using a 3m tape measure. The number of tillers in each container was counted beginning two weeks after emergence and fortnightly, thereafter. The SPAD index of the leaf with the top most visible dewlap (LTVD) of the primary tiller was measured using a chlorophyll meter (Minolta SPAD-502, Minolta Co., Osaka, Japan) between 0600 and 0900 hours starting eight weeks after planting and thereafter, fortnightly (Zhao et al., 2010). Starting from eight weeks after emergence, the leaf with the TVD of the primary tiller was plucked at monthly intervals for analyses of nutrient elements using methods presented in Table 2 of Chapter 3. At termination of the experiment, all the leaves were counted and their leaf area was measured using a leaf area meter (Delta-T Devices Ltd., Burwell, Cambridge, UK). Sugarcane plants were excised at the base to separate the shoot and the roots. The roots were washed with water to remove any media particles. Washed roots and shoot components were dried at 95 ^{o}C in a forced air oven for 72 hours and weighed. The data were subjected to Fisher's Analysis of Variance using Genstat statistical software (Genstat 14th edition, VSN International Ltd., Hemel Hempstead, UK). The treatment means were separated using ±SED (standard error difference) means and Least Significant difference test at 5 % significant level (Steel and Torie, 1984). Regression analysis of the data was done using MS Excel 2010 version.

4.7 Results

4.7.1 Seasonal meteorological data

A high amount of rainfall was recorded in December 2016 and it increased to reach a peak in January 2017, declining thereafter as summer tailed off (Figure 20). The average temperature was 27.5 ^{o}C in December 2016 and it gradually decreased to 22.7 ^{o}C in April 2017 (Figure 20). The average monthly evaporation was generally low, with a mean of 4.8 mm per day throughout the period (Figure 20).

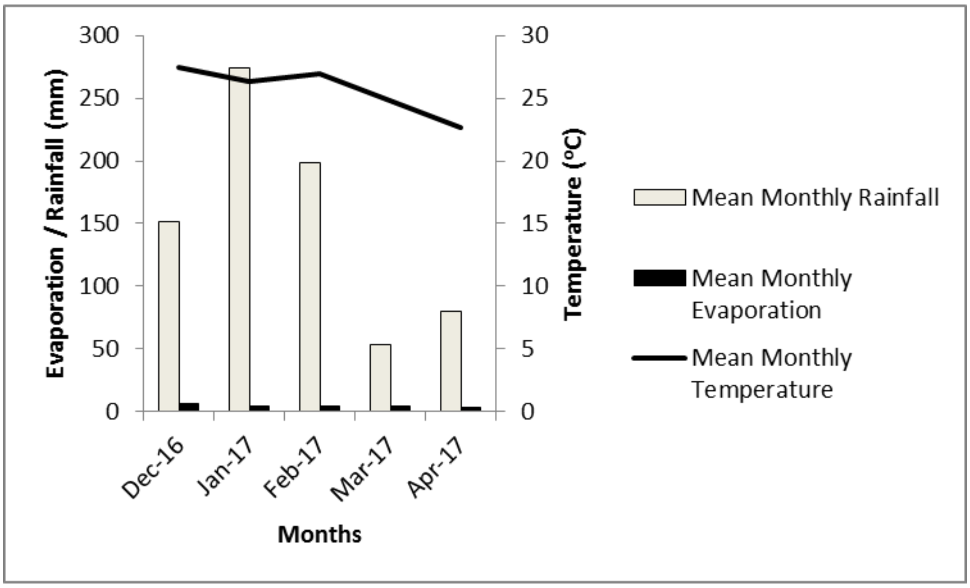

Figure 20: Average monthly temperature, rainfall and evaporation at ZSAES for December 2016 - April 2017

4.7.2Chemical analyses of growth substrates used in the experiments onmedia, fertiliser and container size

The pH ($CaCl_2$) of pig manure + pine bark was slightly acidic (6.61) whereas the other media had pH around the neutral range (7.01 to 7.60) (Table 9). The electrical conductivity of the ZSAES soil medium was much higher than that of the soil-less media (Table 9). Nitrogen content was high in the filter cake only and in the pig manure + pine bark media but, was very low in the ZSAES soil medium (Table 9). Phosphorus content was almost similar across all the media, although the ZSAES soil medium had the least. Potassium content was lower in the filter cake + pine bark relative to other media. The filter cake + pine bark and filter cake only media had the highest calcium content (Table 9). In comparison, the pig manure + pine bark medium had the highest concentration of magnesium, sodium, copper and iron while the ZSAES soil medium had the least. Manganese concentration was highest in the filter cake only medium (Table 9). The ZSAES soilmedium had higher bulk density than the tested soil-less media (Figure 21).

Table 9: Chemical analysis of pig manure + pine bark, filter cake only, filter cake + pine bark, and ZSAES soil medium (control) that was measured in December 2016

Parameter	Pig manure + pine bark	Filter cake only	Filter cake + pine bark	ZSAES soil medium
pH ($CaCl_2$)	6.61	7.51	7.01	7.60
EC (uS/cm)	921	536	346	1470
N (%)	1.11	1.20	0.97	0.40
P_2O_5 (ppm)	309	323	298	228
K (ppm)	2866.7	2789.3	1622.3	2709.2
Ca (ppm)	3160	5768	5824	2830
Mg (ppm)	2477	2250	1922	841
Na (ppm)	752.3	236.7	139.8	287.5
Cu (ppm)	29.7	6.3	11.7	3.6
Zn (ppm)	114.9	64.9	48.9	4.3
Fe (ppm)	1129.4	768.7	1094.0	318.9
Mn (ppm)	231.8	402.0	389.8	203.1

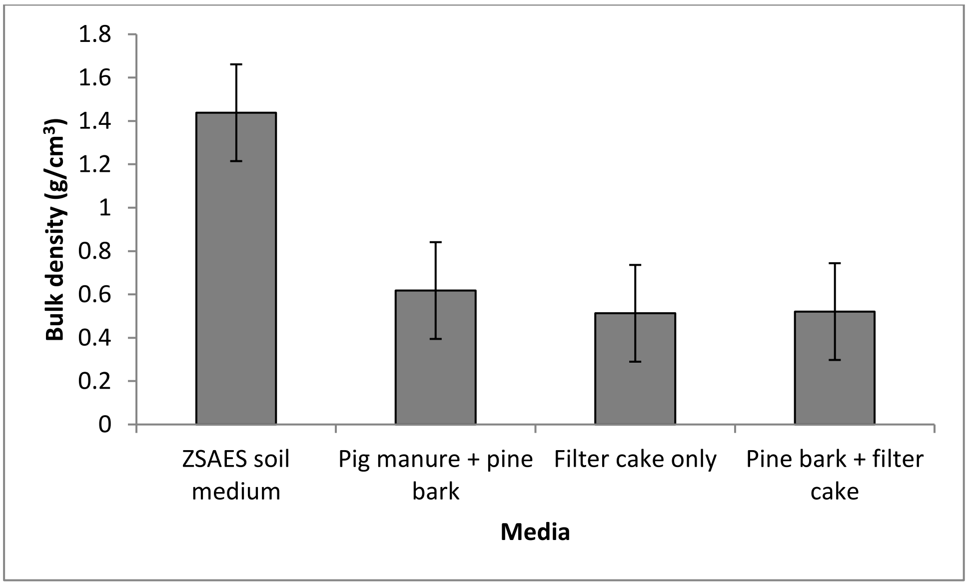

Figure 21: Bulk densities of pig manure + pine bark, filter cake only, filter cake + pine bark, and ZSAES soil medium (control) measured in December 2016 used in experiments on media, fertiliser regime and container size

4.7.3 Total volume of water that drained from the container

Filter cake + pine bark and pig manure + pine bark gave the highest total volume of irrigation water that drained from the container, which was about 18% higher than the ZSAES soil medium (control) (Figure 22). The lowest total volume of irrigation water that drained from container was observed in the filter cake only although it was not statistically different from the ZSAES medium (Figure 22).

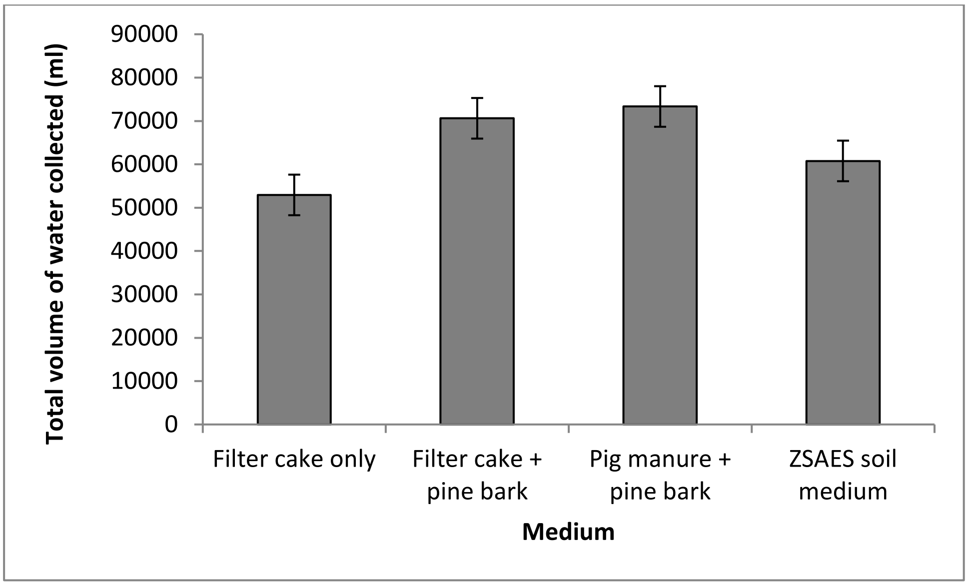

Figure 22: Total volume of water that drained from containerwithpig manure + pine bark, filter cake only, filter cake + pine bark, and ZSAES soil medium (control) measured daily in December 2016 to April 2017

4.7.4 Germination percent and rate of cane setts

There was no statistical difference between media on germination percent of sugarcane setts in the containers. However, germination rate of setts grown in ZSAES soil medium was significantly lower than filter cake only, filter cake + pine bark and pig manure + pine bark (Figure 23). There was no significant difference between varieties on germination percent or rate of sugarcane setts.

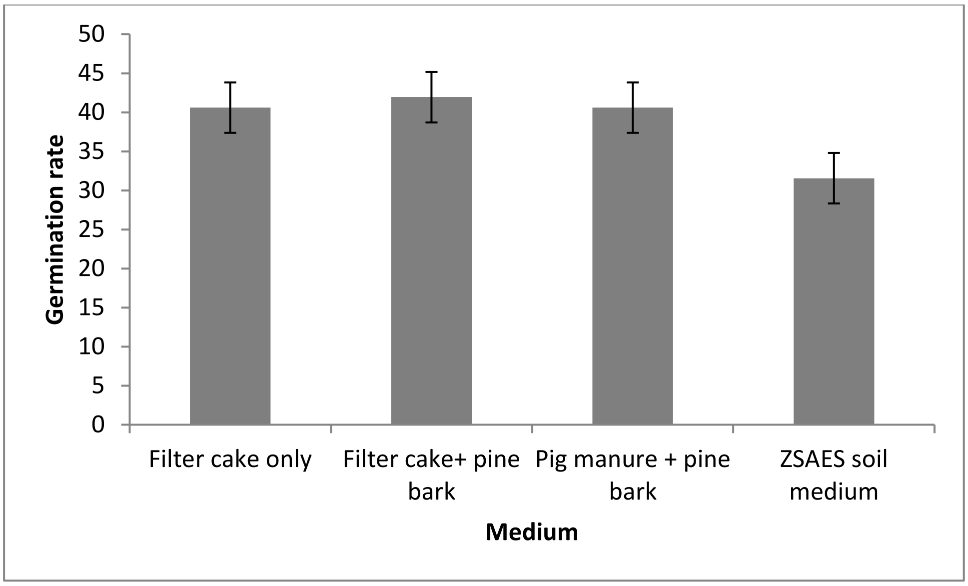

Figure 23: Germination rate of cane setts planted in different growth media (filter cake only, filter cake + pine bark, pig manure + pine bark, andZSAES soil medium) in December 2016 (level of significance *)

4.7.5 Stem height of primary tiller of sugarcane

There was no interaction between growth media and variety on stem height of primary tiller of sugarcane. From 25 to 32 DAP, the stem height of primary tiller of sugarcane plants grown in the ZSAES medium were shorter than the other media (Table 10). After 32 to 64 DAP, response of stem height to the growth media was similar. However, at ≥ 74 days after planting, the plants grown in pig manure + with pine bark had the shortest stems of all the plants grown in the other media tested (Table 10). There was no significant difference between the three sugarcane varieties on stem height of primary tiller of sugarcane except at 25 and 61 DAP which showed shortest stems in ZN7. The relationship between stem height and shoot dry mass (Figure 24A), plant height and number of tillers per container (Figure 24B) showed a negative relationship. However, the relationship between plant height and internode length showed a very strong positive relationship (Figure 24C).

Table 10: Stem height of sugarcane plants of three varieties (ZN7, ZN8 and ZN10) grown in different growth media (filter cake only, filter cake + with pine bark, pig manure + with pine bark, and ZSAES soil medium) for plants grown in containers that were measured from 25 to 115 DAP

Media	**25 DAP**	**32 DAP**	**47 DAP**	**61 DAP**	**74 DAP**	**86 DAP**	**100 DAP**	**115 DAP**
Filter cake only	13.22b	15.94b	28.67	43.7	60.9b	76.9b	89b	96.4b
Filter cake + pine bark	13.22b	15.94b	28.67	43.7	60.9b	76.9b	89b	96.4b
Pig manure + pine bark	13.56b	18.06b	29.39	40.9	49.5a	54.6a	60.6a	67.9a
ZSAES soil medium	10.39a	12.61a	24.89	38.1	56.8ab	76.8a	89.7b	97.5b
P value	0.005	0.002	0.076	0.233	0.019	<0.001	<0.001	<0.001
LSD	1.984	2.731	NS	NS	7.9	7.97	8.5	9.16
Variety								
ZN7	11.7a	14.7	25.71	38.04a	54.9	70.1	82.7	92.4
ZN8	14b	17.29	29.17	40.21a	54.6	68.5	79	86.6
ZN10	12.58ab	15.96	28.5	45.83b	61.6	74.9	83.8	89.4
P value	0.035	0.100	0.073	0.012	0.075	0.159	0.385	0.344
LSD	1.718	NS	NS	5.07	NS	NS	NS	NS
CV (%)	16.0	17.6	13.4	14.5	14.2	11.5	10.7	10.5

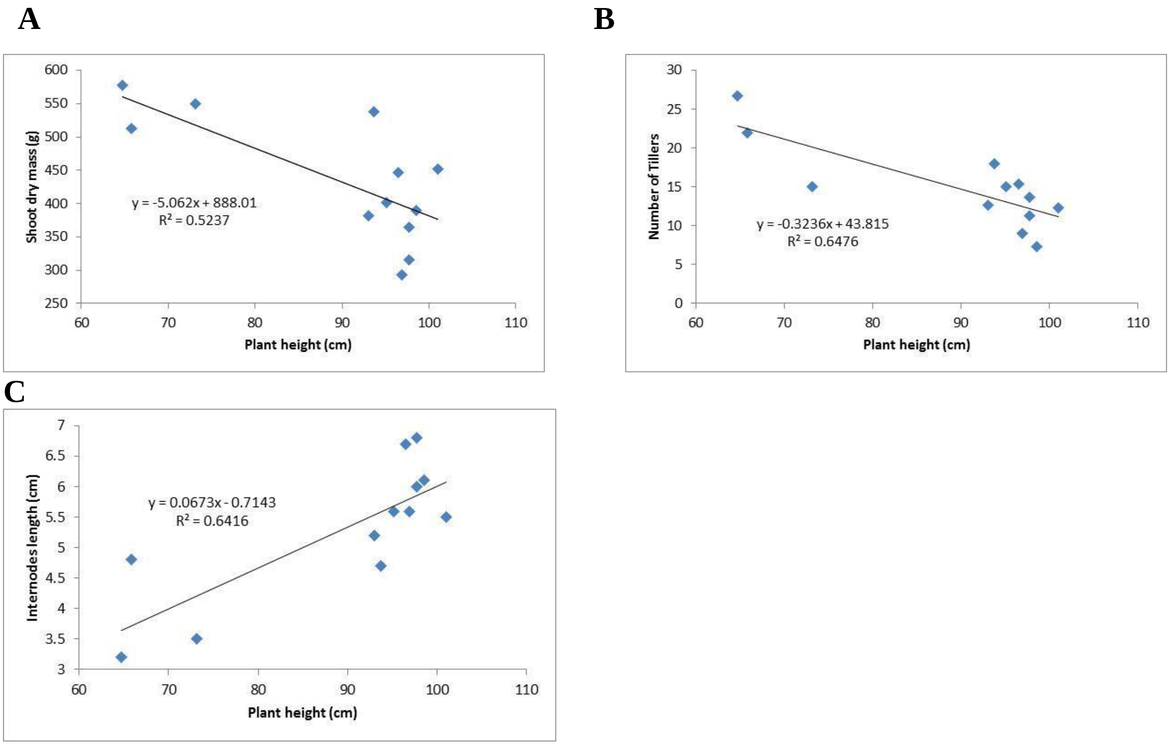

Figure 24: Relationships between plant height and shoot dry mass (A), plant height and number of tillers (B), and plant height and internode length (C)

4.7.6 Number of tillers of sugarcane plants per container

Number of tillers per container was markedly higher in sugarcane plants that were grown in the pig manure + pine bark than in the other media at all sampling times (Table 11). There were no differences in the tillering of the plants in the filter cake only, filter cake + pine bark and the ZSAES soil media before 60 DAP (Table 11). From 60 to 85 DAP, the number of tillers per container on plants grown in the filter cake + pine bark and filter cake only was the lowest (Table 11). Beyond 85 DAP, the number of tillers of sugarcane plants grown in filter cake + pine bark was the lowest when compared to the other three media. The variety ZN7 consistently had the lowest number of tillersper container at all sampling times (Table 11). Varieties ZN8 and ZN7 produced equal number of tillers per container ≤60 DAP. Beyond 60 DAP, ZN8 had more tillers per container than ZN10 (Table 11).

Table 11: Number of tillers per container of three sugarcane varieties (ZN7, ZN8 and ZN10) grown in filter cake only, filter cake + pine bark, pig manure + pine bark, and ZSAES soil medium measured from 31 to 115 days after planting

Media	**31 DAP**	**46 DAP**	**60 DAP**	**73 DAP**	**85 DAP**	**99 DAP**	**115 DAP**
Filter cake only	0.78a	3.33a	7.11a	9.56a	10.44a	12b	13.56b
Filter cake + pine bark	0.78a	4.67a	7.78ab	8.33a	8.89a	9.22a	10.44a
Pig manure + pine bark	2.11b	8.56b	16c	18.89c	19.44c	21c	21.22c
ZSAES soil medium	0.78a	4.78a	10.56b	13.22b	13.89b	13.56b	14.22b
P value	0.015	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD	0.946	1.849	3.060	3.115	2.655	2.299	2.089
Variety							
ZN7	0.33a	3.42a	7.33a	9.17a	9.33a	9.67a	10.92a
ZN8	1.25b	6.83b	12.75b	16.08c	17c	17.75c	18.08c
ZN10	1.75b	5.75b	11b	12.25b	13.17b	14.42b	15.58b
P value	0.005	<0.001	0.001	<0.001	<0.001	<0.001	<0.001
LSD	0.819	1.601	2.65	2.698	2.299	1.991	1.809
CV (%)	87.5	35.6	30.4	25.6	20.7	16.9	14.4

4.7.7 SPAD index on the leaf with TVD of primary tiller

The SPAD index decreased in subsequent samplings, and so did the difference among the growth media (Table 12). At 75 DAP, filter cake only had the highest SPAD index on the leaf with TVD of primary tiller than other media. At 85 DAP, filter cake had the highest SPAD index on the leaf with TVD of primary tiller but statistically was comparable to the ZSAES soil medium. Also at 85 DAP, pig manure + pine bark and filter cake + pine bark had the lowest SPAD index on the leaf with TVD leaf of primary tiller. Beyond 85 DAP, there was no statistical difference between the growth media (Table 12). VarietyZN7 had consistently higher SPAD index than ZN8 and ZN10 at 75 and 115 days after planting (Table 12). The relationship between the SPAD index and the number of tillers showed a negative relationship (Figure 25).

Table 12: SPAD index on the leaf with TVD of primary tiller of ZN7, ZN8 and ZN10 sugarcane varieties grown incontainers with pig manure + pine bark, filter cake only, filter cake + pine bark, and ZSAES soil medium (control) measured from 75 to 115 days after planting in December 2016 to April 2017

Media	SPAD **at 75DAP**	SPAD **at 85DAP**	SPAD **at 99DAP**	SPAD **at 115DAP**
Filter cake only	44.74b	42.19c	36.99	36.99
Filter cake + pine bark	39.37a	38.44ab	36.49	35.78
Pig manure + pine bark	40.47a	35.52a	34.39	34.89
ZSAES soil medium	40.47a	40.08bc	35.17	35.93
P value	0.017	0.002	0.589	0.706
LSD	3.260	3.220	NS	NS
Variety				
ZN7	44.07b	40.82	37.38	38.59b
ZN8	42.31b	38.88	35.34	34.46a
ZN10	38.28a	37.48	34.55	34.64a
P value	0.001	0.065	0.290	0.020
LSD	2.824	NS	NS	3.175
CV (%)	8.1	8.5	12.4	10.5

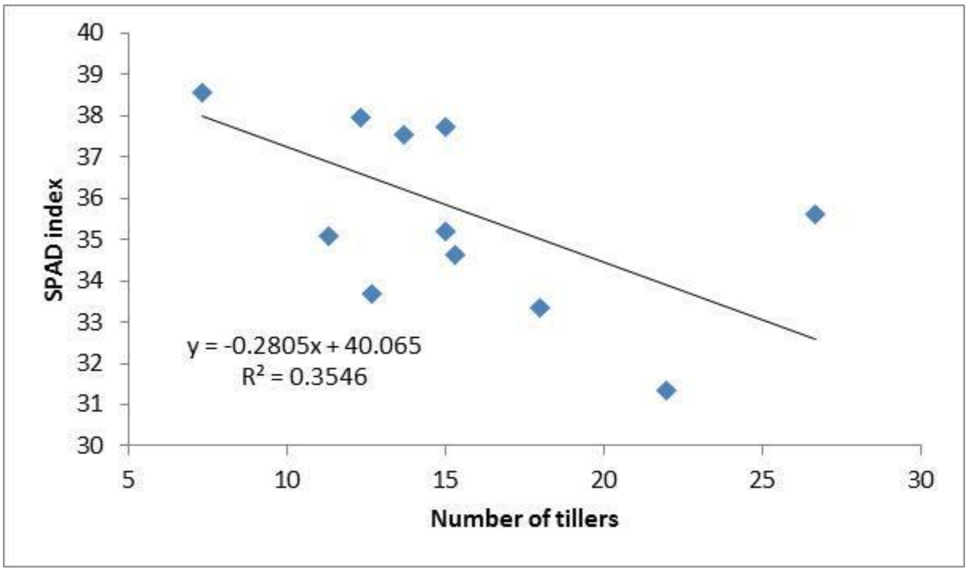

Figure 25: Relationship between number of tillers and SPAD index

4.7.8 Foliar leaf analyses

4.7.8.1Leaf Nitrogen content

There was media x variety interaction on leaf N concentration at 87 DAP. All the three varieties grown in pig manure + pine bark and ZSAES soil medium had similar leaf N concentration (Figure 26). In contrast, ZN7 and ZN10 varieties had higher leaf N concentration than ZN8 in the filter cake only (Figure 26). The variety ZN8 had the lowest leaf N concentration than ZN7 and ZN10 grown in the filter cake + pine bark (Figure 26).

At 75 DAP, there was more leaf N content in sugarcane grown in the pig manure + pine bark and filter cake only (Table 13). At 101 DAP and 115 DAP, the leaf N content in all media was not significantly different (Table 16). At ≥101 DAP, ZN10 variety had more leaf N than ZN7 and ZN8 varieties (Table 13).

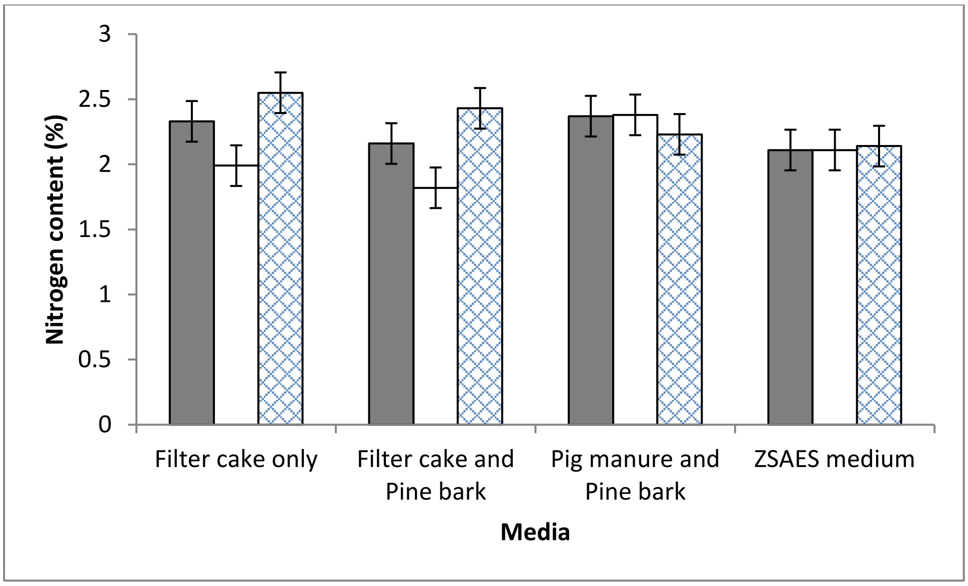

Figure 26: Nitrogen content on the leaf with TVD of primary tiller of sugarcane varieties (■ZN7, □ZN8, ⊠ZN10) grown in containers with pig manure + pine bark, filter cake only, filter cake + pine bark, and ZSAES soil medium (control) in December 2016 to April 2017 measured at 87 DAP (level of significance *)

Table 13: Nitrogen content on the leaf with TVD of primary tiller of ZN7, ZN8 and ZN10 sugarcane varieties grown in containers with pig manure + pine bark, filter cake only, filter cake + pine bark, and ZSAES soil medium (control) in December 2016 to April 2017 measured from 75 DAP to 115 DAP

Media	**75DAP**	**101 DAP**	**115DAP**
Filter cake only	2.58b	2.21	1.95
Filter cake + pine bark	2.28a	2.05	1.87
Pig manure + pine bark	2.58b	2.06	1.88
ZSAES soil medium	2.36a	1.92	1.89
P value	0.005	0.061	0.746
LSD	0.185	NS	NS
CV (%)	7.8	10.4	8.3
Variety			
ZN7	2.44	1.88a	1.81a
ZN8	2.40	2.02a	1.87a
ZN10	2.51	2.28b	2.02b
P value	0.404	<0.001	0.009
LSD	NS	0.181	0.133
CV	7.8	10.4	8.3

4.7.8.2Leaf Phosphorus content

The leaf P concentration was consistently and significantly lowest in TVD of primary tiller grown in the ZSAES soil medium (Table 14). At ≤87 DAP, there was more leaf P in TVD of primary tiller grown in the pig manure + pine bark (Table 14). Beyond 87 DAP, there was more leaf P content in TVD of primary tiller grown in the filter cake only and filter cake + pine bark. The varieties differed in leaf P only in the early days of the experiment (at 75 DAP) and beyond this, there were no significant differences. At 75 DAP, there was more leaf phosphorus concentration in the ZN10 variety, although it was significantly equal to ZN7 (Table 14). The relationship between leaf phosphorus and leaf potassium concentrations showed a strong negative relationship (Figure 27).

Table 14: Phosphorus content on the leaf with TVD of primary tiller of ZN7, ZN8 and ZN10 sugarcane varieties grown incontainers with pig manure + pine bark, filter cake only, filter cake + pine bark, and ZSAES soil medium (control) in December 2016 to April 2017 measured from 75 DAP to 115 DAP

Media	**75DAP**	**87DAP**	**101 DAP**	**115DAP**
Filter cake only	0.58b	0.54b	0.53c	0.49c
Filter cake + pine bark	0.62b	0.60b	0.48bc	0.47c
Pig manure + pine bark	0.81c	0.63b	0.40ab	0.36ab
ZSAES soil medium	0.40a	0.27c	0.32a	0.29a
P value	<0.001	<0.001	0.002	0.006
LSD	0.065	0.148	0.109	0.119
Variety				
ZN7	0.63b	0.54	0.56	0.39
ZN8	0.52a	0.47	0.41	0.43
ZN10	0.66b	0.53	0.63	0.40
P value	<0.001	0.486	0.351	0.730
LSD	0.056	NS	NS	NS
CV	11.1	29.8	25.8	30.2

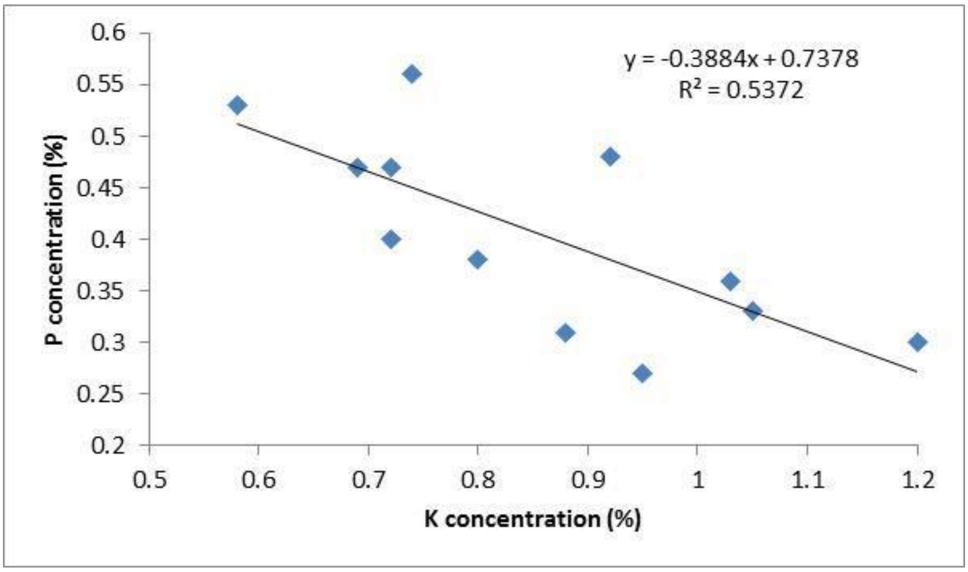

Figure 27: Relationship between potassium and phosphorus concentrations in sugarcane leaves

4.7.8.3Leaf Potassium content

At 115 DAP, there was interaction between media and variety on leaf potassium concentration (Figure 28). All the three varieties grown in filter cake + pine bark had similar leaf K concentration. In contrast, ZN7 and ZN8 varieties had higher leaf K concentration than ZN10 grown in the filter cake only and pig manure + pine bark (Figure 28). The variety ZN8 had higher leaf K concentration than ZN7 and ZN10 grown in the ZSAES soil medium (Figure 28). At 75 DAP, there was more leaf K concentration in sugarcane grown in the ZSAES soil medium than other media tested, although at 101 DAP it was statistically similar to pig manure + pine bark (Table 15). At 75 DAP and 101 DAP, ZN7 and ZN8 varieties had higher leaf K concentration than ZN10 (Table 15).

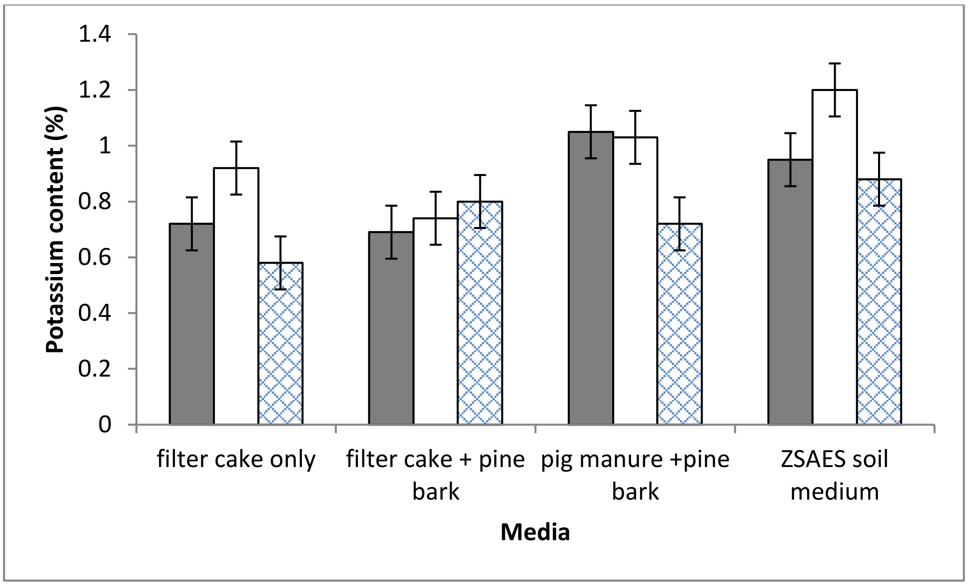

Figure 28: Potassium content on the leaf with TVD of primary tiller of sugarcane varieties (■ZN7, □ZN8, ▨ZN10) grown in containers with pig manure + pine bark, filter cake only, filter cake + pine bark, and ZSAES soil medium (control) in December 2016 to April 2017 measured at 115 DAP (level of significance *)

Table 15: Potassium content on the leaf with TVD of primary tiller of ZN7, ZN8 and ZN10 sugarcane varieties grown in containers with pig manure + pine bark, filter cake only, filter cake + pine bark, and ZSAES soil medium (control) in December 2016 to April 2017

Media	**75DAP**	**101 DAP**	**115DAP**
Filter cake only	1.24a	1.00ab	0.74a
Filter cake + pine bark	1.16a	0.86a	0.74a
Pig manure + pine bark	1.15a	1.11bc	0.93b
ZSAES soil medium	1.46b	1.24c	1.01c
P value	0.008	0.001	<0.001
LSD	0.191	0.173	1.113
Variety			
ZN7	1.40b	1.03ab	0.85ab
ZN8	1.25ab	1.17b	0.97b
ZN10	1.11a	0.95a	0.74a
P value	0.006	0.021	<0.001
LSD	0.165	0.150	0.098
CV	15.6	17	13.6

4.7.8.4Leaf Magnesiumcontent

At 115 DAP, there was interaction between media and variety on leaf magnesium concentration (Figure 29). All the three varieties grown in ZSAES soil medium had similar leaf Mg concentration. In contrast, ZN10 variety had higher leaf Mg concentration than ZN7 and ZN8 grown in the filter cake only and pig manure + pine bark (Figure 29). The variety ZN7 had the highest leaf Mg concentration than ZN8 and ZN10 grown in the filter cake + pine bark (Figure 29).

At 75 DAP and 87 DAP, there was more leaf Mg concentration in sugarcane grown in the pig manure + pine bark (Table 16). However, at 101 DAP, there was more leaf Mg concentration in sugarcane grown in in the filter cake only. At all samplings, there was less leaf Mg concentration in sugarcane grown in the ZSAES soil medium (Table 16). At ≤101 DAP, ZN10 had markedly more leaf Mg than other varieties, although it was statistically the same to ZN7 at ≤87 DAP (Table 16).The relationship between magnesium and potassium showed a strong negative relationship (Figure 30).

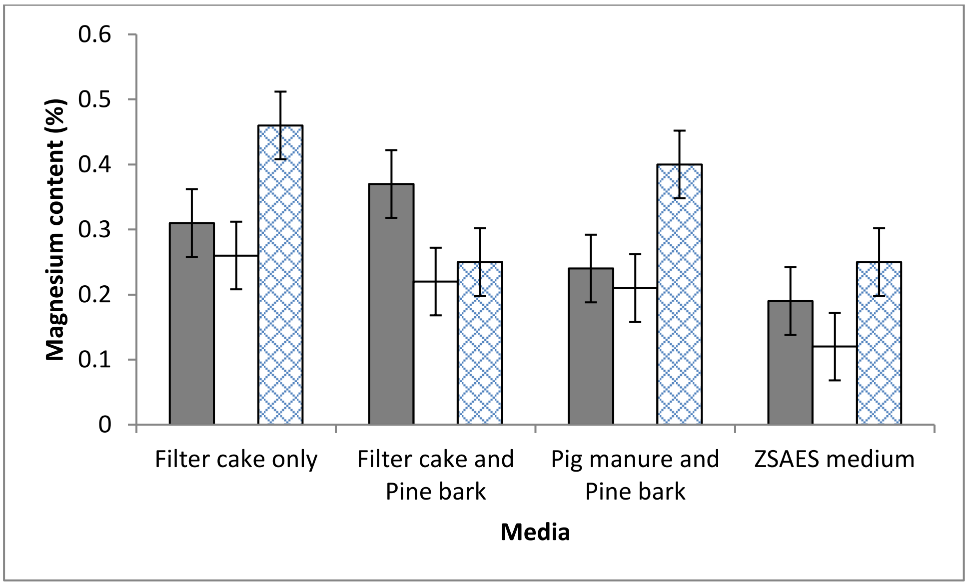

Figure 29: Magnesium content on the leaf with TVD of primary tiller of sugarcane varieties (■ZN7, □ZN8, ▨ZN10) grown in containers with pig manure + pine bark, filter cake only, filter cake + pine bark, and ZSAES soil medium (control) in December 2016 to April 2017 measured at 115 DAP (level of significance *)

Table 16: Magnesium content on the leaf with TVD of primary tiller of ZN7, ZN8 and ZN10 sugarcane varieties grown in containers with pig manure + pine bark, filter cake only, filter cake + pine bark, and ZSAES soil medium (control) in December 2016 to April 2017 measured from 75 DAP to 101 DAP

Media	**75DAP**	**87DAP**	**101 DAP**
Filter cake only	0.28b	0.36b	0.37b
Filter cake + pine bark	0.27b	0.35b	0.34b
Pig manure + pine bark	0.42c	0.44c	0.34b
ZSAES soil medium	0.18a	0.17a	0.16c
P value	<0.001	<0.001	<0.001
LSD	0.077	0.074	0.064
Variety			
ZN7	0.31b	0.35b	0.30b
ZN8	0.22a	0.24a	0.24a
ZN10	0.33b	0.40b	0.37c
P value	0.009	<0.001	<0.001
LSD	0.067	0.064	0.055
CV	27.8	23	21.6

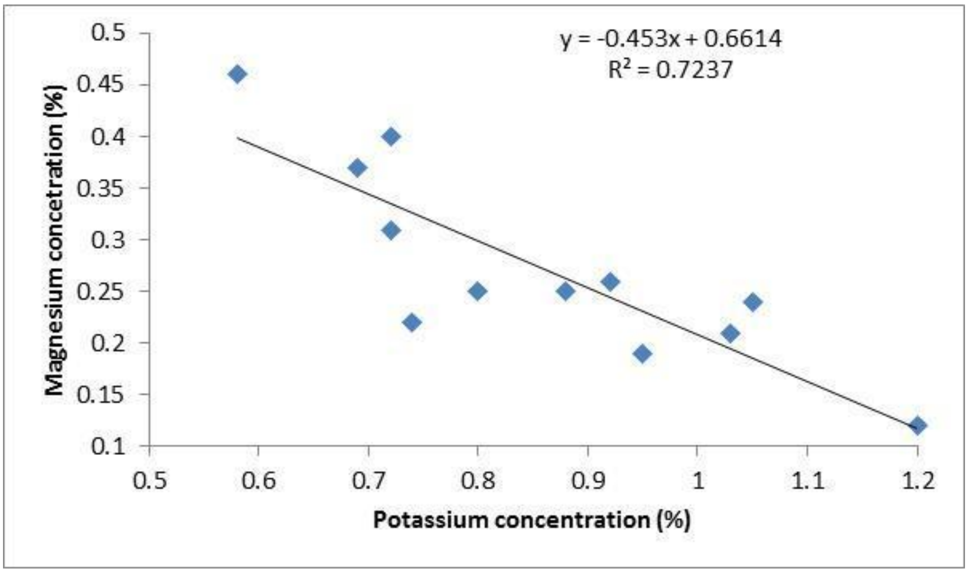

Figure 30: Relationship between magnesium and potassium concentrations in sugarcane leaves.

4.7.8.1 Leaf Calcium content

Generally, leaf Ca content was markedly higher in media involving filter cake and lower in the pig manure + pine bark and the ZSAES soil media (Table 17). Nonetheless, in the pig manure + pine bark, the plants varied little in leaf Ca content when compared to the ZSAES soil medium as they aged (≥101 DAP). Similarly to the growth media, the leaf Ca content of the three varieties tested peaked at 101 DAP, but the three varieties did not differ significantly in leaf Ca at all sampling times except at 75 DAP (Table 17). The relationship between calcium and phosphorus showed a strong positive relationship (Figure 31).

Table 17: Calcium content on the leaf with TVD of primary tiller of ZN7, ZN8 and ZN10 sugarcane varieties grown in containers with pig manure + pine bark, filter cake only, filter cake + pine bark, and ZSAES soil medium (control) in December 2016 to April 2017 measured from 75 DAP to 115 DAP

Media	**75DAP**	**87DAP**	**101 DAP**	**115DAP**
Filter cake only	0.27c	0.36c	0.41b	0.37b
Filter cake + pine bark	0.30c	0.38c	0.41b	0.33b
Pig manure + pine bark	0.23b	0.29b	0.31a	0.21a
ZSAES soil medium	0.18a	0.22a	0.24a	0.23a
P value	<0.001	<0.001	<0.001	<0.001
LSD	0.034	0.042	0.086	0.061
Variety				
ZN7	0.22a	0.31	0.30	0.27
ZN8	0.27b	0.30	0.36	0.27
ZN10	0.24a	0.33	0.37	0.32
P value	0.013	0.257	0.112	0.151
LSD	0.029	NS	NS	NS
CV	14.2	13.9	25.9	21.9

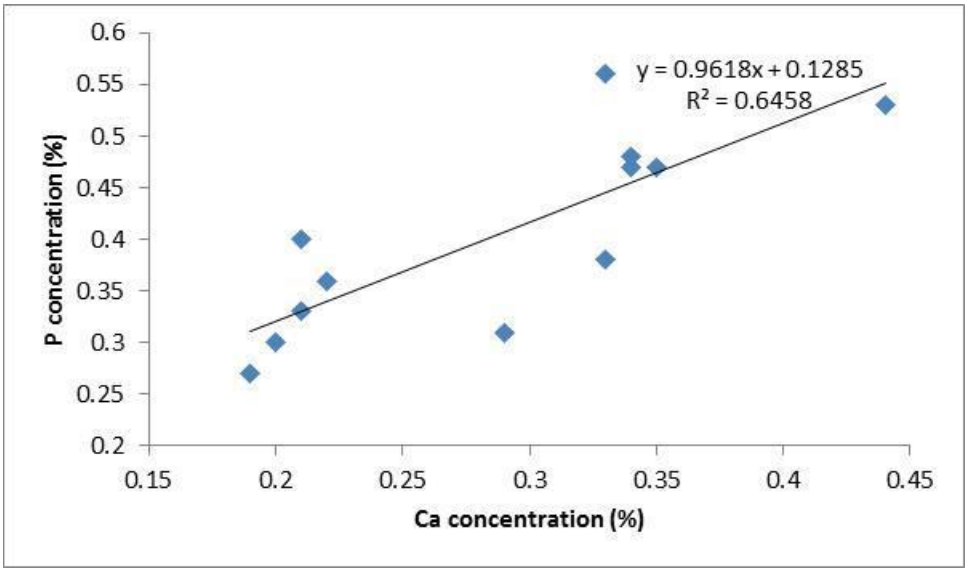

Figure 31: Relationship between Ca and P concentrations in sugarcane leaves

4.7.9 Dry matter of sugarcane plants

There was media x variety interaction on dry matter of green leaves at 115 DAP. All the three varieties grown in filter cake + pine bark and ZSAES soil medium had similar dry matter of green leaves (Figure 32). In contrast, ZN7 and ZN8 varieties had higher dry matter of green leaves than ZN10 in the filter cake only and pig manure + pine bark (Figure 32).

Pig manure + pine bark had more root, shootand total plant dry matter (TPDM) than any other media tested (Table 18). Filter cake only, filter cake + pine bark and ZSAES soil media, statistically had equal root, shoot and total plant dry matter (TPDM). There was no significant difference among varieties in root, shoot and total plantdry matter (Table 18).The relationship between TPDM and number of tillers (Figure 33A), TPDM and shoot dry matter (Figure 33B) showed a strong positive relationship. However, TPDM and internode length (Figure 33C), TPDM and leaf calcium content (Figure 33D) showed a strong negative relationship.

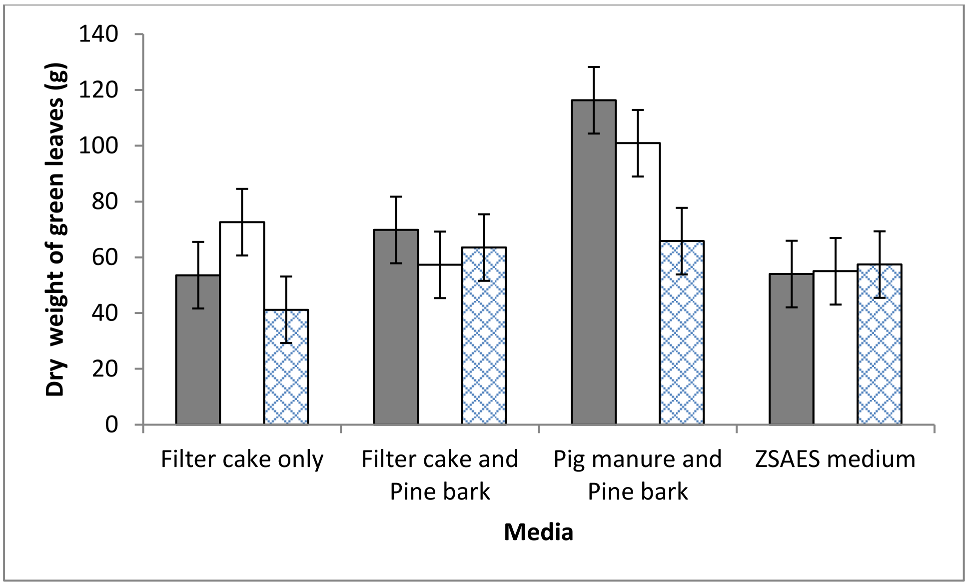

Figure 32: Dry matter of green leaves of all tillers per container of three varieties, (■ ZN7, □ZN8, ⊠ZN10) grown in containers with filter cake only, filter cake + pine bark, pig manure + pine bark, and ZSAES soil medium in December 2016 to April 2017 measured at 115 DAP (level of significance *)

Table 18: Dry matter of roots, tops, stalks, trash and total plant of all tillers per container of three varieties, ZN7, ZN8 and ZN10 grown in containers with filter cake only, filter cake + pine bark, pig manure + pine bark, and ZSAES soil medium in December 2016 to April 2017 measured at 115 DAP

Media	**Roots**	**Tops, Stalks and Trash**	**Shoot**	**Total**
Filter cake only	100.4b	327b	382a	483b
Filter cake + pine bark	99.8b	315b	378a	478b
Pig manure + pine bark	136.2a	452a	546b	683a
ZSAES soil medium	117.9ab	378ab	433a	551b
P value	0.018	0.019	0.005	0.003
LSD	25.04	90.7	97.1	112.3
Variety				
ZN7	112.8	348	421	534
ZN8	113.6	403	474	588
ZN10	114.1	353	410	524
P value	0.992	0.297	0.258	0.359
LSD	NS	NS	NS	NS
CV (%)	22.7	25.4	9.1	21

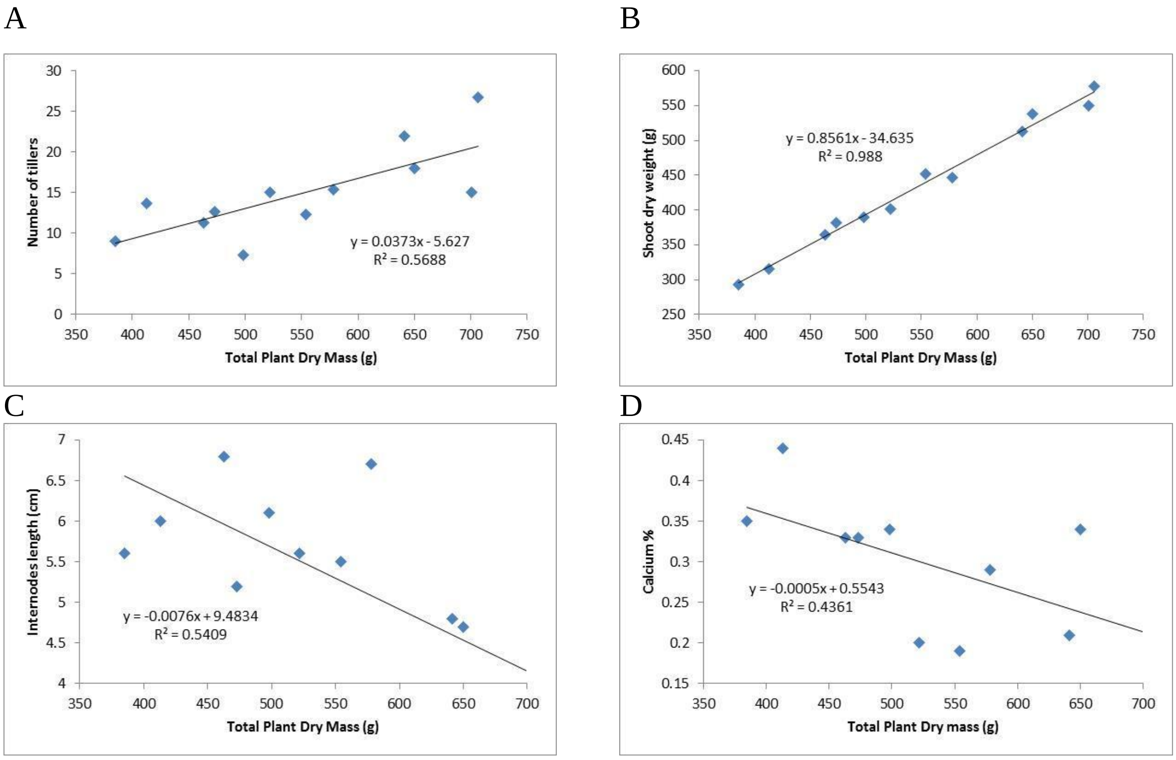

Figure 33: Relationships between TPDM and number of tillers (A), TPDM and shoot dry matter (B), TPDM and internode length (C), TPDM and Calcium (D)

4.7.10 Green leaf area of sugarcane tillers per container

There was media x variety interaction on green leaf area at 115 DAP. All the three varieties grown in filter cake only, filter cake + pine bark and ZSAES soil medium had similar green leaf area (Figure 34). In contrast, ZN7 variety had higher green leaf area than ZN8 and ZN10 in the pig manure + pine bark (Figure 34). The relationship between green leaf area (GLA) and number of green leaves showed a strong positive relationship (Figure 35).

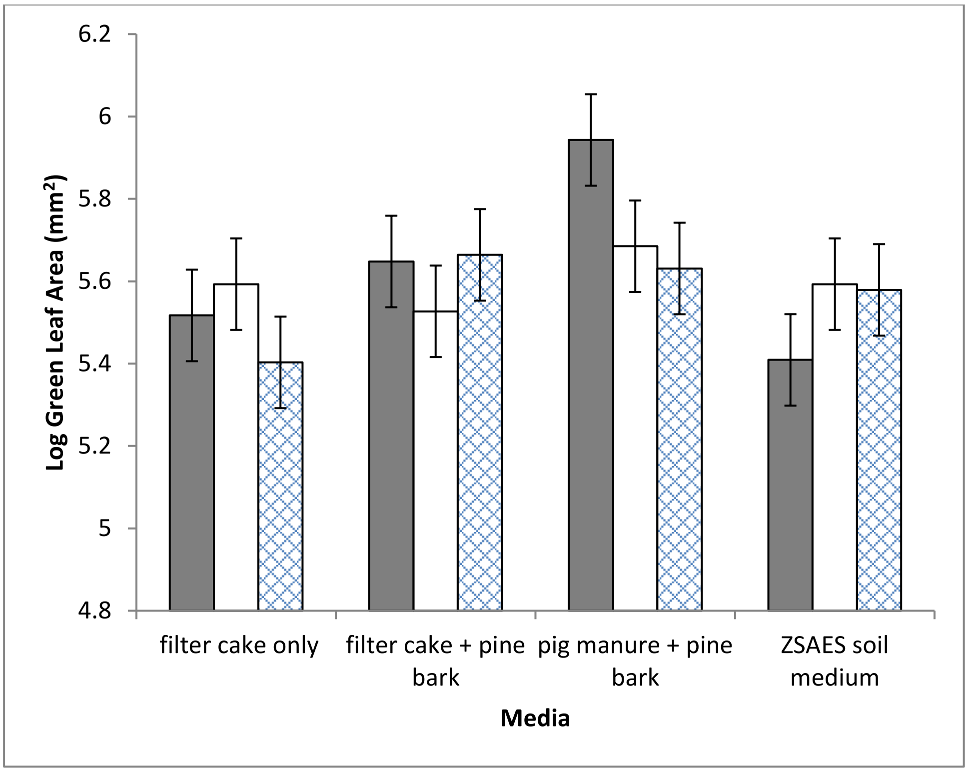

Figure 34: Green leaf area of all tillers per container of three varieties, (■ZN7, ☐ZN8, ▨ZN10) grown in containers with filter cake only, filter cake + pine bark, pig manure + pine bark, and ZSAES soil medium in December 2016 to April 2017 measured at 115 DAP (level of significance *)

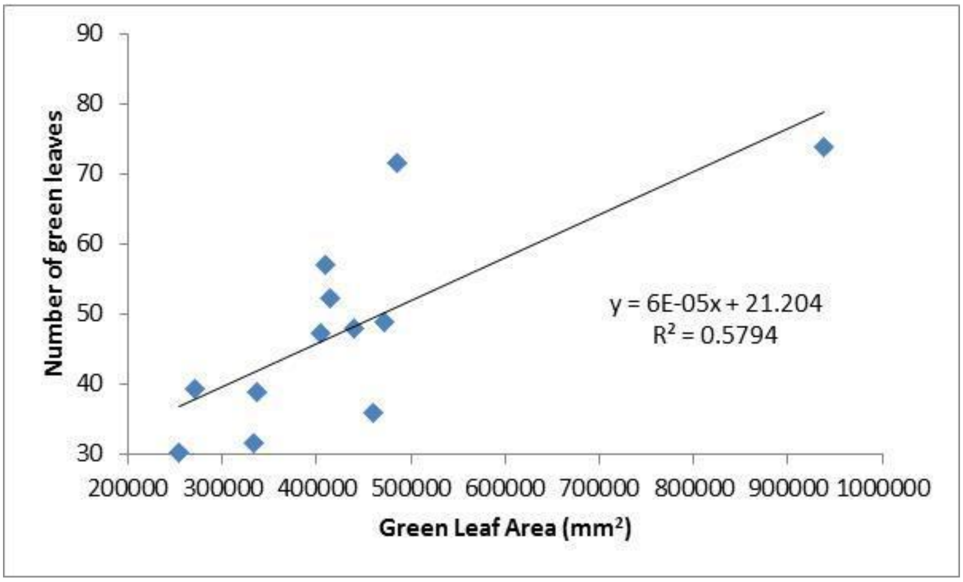

Figure 35: Relationships between green leaf area and number of green leaves

4.7.11 Number of green leaves per container

At 115 DAP, there was interaction between media and variety on number of green leaves per container. All the three varieties grown in filter cake + pine bark had similar number of green leaves per container (Figure 36). In contrast, ZN8 variety had more green leaves per container than ZN7 and ZN10 in the filter cake only (Figure 36). Pig manure + pine bark produced the largest differences between the varieties in number of green leaves, ZN7 and ZN8 had more green leaves than ZN10 in this medium (Figure 36).Varieties ZN8 and ZN10 had more green leaves per container than ZN10 in the ZSAES soil medium (Figure 36). The relationship between number of green leaves and leaf potassium concentration showed a strong positive relationship (Figure 37).

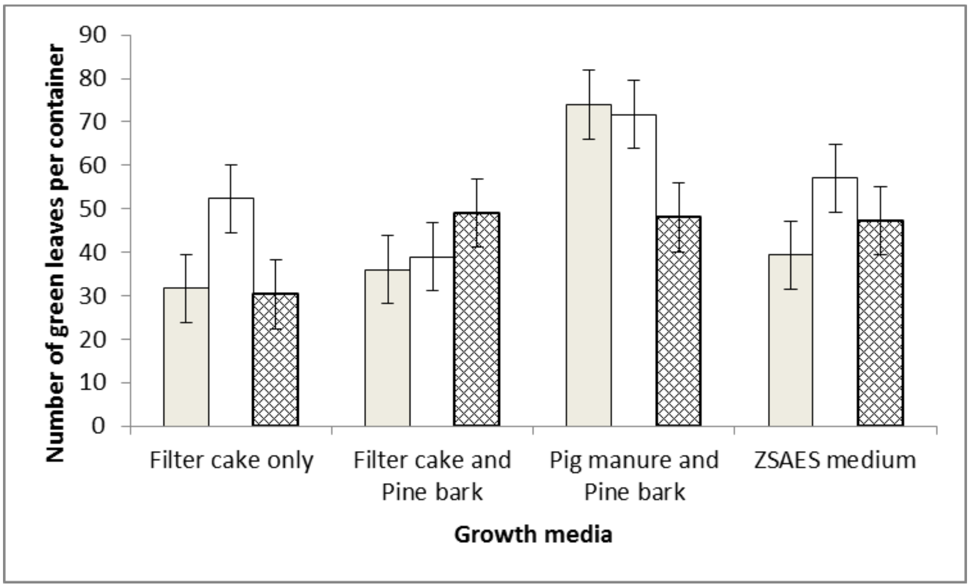

Figure 36: Number of green leaves of all tillers per container of three varieties, (■ZN7, □ZN8, ⊠ZN10) grown in containers with filter cake only, filter cake + pine bark, pig manure + pine bark, and ZSAES soil medium in December 2016 to April 2017 measured at 115 DAP (level of significance *)

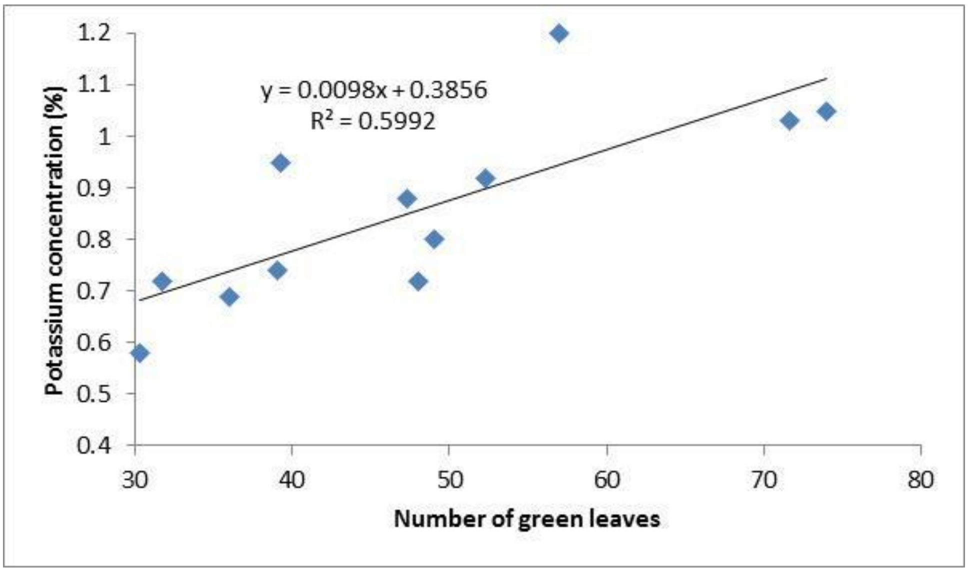

Figure 37: Relationship between number of green leaves and leaf potassium concentration (%)

4.7.12 Internode lengths of primary tiller

Cane grown in filter cake + pine bark,filter cake only and ZSAES soil medium consistently and significantlyhad the longest fourth to the eighth internodes lengths including the average internodes lengths while cane grown in the pig manure + pine bark medium had the shortest (Table 19). Variety ZN10 had significantly the longestfirst to fifth internodes lengths including average internode lengths than other varieties (Table 19). The relationship between internodeslengths and number of tillers showed a strong negative relationship (Figure 38).

Table 19: Internodes length of primary tiller of ZN7, ZN8 and ZN10 sugarcane varieties grown in containers with pig manure + pine bark, filter cake only, filter cake + pine bark, and ZSAES soil medium (control) in December 2016 to April 2017 measured at 115 DAP)

Treatment Medium	First	Second (base)	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Average (topmost)
Filter cake only	2.49^{ab}	3.39	4.46	5.58^{b}	6.19^{b}	6.70^{b}	7.33^{b}	7.23^{b}	5.4^{b}
Filter cake + pine bark	3.07^{b}	4.47	5.41	6.26^{b}	6.67^{b}	7.49^{bc}	7.42^{b}	7.32^{b}	6.0^{b}
Pig manure + pine bark	2.13^{a}	3.12	3.91	4.27^{a}	4.62^{a}	4.41^{a}	4.20^{a}	4.07^{a}	3.8^{a}
ZSAES soil medium	2.31^{a}	3.42	4.36	5.57^{b}	6.91^{b}	8.17^{c}	8.59^{c}	8.12^{b}	5.9^{b}
P value	0.048	0.056	0.099	0.006	<0.001	<0.001	<0.001	<0.001	<0.001
LSD	0.677	NS	NS	1.046	1034	1.095	0.969	0.998	0.81
Variety									
ZN7	2.25^{a}	3.12^{a}	4.01^{a}	5.03^{a}	6.05^{ab}	6.59	7.36	6.97	5.2^{a}
ZN8	1.87^{a}	2.57^{a}	3.53^{a}	4.46^{a}	5.32^{a}	6.29	6.55	6.69	4.7^{a}
ZN10	3.37^{b}	5.12^{b}	6.07^{b}	6.76^{b}	6.92^{b}	7.19	6.78	6.39	6.1^{b}
P value	<0.001	<0.001	<0.001	<0.001	<0.004	0.159	0.145	0.393	0.001
LSD	0.587	0.880	1.044	0.906	0.896	NS	NS	NS	0.70
CV (%)	27.8	29	27.3	19.8	17.4	16.8	14.4	15.3	15.7

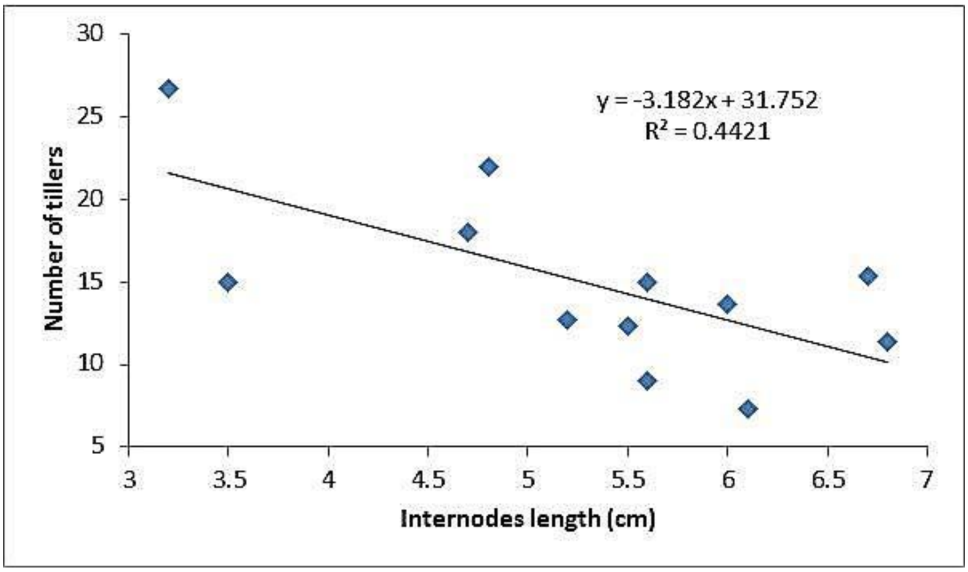

Figure 38: Relationship between internode lengths and number of tillers

4.7.13 Stem diameter of the primary tiller

Interaction between media and variety on stem diameter of primary tiller was significant (Figure 39). Stem diameter of primary tiller was higher in the variety ZN7 than ZN8 and

ZN10 that were grown in the filter cake only, filter cake + pine bark and pig manure + pine bark (Figure 39). In contrast, all the three varieties grown in ZSAES soil medium had similar stem diameter of primary tiller (Figure 39).

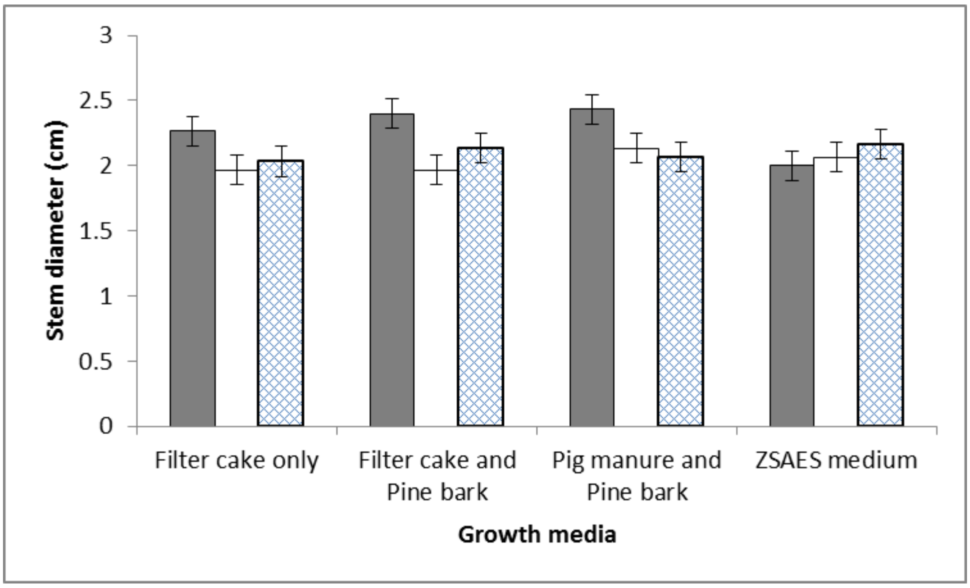

Figure 39: Stem diameter of primary tiller of three varieties, (■ZN7, □ZN8, ▨ZN10) grown in containers with filter cake only, filter cake + pine bark, pig manure + pine bark, and ZSAES soil medium in December 2016 to April 2017 measured at 115 DAP (level of significance *)

4.8 Discussion

A growth medium that is suitable for growing sugarcane plants in containers with minimum stress should be able to optimally supply water and nutrients to the crop (Majsztrik et al., 2011). More so, the growth medium should allow maximum circulation of air in the containers for roots to respire and must anchor the plants to avoid damage (Raviv et al., 2002). In this study, four medium compositions were tested. Among them were three soil-less media, namely filter cake + pine bark, filter cake only and pig manure + pine bark. The fourth growth medium was a soil-based mixture called the ZSAES soil medium. Water retention was higher in filter cake only and in the ZSAES soil medium than in the pig manure + pine bark and the filter cake + pine bark (Figure 22). This was expected to severely restrict aeration and to cause water logging, making the filter cake only and the ZSAES soil medium less suitable substrates for use in containerised production than the pig manure + pine bark and the filter cake only. However, the pig manure + pine bark was slightly acidic (Table 9) and this was expected to restrict uptake of nutrients unless the substrate was amended by liming (Ridge, 2013).

Restricted oxygen supply in the ZSAES soil medium due to poor aeration associated with water logging conditions may have contributed to the suppressed germination rate of cane setts in this substrate (Figure 23). These problems were not observed in plants that were grown in any of the soil-less media tested. This suggests that, if the ZSAES soil medium is to be used as substrate for growing sugarcane plants, it has to be modified to increase aeration so as to enable optimal germination. Sugarcane setts require less water for germination, as too much water destroys the bud (Binbol et al., 2016).However, Oliveira et al. (2011) noted that air and substrate temperatures are very critical in germination of sugarcane. Srivastava and Rai (2012) reported that sprouting of sugarcane is optimum at 32 to 38 ^{o}C and slows down at temperatures below 25 ^{o}C.

Delayed germination of sugarcane plants in the ZSAES soil medium resulted in reduced stem heights of sugarcane plantsduring the first 46 days after planting (Table 10). However, as plants aged from 47 DAP to 61 DAP, there were no differences between the media on stem height. This may be explained by high growth of plants grown in the ZSAES soil medium, that able to catch the stem height of plants grown in the other media. Media used in containerised production vary in water holding capacity, texture, pH, anion and cation exchange capacities, porosity and fertility that can influence the growth of plants (Raviv and Lieth, 2008).

On one hand, sugarcane plants grown in pig manure + pine bark showed a suppressed stem elongation when compared to other media (Table 10). Stem elongation is very important in sugarcane plants, especially during the maturation stage, because the stems serve as storage sinks for loading sucrose, the desired product in sugarcane production (Clowes and Breakwell, 1998; Ridge, 2013). On the other hand, the plants grown in pig manure + pine bark had higher tiller production than those grown in other media (Table 11). Assuero and Tognetti (2010) revealed that the most limiting elements of tiller production are nitrogen and phosphorus, although potassium also promotes tillering when nitrogen is inadequate. Nitrogen has been found to directly affect the leaf appearance rate which control the number of tillers formed (Lemaire and Chapman, 1996). Prolific tiller production in pig manure +pine bark at ≥31 might have reduced stem elongation of sugarcane plants in this growth medium (Figure 24B). Kapur et al. (2011) and Kang et al. (2013) reported that number of tillers reduces the stalk length of sugarcane. Besides greater tillering in pig manure + pine bark, the shoot and root dry mass was also higher in this medium than in the other media tested (Table 18). Tillering, but not plant height, was positively correlated to total plant dry mass (Figure 33A), which suggests that it contributes to biomass production in sugarcane than stem elongation. However, from the literature, elongation of sugarcane stalks during growth phase depends on the genotype, nutritional content and moisture content of the media it is grown (Ridge, 2013; and Tena, 2016). There were no significant differences between sugarcane varieties in stem height at most sampling times except at 25 DAP and 61 DAP (Table 10). This means genotypic differences of sugarcane varieties have no influence on stem height of plants. However, Freire et al. (2010) revealed that sugarcane varieties differ in stem elongation. At ≥31 DAP, differences between varieties were observed in a number of tillers (Table 11). As expected, due to genotypic differences, beyond 46 DAP, the variety ZN7 maintained lower tiller production than the other varieties (Zhou, 2003).

Plants grown in the filter cake only had higher leaf SPAD index than other media at 75 DAP and 85 DAP, thereafter, there was no differences between the media in leaf SPAD index. This may be explained by lower tillering of sugarcane plants (Table 11 and Figure 25) coupled with higher inherent nitrogen content in filter cake only when compared to other media (Table 9). Fewer tillers in the filter cake were able to use available nitrogen in this medium which resulted in higher leaf SPAD index during the first 85 days after planting. There is positive relationship between nitrogen and leaf SPAD index of sugarcane plants (Rigon et al., 2013; IIkaee et al., 2016 and Dinh et al., 2017).

The interaction between media and variety on dry matter of green leaves showed that ZN7 and ZN8 varieties had higher dry matter of green leaves than ZN10 grown in the pig manure + pine bark and filter cake only media (Figure 32). Both pig manure + pine bark and filter cake only had more inherent nitrogen than other media (Table 9). Varieties ZN7 and ZN8 may have extracted more N better than ZN10 to result in higher dry matter of green leaves. This is also supported by greater green leaf area (Figure 34) and more green leaves per container of ZN7 variety than ZN10 grown in the pig manure + pine bark (Figure 36).Rakkiyappan et al (2007) revealed that sugarcane varieties have differences in uptake of nitrogen and this also varies according to plant parts viz stem, leaves, tops and roots.

Nitrogen and phosphorus are elements that contributed to higher growth (green leaf area and tillering) and dry matter accumulation in sugarcane plants (Ridge 2013; Vuyyuru et al., 2019). Nitrogen promotes growth by increasing cytokinin production, which consequently increases cell wall elasticity, cell division of meristematic cells, and cell growth (Lawlor, 2002).

Generally, leaf phosphorus, potassium and calcium concentrations were similar among plants grown on all the media tested. However, magnesium and nitrogen amounts were very low in the ZSAES soil medium (Table 9). It was, therefore, expected that the growth of plants in the ZSAES soil medium would be lower than in the soil-less media tested. However, the growth of sugarcane plants in the ZSAES soil medium surpassed most soil-less media tested, except pig manure + pine bark. This could be attributed to better water retention (Figure 22) and nutrient balance in the ZSAES soil medium than in the other growth media tested. Sugarcane uses substantial quantities of water to produce massive dry matter (Freitas et al., 2012). Although the growth of sugarcane plants in the pig manure + pine bark were better than other soil-less media, there is need to add more nutrients to increase the length of internodes.

Nutrient elements (nitrogen, phosphorus and potassium) measured in sugarcane leaves declined as the plants aged. Leaf concentration of these nutrients decreased despite the periodic addition of the nutrients to the substrate via the Hoagland solution. It must be noted, however, that the amount of the nutrients in the Hoagland solution remained constant throughout the test period. Thus, as the plants aged, the number of tillers and stem height increased tremendously without concomitant increase in nutrients, thereby reducing leaf nutrient content. Consequently, the SPAD index of leaves, which is closely related to nitrogen concentration, declined as the number of tillers increased (Figure 25). SPAD readings have a direct relationship with total chlorophyll in leaves, with the latter being greatly influenced by nitrogen content (Rigon et al., 2013; IIkaee et al., 2016 and Dinh et al., 2017). Calcium and magnesium concentrations in leaves fluctuated without any consistent trend.

Nitrogen concentrations in leaves of all media tested ranged from 1.87 % in filter cake + pine bark at 115 DAP to 2.58 % in pig manure + pine bark at 75 DAP (Table 13). These values were from marginal to completely adequate when compared with the range 1.6 to 1.95 % that has been reported in a number of countries to be critical for deficiency (Table 20). At 75 DAP, leaf nitrogen concentration of sugarcane plants grown in pig manure + pine bark and filter cake only,which had inherently high N (Table 9), ranged from 1.11 to 1.20 % compared with the range of 0.40 to 0.97 % in the ZSAES soil medium and filter cake + with pine bark with inherently poor N status. This meant that the addition of N to the medium via the Hoagland solution could not compensate for the poor N status in the ZSAES soil medium and filter cake + pine bark at 75 DAP. Mean leaf nitrogen concentration of all varieties tested ranged from 1.81 % to 2.51 % (Table 13), which translated to a range above the critical level (Table 20). Of all the sugarcane varieties tested, ZN7 seemed the least able to get enough N from the media. Consequently, supplementary N may need to be given when this variety is grown in containers.

Table 20: Critical third leaf calcium, magnesium, phosphorus, potassium and nitrogen concentrations for deficiency used in different countries for the vegetative growth of sugarcane

Nutrient	South Africa	Australia	Mauritius	United States of America (Florida)
Nitrogen	1.6 - 1.9	1.8	1.95	1.8
Phosphorus	0.16 - 0.19	0.19	0.21	0.19
Potassium	1.05	1.1	1.25	0.9
Calcium	0.15	0.2	0.2	0.2
Magnesium	0.08	0.08	0.1	0.12
References	Meyer et al., 1971; SASRI, 2013	Calcino et al., 2000	Basserau, 1988	McCray et al., 2009

All media were supplied enough P for sugarcane growth. The leaf P concentrations ranged from 0.27 % in the ZSAES soil medium to 0.81 % in pig manure + pine bark (Table 14), a range that was well above the critical level of 0.16 % (Table 20). Leaf P concentrations ranged from 0.39 % to 0.66 % among the varieties tested, indicating that none of the varieties had a problem with P acquisition from the media. A strong inverse relationship between leaf phosphorus and potassium concentrations (Figure 27) that existed may indicate that whatever conditions that caused P to accumulate caused K to decrease. In contrary, Ridge (2013) showed no antagonistic relationship between P and K. A strong positive relationship that existed between leaf phosphorus and calcium concentrations (Figure 31) suggested a synergy in uptake between the two elements. However, inverse relationship between P and Ca in sugarcane leaves has been reported (Meyer, 2013; Rhodes et al., 2018). Rhodes et al. (2018) reported that K^+ ions are generally taken up more efficiently than Mg or Ca due to the effective H^+/K^+ symport (a protein that transports $H^+$and K^+ ions simultaneously across root cell membranes).

Potassium concentrations in leaves of plants grown in filter cake + pine bark (0.86 %) were below the range 0.9 to 1.25 % (Table 15) which has been reported to be the critical level for deficiency for sugarcane, whilst the K concentrations in leaves of plants grown in the filter cake only (1.0 %) were marginal for optimal plant growth. Thus, the substrates failed to provide adequate K for sugarcane growth despite that this nutrient was added to the growth media in a Hoagland solution. Plants grown in the pig manure + pine bark and the ZSAES soil medium had leaf potassium concentrations in the range of 1.11 to 1.24 %, and, thus, were marginal for sugarcane growth as they fell within the range 0.9 to 1.25 % considered just enough for sugarcane growth (Table 20). ZN8 was the only variety with mean leaf potassium concentration (1.17 %) within the critical range for deficiency at 101 days after planting (Table 15). The ZN8 variety grown in the ZSAES soilmedium was the only treatment with leaf concentration above optimal levels at 115 days after planting. There was a positive relationship between leaf K and the number of green leaves (Figure 37), which suggests that K may be important in the production of leaves in sugarcane (Ridge, 2013). Filter cake only and filter cake + pine bark may have to be supplemented with more potassium to avoid deficiency in sugarcane plants in that medium.

Magnesium content in the leaves of all media tested was between 0.16 and 0.44 % (Table 16), a range above the critical level range of 0.08 to 0.12 % (Table 20), and meaning that all media provided adequate magnesium for vegetative growth of sugarcane. Leaf magnesium concentration in varieties tested ranged from 0.22 to 0.40 % (Table 15), showing adequacy in the supply of magnesium to the plants of all sugarcane varieties (Table 20). Depressed leaf magnesium concentration in the pig manure + pine bark and ZSAES soil medium were associated with increased potassium (Figure 30). This may suggest that the deficiency of leaf potassium in filter cake only and filter cake + pine bark may have been caused by high levels of magnesium (Rhodes et al., 2018).

The mean leaf calcium concentration of plants grown in all media tested was in the range of 0.18 to 0.41 %, thus ranging from marginal to sufficient according to the range 0.15 to 0.2 % reported to be the critical levels for deficiency for sugarcane in a number of countries (Table 20). The leaf calcium concentrations of all the varieties were also above the critical calcium range of 0.15 to 0.2 % reported to be optimal in a number of countries (Table 20). There was a negative relationship between calcium and TPDM (Figure 33D), which may show that there was dilution of calcium concentration as the plant biomass increased.

4.9 Conclusions

The emergence of cane setts was lower in the ZSAES soil medium than in the soil-less media tested. Plant growth in terms of tillering, shoot and root dry mass, green leaf area and the number of leaves was much higher in pig manure + pine bark than in the other media tested. However, stem elongation of plants grown in pig manure + pine bark was severely suppressed, making this medium undesirable. Nonetheless, plants grown in pig manure + pine bark had adequate leaf calcium, potassium, magnesium, nitrogen and phosphorus concentrations in the leaves. Potassium was not adequate for plants grown in filter cake only and filter cake + pine bark. The difference between varieties in plant growth was only observed in the number of tillers, with ZN7 maintaining fewer tillers than ZN8 and ZN10. In leaf nutrition, all varieties attained leaf nutrient concentrations above the critical levels, except potassium which was only adequate in variety ZN8.

CHAPTER 5

ASSESSING RATES OF A BLEND FERTILISERSUITABLEFOR GROWING SUGARCANE PLANTS IN CONTAINERS

5.1 Abstract

Growing sugarcane plants in containers is essential for research purposes. Information on fertiliser requirements for sugarcane plants grown in containers is limited. The objective of this experiment was to test Triple 16 Blend fertiliser application rates on vegetative growth performance and leaf nutrient concentrations of container grown sugarcane in four growth media. A Completely Randomised Design (CRD) consisting of four types of media and five rates of a blend fertiliser in factorial arrangement with three replications was used in this study. The four types of media were: filter cake only, pine bark + filter cake, pig manure + pine bark and ZSAES soil medium. The five fertilizer application rates were 312.5mg/l, 937.5mg/l, 1562.5, 2187.5mg/l of medium and Hoagland nutrient solution (100 % strength) as control. At ≤67 DAP, stem elongation and tillering were more pronounced in plants grown in pig manure + pine bark than in the other media. After 67 DAP, plants grown in pig manure + pine bark tillered profusely but their stem elongation was reduced by 112 % in plants that was applied nutrient solution. Stem elongation and internodes length were more pronounced in plants grown in the ZSAES soil medium and applied nutrient solution and 312.5 mg/l blend fertliser. Number of tillers per container increased by 115 % in plants grown in pig manure + pine bark than in the ZSAES soil applied nutrient solution. Brown rust incidence increased by 2.5 % in plants grown in filter cake + pine bark than in the ZSAES soil medium. Brown rust incidence also increased with blend fertilizer application rates >937.5 mg/l. Plants grown in pig manure + pine bark and ZSAES soil media had 29 % and 25 % higher in total plant dry matter than filter cake + pine bark, respectively. Green leaf area of plants that were applied nutrient solution and 312.5 mg/l was smaller when compared to other fertilizer application rates. Leaf N, P K was higher in plants grown in pig manure + pine bark than other media, where nutrient solution and 312.5 mg/l blend fertilizer was applied. Plants grown in the ZSAES soil medium had low leaf magnesium and calcium. The recommendation was to use 937.5 mg/l Triple 16 blend fertilizer in any of the media tested except pig manure + pine bark.

Key words: sugarcane, blend fertiliser rate, container, media.

5.2 Introduction

Most of the rates of nitrogen, phosphate and potassium recommended for sugarcane production had been assessed independently without assessing the interactions that can exist between these nutrients. Complex interactions between nitrogen, phosphorus and potassium exist (Shukla et al., 2009; Mariano et al., 2016). Usherwood and Segars (2001) noted that low phosphorus, potassium or sulphur could drastically reduce the effectiveness of nitrogen by limiting nitrogen use efficiency, thus reducing crop productivity. A balanced nutrition is, therefore, required for sugarcane to express its full genetic potential (Kingston, 2014; Leite et al., 2016). One way of balancing nutrition in sugarcane is to use blend fertiliser composed of different proportions of primary macro elements (Afghan et al., 2004; Chandiposha et al., 2014) and, in some cases, micro-nutrients, especially Zn, B and Mo (Dimkpa and Bindraban , 2016). Blend fertiliser comprises all the primary macro elements (N, P and K) required by the sugarcane plant (Miserquea and Pirard, 2004). Blending of fertilisers has advantages which include labour cost reduction and saving on time since the application of the three nutrients is combined in one operation (Miserquea and Pirard, 2004; Kwong, 2005). However, a challenge that arises from the use of blend fertiliser is that of the segregation of its constituents, which excerbated is when different particle sizes are used (Miserquea and Pirard, 2004). Segregation in blend fertilisers can result in non-uniform application of nutrients. In addition, some straight fertilisers are also not chemically compatible to form a blend (McCauley et al., 2009).

Blend fertiliser is made by mixing different ratios of nitrogen, phosphorus and potassium according to crop requirements and adding filler material to facilitate granulation and ease of application (Miserquea and Pirard, 2004). The most common ratios of nitrogen, phosphorus and potassium used in sugarcane globally are 2:1:3, 2:1:2, 3:1:5 and 1:2:1, respectively, depending on target yield and soil tests (Wood, 1990). For attainment of high sugarcane yield, potassium fertilisers are required in equal or greater amounts to nitrogen or phosphorus (Kwong, 2002). In Zimbabwe, the nitrogen, phosphorus and potassium blend ratio commonly used in sugarcane production is 1:1:1 (Clowes and Blackwell, 1998).

There is limited information on the amount of nitrogen, phosphorus and potassium blend fertiliser required by sugarcane grown in containers. The dynamics of nutrients in the field and in containers are not the same due to differences between field and pot conditions in volume, medium composition, temperature, moisture and other factors (Whitfield et al, 1996;

Bell et al., 2000; Yang et al., 2007). Applying nitrogen, phosphorus and potassium rates recommended for sugarcane in the field to sugarcane plants grown in containers may not give the same results. The volume of media in containers used for growing sugarcane is very small and therefore supports growth of fewer tillers than in field conditions (Yang et al., 2010). In containers, the movement of water is slower than in the field as it escapes through tiny drainage holes. This slow movement may create high moisture conditions in the containers, leading to compaction of the medium, which would reduce sugarcane plant growth. This challenge is exacerbated by the need for high frequency of irrigation in containers as compared to field conditions (Majsztrik et al., 2011).

5.3 Aim

To evaluate the suitability of growth medium and blend fertiliser application rate on vegetative growth and leaf nutrient concentrations of container-grown sugarcane plants.

5.4 Specific objectives

5.4.1 To test five Triple 16 blend fertiliser rates that include 312.5mg/l of medium, 937.5mg/l of medium, 1562.5mg/l of medium, 2187.5mg/l of medium and Hoagland nutrient solution (100 % strength) on four media namely filter cake only, filter cake + pine bark, pig manure + pine bark and ZSAES soil medium (control) on the growth performance of sugarcane plants (germination percent, stem height, number of tillers, SPAD index, green leaf area, number of leaves, dry matter of above and below ground parts of plants)

5.4.2 To evaluate five Triple 16 blend fertiliser rates that include 312.5mg/l of medium, 937.5mg/l of medium, 1562.5mg/l of medium, 2187.5mg/l of medium and Hoagland nutrient solution (100 % strength) on four media namely filter cake only, filter cake + pine bark, pig manure + pine bark and ZSAES soil medium (control) on leaf nutrient concentrations (N, P, K, Mg and Ca percent) of sugarcane plants

5.5 Hypothesis

The vegetative growth and leaf nutrient concentrations response of container-grown sugarcane to blend fertiliser application rate varies with the growth medium used.

5.6 Materials and methods

5.6.1 Study area

The experiment was done in the summer of the 2017/18 season at the Zimbabwe Sugar Association Experiment Station (ZSAES) in the South Eastern Lowveld of Zimbabwe. The Station is located 21^{o}01′S latitude and 28^{o}38′N longitude at an altitude of 430 m above sea level. The average annual rainfall received in the area is 625 mm per annum, much of it falls in summer months of October to March. The average air temperatures range from 26 ^{o}C in summer to 16 ^{o}C in winter.

5.6.2 Design and treatments

A Completely Randomised Design (CRD) consisting of four growth media in factorial combination with five fertiliser application rates and three replications was used. The four types of media were filter cake only, pine bark + filter cake (1:1 v/v), pig manure + pine bark (1:1 v/v), and ZSAES soil medium (topsoil: river sand: composted cattle manure; 5:2:2 v/v). The five fertiliser application rates tested were 312.5 mg/l (5 g per container), 937.5 mg/l (15 g per container), 1562.5 mg/l (25 g per container), and 2187.5 mg/l (35 g per container) Triple 16 blend fertiliser and Hoagland modified solution (or nutrient solution) was the control. Hoagland modified solution was made according to Hoagland and Arnon, (1950) and comprised the following salts: KNO_3, $Ca(NO_3)_2 \bullet 4H_2O$, $MgSO_4 \bullet 7H_2O$, KH_2PO_4, Fe-EDTA, H_3BO_3, $CuSO_4 \bullet 5H_2O$, $ZnSO_4 \bullet 7H_2O$, $MnCl_2 \bullet 4H_2O$, $Na_2MoO_4 \bullet 2H_2O$.

5.6.3 Plant culture

The plants were grown in plastic containers of the following dimensions: 35 cm top diameter, 23 cm bottom diameter and 27.5 cm height. The containers were filled with filter cake only, filter cake + pine bark (1:1 v/v), pig manure + pine bark (1:1 v/v), and ZSAES soil medium to within 7.5 cm from the brim leaving space for irrigation water. Prior to planting, the soil-less media was saturated with water for 72 hours by plugging the drainage holes.The ZSAES soil medium was only saturated for 24 hours prior to planting without plugging drainage holes. Sugarcane setts of ZN8 variety (9 months old) were cut at the base from S3 field using cane knives which were sterilized by immersing them for 5 minutes in diluted Propan-2-ol or isopropanol (JEYES fluid) (0.5 L JEYES fluid per 10 L of water). Three internodes from the base and top of the stalk were discarded using a cane knife. One eyed setts were cut from the remaining stalk before dipping them for five minutes in Triadimenol (Shavit) (1ml Shavit /

1000 ml of water) to prevent ratoon stunting disease. Five ‘one’ eyed setts of sugarcane were then planted on 26 September 2017 at the surface of the medium in each container. Upon emergence, the sett plants were thinned to leave a single plant per container. Fertiliser was applied at planting using Triple 16 blend fertilizer, as according to treatments, and thereafter, fortnightly up to 56 days after planting. Blend fertiliser was drilled into the medium after irrigation and covered. Modified Hoagland solution (Hoagland and Arnon, 1950) was applied at planting and every other day at a rate of 0.25 L per container per day up to 56 days after planting. The sugarcane plants were initially irrigated with one litre of water per day per container in the first month and then adjusted to 1.5 and 2.5 L per day per container during the second and third months, respectively. From the beginning of fourth month until the end of the experiment (112 DAP), the plants were irrigated with 3.0 L of water per day per container. All the weeds were uprooted by hand from planting until the end of the experiment. Fipronil (Regent) at the rate of 135 ml Regent /15L of water was used to control termites, aphids and other pests.

5.6.4 Measurements and data analysis

During the experimental period, seasonal meteorological data that included quantity of rainfall, aerial temperature, and evaporation was collected from the ZSAES Automatic Weather Station, which was approximately 100 m from the experimental site. Before planting, the nutrient status of each media used in the experiment was analysed using methods in Table 1 and the results are presented in Table 8. The data that was collected on plants is shown in Table 21.

Table 21: Parameters that were measured on sugarcane plants, frequency of collecting the data and methods used

Parameter	Frequency	Method
Stem height (cm)	38 DAP; thereafter fortnightly till 108 DAP	Using a metre rule, from the base of the plant at the surface of the medium to the apex of the primary tiller
Number of tillers	38 DAP; thereafter fortnightly till 108 DAP	Counting all tillers in a container
SPAD index	38 DAP; thereafter fortnightly till 108 DAP	Measured on leaf with the topmost visible dewlap leaf (LTVD) using a chlorophyll meter (Minolta SPAD-502, Minolta Co., Osaka, Japan) (Zhao et al., 2010)
Brown Rust incidence	Done once at harvest 112 DAP	Counting number of containers with plants showing Brown Rust
Dry Matter	Done once at harvest 112 DAP	All tillers were excised at the base to separate shoots and roots. The roots were washed with water. The shoots were separated into different components of trash and leaves. The roots and components of shoots were placed in a forced air oven at 105 ^{o}C for 72 hours and then weighed
Green leaf area	Done once at harvest 112 DAP	The leaf area of all green leaves was measured usinga leaf area meter (Delta-T Devices Ltd., Burwell, Cambridge, UK).
Number of green leaves	Done once at harvest 112 DAP	All mature green leaves were counted
Number of internodes	Done once at harvest 112 DAP	Number of internodes on the primary tillers was counted.
Stem girth	Done once at harvest 112 DAP	Was measured on primary tiller at the base (first internode) using a Dial calliper 150mm
Leaf calcium concentration	Done once at harvest 112 DAP	EDTA method (Derderian, 1961)
Leaf potassium concentration	Done once at harvest 112 DAP	EDTA method (Derderian, 1961)
Leaf magnesium concentration	Done once at harvest 112 DAP	EDTA method (Derderian, 1961)
Leaf nitrogen concentration	Done once at harvest 112 DAP	Kjedahl digestion method (Persson et al., 2008)
Leaf phosphorus concentration	Done once at harvest 112 DAP	Vanado-molydo phosphate method (Bray and Kurtz, 1945)

Prior to statistical analysis, the data was tested for meeting the assumptions of ANOVA and appropriate transformations were done. The data was subjected to Fisher's Analysis of Variance using Genstat statistical software (Genstat 14th edition, VSN International Ltd., Hemel Hempstead, UK. The treatment means were separated using Least Significant Difference and Standard Error Difference test at 5% level (Steel and Torie, 1984). Simple regression and principal component analyses were done using MS Excel 2010 version and Xstat 2010 version, respectively.

5.7 Results

5.7.1 Seasonal meteorological data

The rains started with a very low 3 mm recorded in September 2017 but increased to 33.6 mm in October before reaching a peak in November 2017. Rainfall levels then began to decline in December 2017 before falling sharply to 9 mm in January 2018 (Figure 40). Temperatures were cool in August, gradually rose to a peak of 26.5 °C in December and then fell marginally in January 2018. The average monthly evaporation rate was generally high with an average of 6.32 mm per day throughout the experimental period (Figure 40).

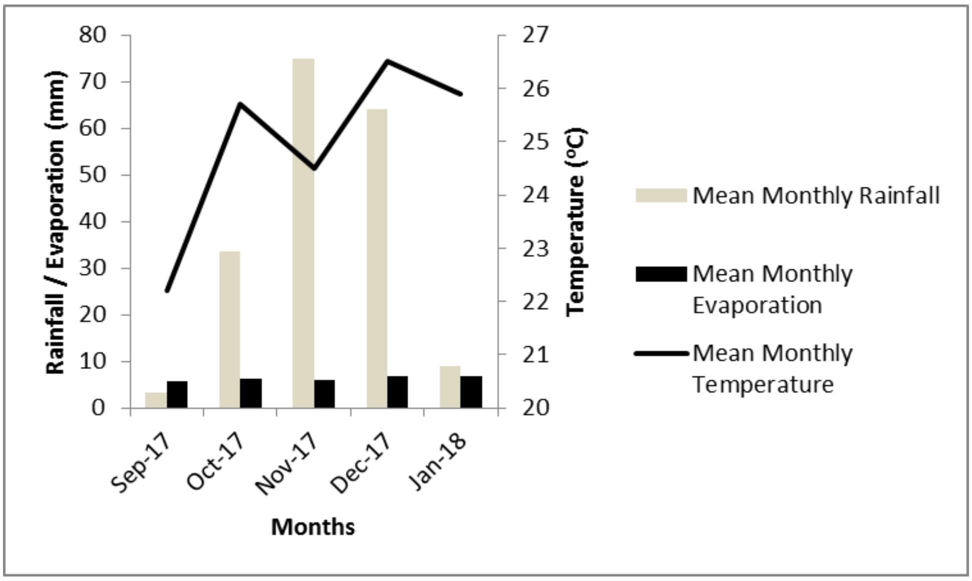

Figure 40: Average monthly temperature, rainfall and evaporation rate at ZSAES for September 2017/ January 2018 period

5.7.2 Stem height of primarytiller sugarcane plants

There was media x fertiliser application rate interaction on stem height of primary tiller sugarcane plants at 95 DAP and 108 DAP. The stem height of plants grown in the ZSAES soil medium, which were applied nutrient solution and 312.5 mg/l were taller than other media, at 108 DAP (Figure 41). In contrast, stem height of plants grown in the ZSAES soil medium and filter cake + pine bark, which were applied 937.5 mg/l and 1562.5 mg/l blend fertlizer were taller than pig manure + pine bark and filter cake only (Figure 41). Stem heights of plants grown in all the media except pig manure + pine bark, which were applied 2187.5 mg/l blend fertlizer were similar (Figure 41).

There was a significant effect ($p<0.05$) of media on stem height of primary tiller at 38, 53 and 81 DAP (Table 22). Stem height of plants grown in the pig manure + pine bark was taller than other media at 38 and 53 DAP, although it was not different to plants grown in the filter cake + pine bark at 53 DAP (Table 22). As the plants grew, the stem height became significantly similar in all the media at 67 DAP. However, at 81 DAP the stem height of plants grown in the ZSAES soil medium, filter cake only and filter cake + pine bark were significantly taller than plants grown in the pig manure + pine bark (Table 22). There was no significant effect ($p>0.05$) of fertiliser application rate on stem height of primary tiller at 38, 53 and 67 DAP, except at 81 DAP (Table 22). At 81 DAP, the stem height of plants that were applied nutrient solution and 312.5 mg/l blend fertiliser was taller than other fertiliser application rates (Table 22).

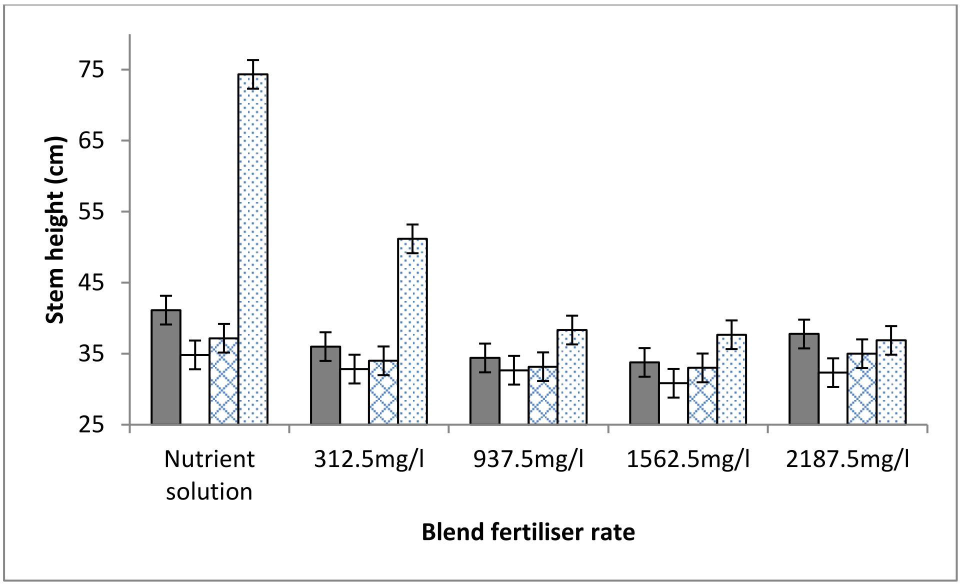

Figure 41: Stem height of sugarcane plants of ZN8 variety grown in different growth media (▨ filter cake only, ■ filter cake + pine bark, □ pig manure + pine bark, ⊡ ZSAES soil medium) and applied different fertiliser application rates (312.5 mg/l, 937.5 mg/l, 1562.5 and 2187.5 mg/l Triple 16 Blend and nutrient solution) measured at 108 DAP in January 2018 (level of significance *)**

Table 22: Stem height of sugarcane plants of ZN8 variety grown in different growth media (filter cake only, filter cake + with pine bark, pig manure + with pine bark, andZSAES soil medium) and applied different fertiliser application rates (312.5 mg/l, 937.5 mg/l, 1562.5 and 2187.5 mg/l Triple 16 Blend and nutrient solution) measured at 38 DAP to 81DAP in January 2018

Media	**38 DAP**	**53 DAP**	**67 DAP**	**81 DAP**
Filter cake + pine bark	14.63a	22.79ab	27.69	32.27ab
Pig manure + pine bark	18.00b	25.27b	28.57	31.23a
Filter cake only	15.93ab	22.70a	28.01	32.37ab
ZSAES soil medium	14.00a	20.83a	25.86	34.27b
P value	0.004	0.012	0.133	0.031
LSD	2.198	2.551	NS	2.002
Fertiliser application rate				
312.5 mg/l	16.50	23.89	28.60	34.04bc
937.5 mg/l	15.04	23.52	27.73	31.96ab
1562.5 mg/l	15.21	21.88	25.34	30.67a
2187.5 mg/l	15.17	21.60	27.17	31.29a
Nutrient solution	16.29	23.60	28.81	34.71c
P value	0.628	0.347	0.083	0.002
LSD	NS	NS	NS	2.238
CV (%)	19.0	15.1	11.7	8.3

5.7.3 Number of tillers of sugarcane plants per container

There was interaction between media and fertiliser application rate on number of tillers per container at 108 DAP (Figure 42). The number of tillers of sugarcane plants grown in the pig manure + filter cake, which were applied nutrient solution, 312.5 mg/l and 1562.5 mg/l were more than other media, at 108 DAP (Figure 42). In contrast, number of tillers of sugarcane plants grown in the pig manure + filter cake and filter cake + pine bark, which were applied 937.5 mg/l and 2187.5 mg/l blend fertlizer were more than in the filter cake only and the ZSAES soil media (Figure 42).

There was a significant effect ($p<0.05$) of media on number of tillers per container at 38, 53. 67, 81 and 95 DAP (Table 23). The number of tillers per container of plants grown in the pig manure + pine bark was more than in other media at all sampling times. In contrast, plants grown in the ZSAES soil medium had fewer tillers per container at 38, 53. 67, 81 and 95 DAP (Table 23). There was no significant effect ($p>0.05$) of fertiliser application rate on number of tillers per container at 38, 53, 67 and 81 DAP, except at 95 DAP (Table 23). At 95 DAP, the number of tillers per container of plants that were applied 1562.5 mg/l and 937.5 mg/l blend fertiliser was significantly more than other fertiliser application rates (Table 23). The relationship between stem height and number of tillers was a positive relationship (Figure 43).

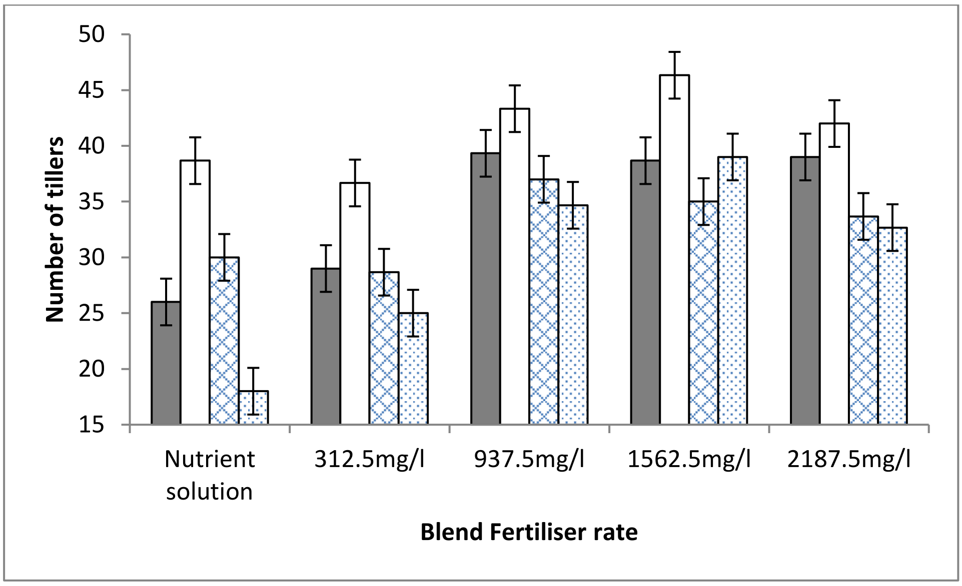

Figure 42: Number of tillers per container of sugarcane plants of ZN8 variety grown in different growth media (▩ filter cake only, ■ filter cake + pine bark, □ pig manure + pine bark, ⬚ ZSAES soil medium) and applied different fertiliser application rates (312.5 mg/l, 937.5 mg/l, 1562.5 and 2187.5 mg/l Triple 16 Blend and nutrient solution) measured at 108 DAP in January 2018 (level of significance *)**

Table 23: Number of tillers per container of sugarcane plants of ZN8 variety grown in different growth media (filter cake only, filter cake + with pine bark, pig manure + with pine bark, andZSAES soil medium) and applied different fertiliser application rates (312.5 mg/l, 937.5 mg/l, 1562.5 and 2187.5 mg/l Triple 16 Blend and nutrient solution) measured at 38 DAP to 95 DAP in January 2018

Media	**38 DAP**	**53 DAP**	**67 DAP**	**81 DAP**	**95 DAP**
Filter cake + pine bark	1.00b	5.00b	13.47b	23.60c	27.00b
Pig manure + pine bark	2.87c	9.53c	19.73c	27.40d	31.13c
Filter cake only	0.87b	4.80b	12.00b	20.67b	23.40a
ZSAES soil medium	0.13a	3.47a	7.53a	15.60a	21.53a
P value	<0.001	<0.001 .	<0.001	<0.001	<0.001
LSD	0.639	1.147	2.166	2.510	2.152
Fertiliser application rate					
312.5 mg/l	1.33	5.75	14.08	21.42	23.42a
937.5 mg/l	1.00	5.67	13.58	22.75	27.75bc
1562.5 mg/l	1.33	5.83	12.58	23.67	28.92c
2187.5 mg/l	1.00	5.33	11.75	21.00	26.25b
Nutrient solution	1.42	5.92	13.92	20.25	22.50a
P value	0.634	0.907	0.263	0.119	<0.001
LSD	NS	NS	NS	NS	2.406
CV (%)	71.2	27.3	22.3	15.6	11.3

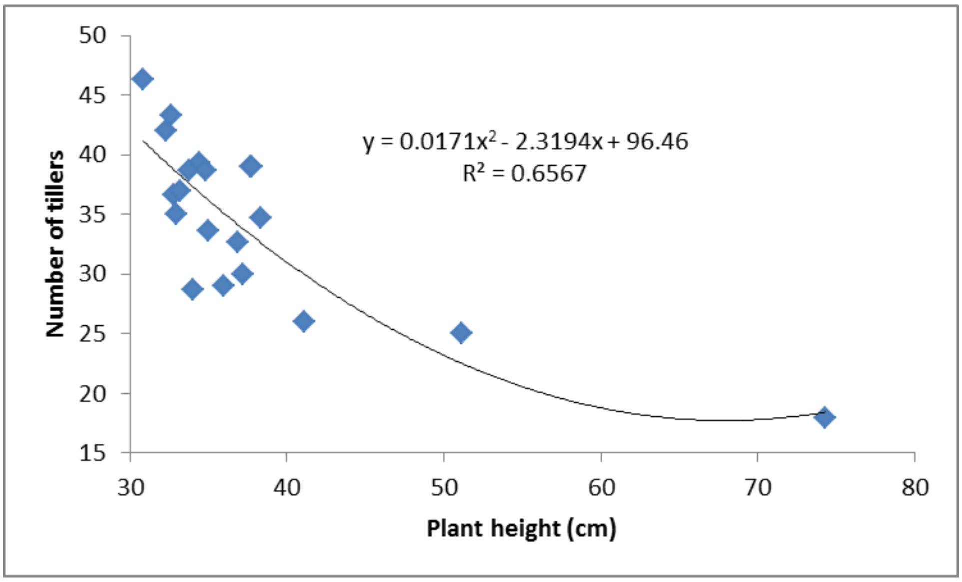

Figure 43: Relationship between stem height and number of tillers at 108 DAP

5.7.4 SPAD index of leaf with TVD of primary tillers

There was media x fertiliser application rate interaction on SPAD index of leaf with TVD of primary tillers at 95 DAP and 108 DAP. The SPAD index of leaf with TVD of primary tillers grown in the pig manure + pine bark and filter cake only, which were applied nutrient solution were more than ZSAES soil medium and filter cake + pine bark, at 108 DAP (Figure 44). In contrast, SPAD index of leaf with TVD of primary tillers grown in all the media, which were applied 312.5 mg/l was similar (Figure 41). SPAD index of leaf with TVD of primary tillers grown in all the media except filter cake only, which were applied 937.5 mg/l blend fertlizer were similar (Figure 44). The SPAD index of leaf with TVD of primary tillers that were grown in the pig manure + filter cake, filter cake only and the ZSAES soil media was more than filter cake + pine bark of plants that were applied either 1562.5 mg/l or 2187.5 mg/l blend fertiliser.

There was no significant effect (p>0.05) of media or fertiliser application rate on SPAD index of leaf with TVD of primary tillersat 53, 67 and 81 DAP.

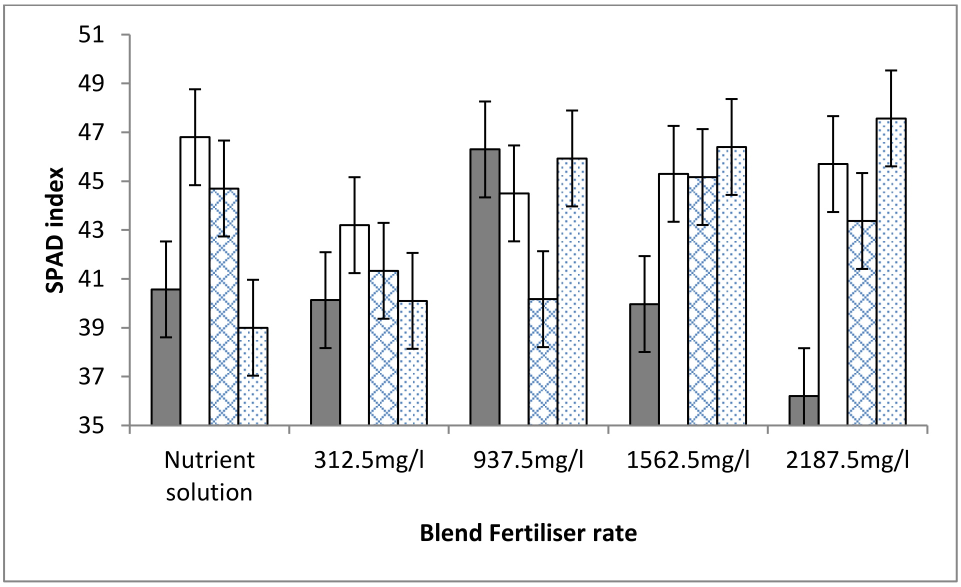

Figure 44: SPAD index of leaf with TVD of primary tillers of ZN8 variety grown in different growth media (⊠ filter cake only, ■ filter cake + pine bark, □ pig manure + pine bark, ⊡ ZSAES soil medium) and applied different fertiliser application rates (312.5 mg/l, 937.5 mg/l, 1562.5 and 2187.5 mg/l Triple 16 Blend and nutrient solution) measured at 108 DAP in January 2018 (level of significance **)

5.7.5 Brown rust incidence in sugarcane leaves

Brown rust (*Puccinia melanocephala*) was noticed in the plants close to the end of the experiment at 112 DAP. The incidence of Brown rust was highest in plants grown in filter cake + pine bark whereas there was no significant difference among those grown in the three other media tested (Figure 45). Generally, Brown rust incidence in sugarcane leaves increased with blend fertiliser rate (Figure 46). The Brown rust incidence was high in plants that were applied ≥ 1562.5mg/l blend fertilizer but was noticeably low in plants that were applied nutrient solution (Figure 46).

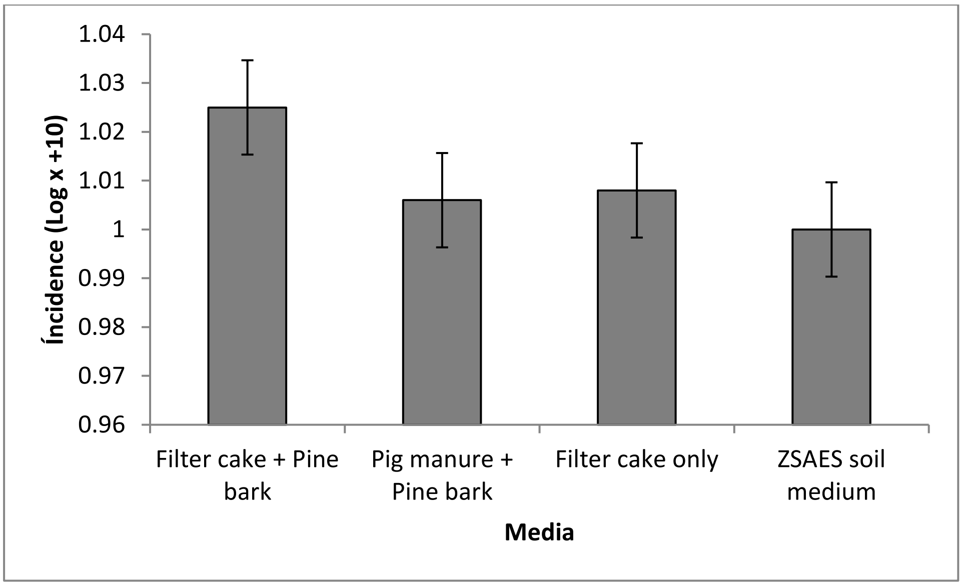

Figure 45: Brown rust incidence on sugarcane leaves of tillers grown in different media (filter cake only, filter cake + pine bark, pig manure + pine bark, ZSAES soil medium) in a container measured at 112 days after planting in January 2018 (level of significance *)**

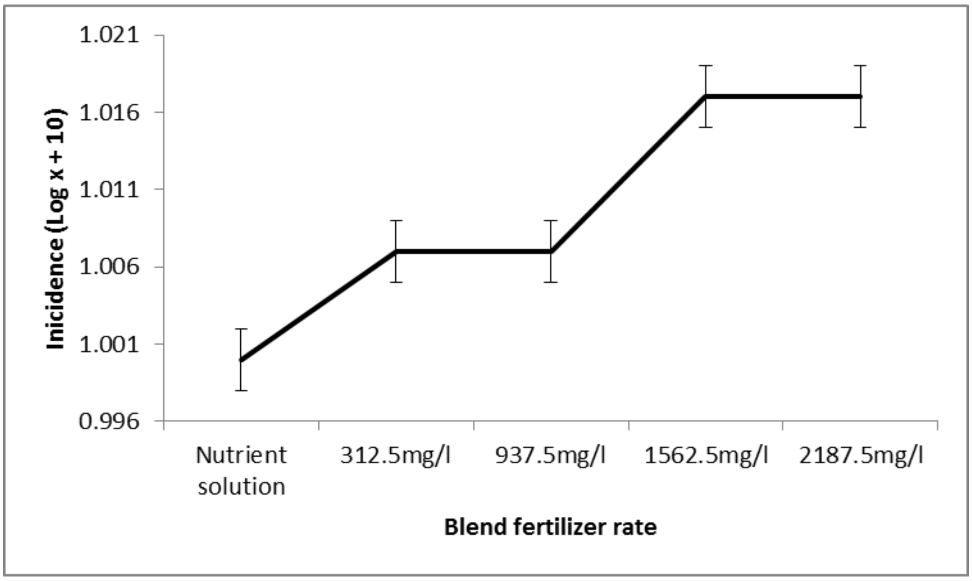

Figure 46: Brown rust incidence on sugarcane leaves of tillers applied different blend fertiliser application rates (nutrient solution, 312.5 mg/l, 937.5 mg/l, 1562.5 mg/l and 2187.5 mg/l) measured at 112 DAP in January 2018 (level of significance **)

5.7.6 Dry matter of sugarcane plants

Pig manure + pine bark had more root and green leaves dry matter, although it was not significantly different with ZSAES soil medium and filter cake only (Table 24). ZSAES soil medium had more shoot dry matter than other media, but was not different with pig manure + pine bark. Pig manure + pine also had more trash dry matter than other media, although it was comparable to pine bark + filter cake. Pig manure + pine bark had more total plant dry matter than other media but was not significantly different with the ZSAES soil medium (Table 24).

There were no differences among fertiliser application rates on shoot dry matter, root biomass and total plant dry mass except on the dry matter of green leaves (data not shown). Plants that were fertilized using nutrient solution had lower dry matter of green leaves than those that were fertilized using blend fertiliser, although there was no difference with the 312.5mg/l blend fertiliser application rate (Figure 47).

Table 24: Dry matter of tillers grown in different media (filter cake only, filter cake + pine bark, pig manure + pine bark, ZSAES soil medium) in a container measured at 112 days after planting in January 2018

Media	Roots	Green leaves	Shoots	Trash	Total
Filter cake + pine bark	187a	108.3a	400.2a	86.9b	674a
Pig manure + pine bark	294b	142.7b	478.3b	93.6b	866b
Filter cake only	235ab	131.4b	384.1a	61.0a	680a
ZSAES soil medium	288b	128.3b	499.6b	53.7a	841b
P value	0.023	0.002	0.003	<0.001	<0.001
LSD	0.1436	16.89	68.7	14.24	110.3
CV (%)	41.2	17.9	21.1	26.1	19.5

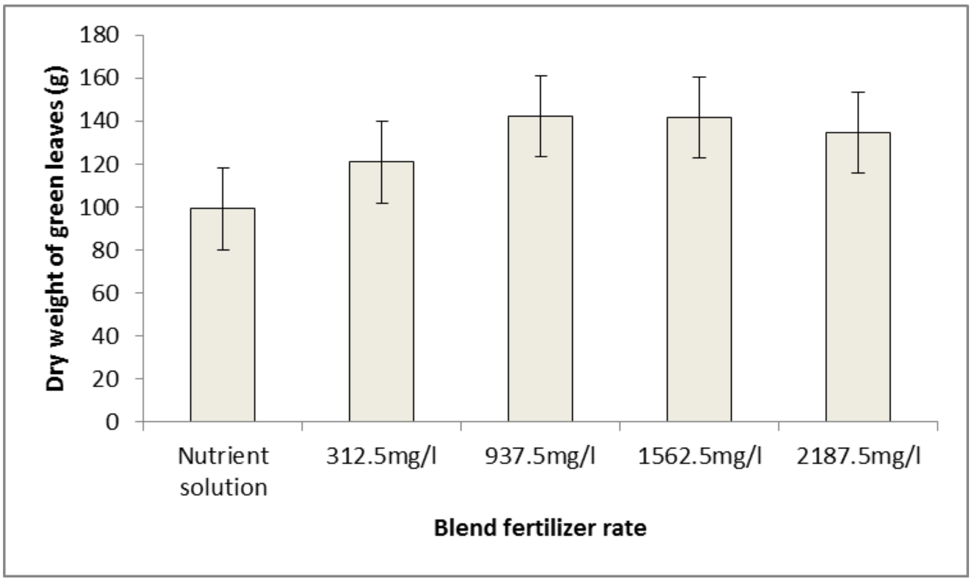

Figure 47: Dry matter of green leaves of tillers applied different blend fertiliser application rates (nutrient solution, 312.5 mg/l, 937.5 mg/l, 1562.5 and 2187.5 mg/l) measured at 112 DAP in January 2018 (level of significance *)**

5.7.7 Green leaf area and number of leaves

Green leaf area was not significantly different among the four media tested (Table 25). Blend fertiliser application rates ≥937.5mg/l appeared optimal for green leaf area. The number of green leaves per container was more in plants grown in pig manure + pine bark, filter cake only and the ZSAES soil media than in the filter cake + pine bark (Table 25). The plants that were applied any of the blend fertiliser application rate had significantly equal number of green leaves and more than plants that were applied nutrient solution (Table 25). The relationship between number of tillers and green leaf area was a positive relationship (Figure 48).

Table 25: Green leaf area and number of leaves per container of tillers grown in different media (filter cake only, filter cake + pine bark, pig manure + pine bark, ZSAES soil medium) in a container measured at 112 days after planting in January

Medium	**Green Leaf Area (mm^2)**	**Number of leaves**
Filter cake + pine bark	882,159	109.7a
Pig manure + pine bark	1,185,260	150.5b
Filter cake only	1,139,592	129.9ab
ZSAES soil medium	1,104,476	133.7b
P value	0.110	0.005
LSD	NS	21.44
Fertiliser application rate		
312.5mg/l	965,996ab	128.6b
937.5mg/l	1,369,307c	145.2b
1562.5mg/l	1,205,871bc	152.1b
2187.5mg/l	1,078,647bc	138.2b
Nutrient solution	769,538a	90.7a
P value	0.002	<0.001
LSD	293732.8	23.97
CV (%)	33	22.2

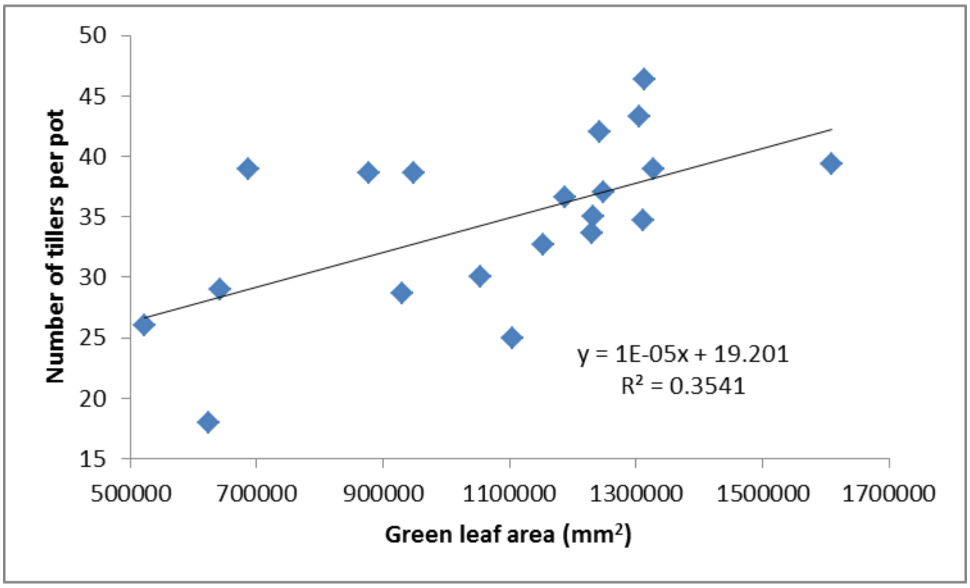

Figure 48: Relationship between number of tillers and green leaf area

5.7.8 Average internode length of primary tiller

There was media x fertiliser application rate interaction on average internode length of primary tiller 112 DAP (Figure 49). The average internode length of primary tiller grown in the ZSAES soil medium, which were applied nutrient solution and 312.5 mg/l blend fertilizer was taller than other media (Figure 49). In contrast, average internode lengths of primary tillers grown in all the media, which were applied ≥937.5 mg/l blend fertliser were significantly equal (Figure 49).

There were more internodes on primary tiller of plants that were applied nutrient solution, 312.5 mg/l and 937.5 mg/l than applied 1562.5 mg/l and 2187.5 mg/l blend fertiliser (Figure 50). There was a strong negative relationship between internode length and number of tillers (Figure 51).

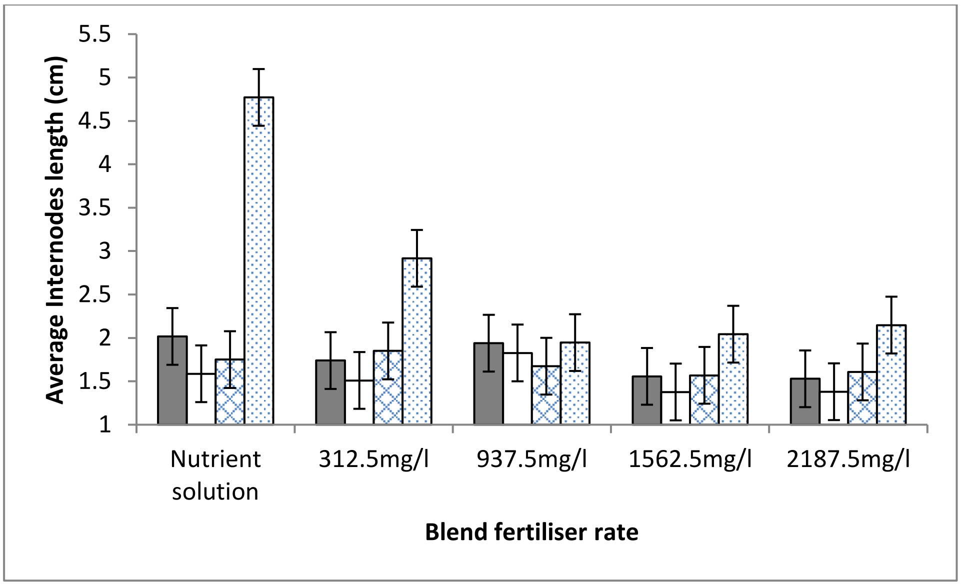

Figure 49: Average internode length of primary tillers grown in different media (▨ filter cake only, ■ filter cake + pine bark, □ pig manure + pine bark, ⊡ ZSAES soil medium) and applied different blend fertiliser application rates (nutrient solution, 312.5 mg/l, 937.5 mg/l, 1562.5 and 2187.5 mg/l) measured at 112 DAP in January 2018 (level of significance *)**

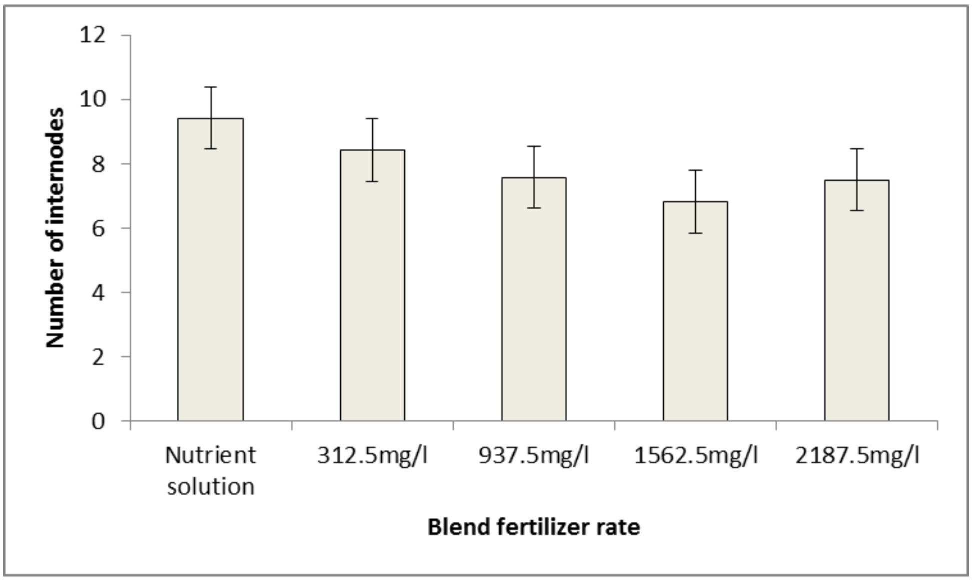

Figure 50: Response of number of internodes to blend fertiliser rate at 112 DAP (level of significance *)**

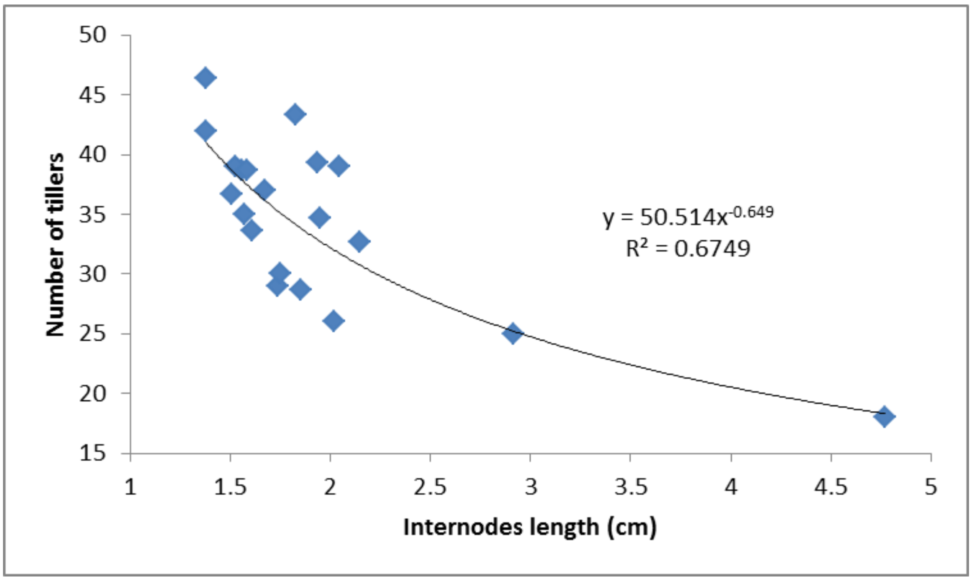

Figure 51: Relationship between number of tillers and internode length

5.7.9 Stem girth of primary tiller

The stem girth of a primary tiller was wider in plants grown in the ZSAES soil medium than in those grown in the three other media tested (Figure 52). The stem girth of the primary tiller in all the soil-less media tested was significantly equal (Figure 52). There were no significant differences in fertiliser application rates on stem girth of primary tiller (data not shown).

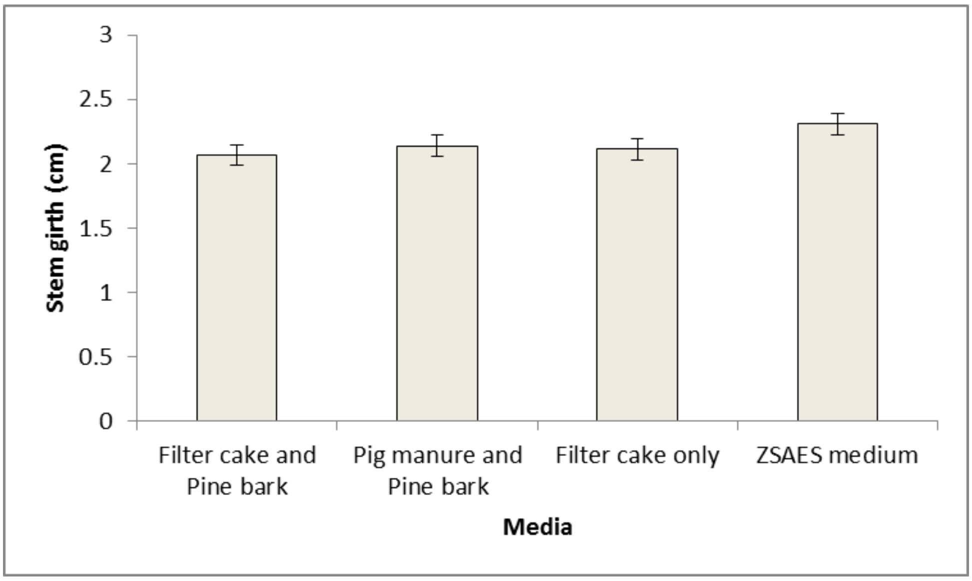

Figure 52: Stem girth of primary tillers grown in different media (filter cake only, filter cake + pine bark, pig manure + pine bark, ZSAES soil medium) measured at 112 DAP in January 2018 (level of significance *)**

5.7.10 Foliar leaf analyses

5.7.10.1 Nitrogen content (%) in the leaf with TVD of primary tiller

There was interaction between media and fertiliser application rate on nitrogen content (%) in the leaf with TVD of primary tiller (Figure 53). The leaf N content of sugarcane plants grown in the pig manure + filter cake was more than other media in plants that were applied nutrient solution and 312.5 mg/l blend fertilizer. In contrast, leaf N content of plants grown in the pig manure + filter cake, filter cake only and the ZSAES soil media was more than filter cake + pine bark, of plants that were applied 937.5 mg/l and 2187.5 mg/l blend fertlizer (Figure 53). There was no significant difference between media in leaf N content of plants that were applied 1562.5 mg/l blend fertilizer (Figure 53). Relationship between leaf potassium and nitrogen concentrations (Figure 54); leaf nitrogen concentration and number of tillers, were both positive (Figure 55).

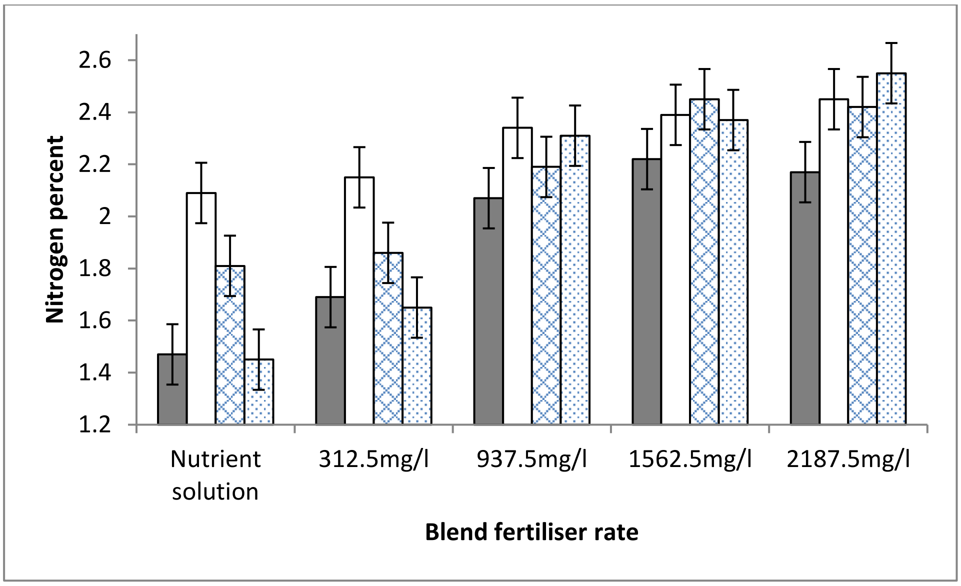

Figure 53: Nitrogen content on the leaf with TVD of primary tillers grown in different media (▨ filter cake only, ■ filter cake + pine bark, □ pig manure + pine bark, ⊡ ZSAES soil medium) and applied different blend fertiliser application rates (nutrient solution, 312.5 mg/l, 937.5 mg/l, 1562.5 and 2187.5 mg/l) measured at 112 DAP in January 2018 (level of significance **)

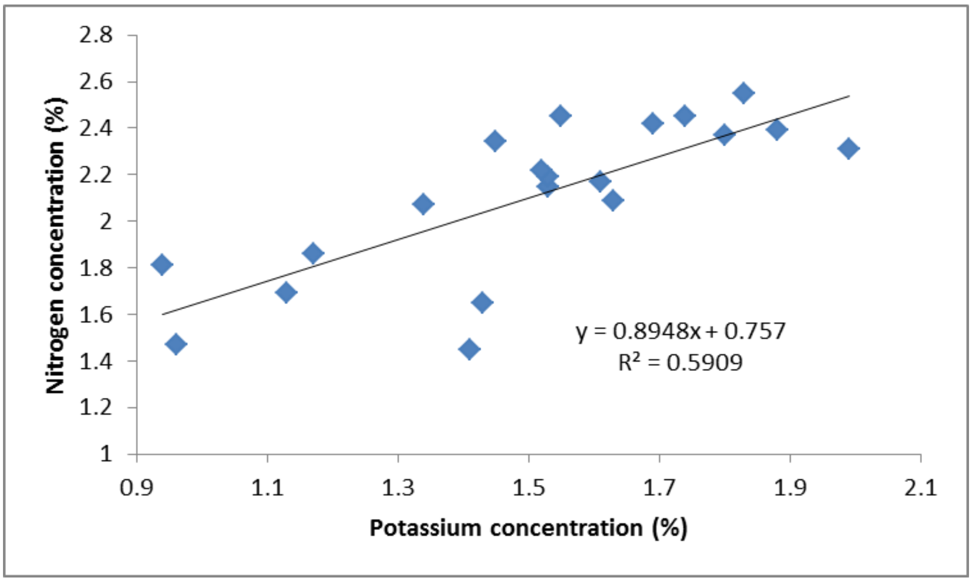

Figure 54: Relationship between leaf potassium and nitrogen concentrations (%) of sugarcane plants

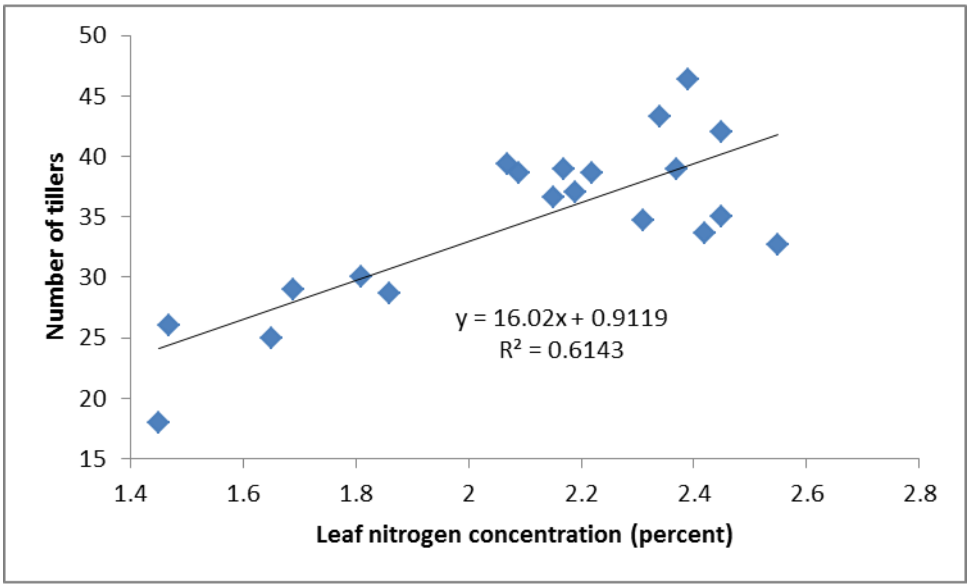

Figure 55: Relationship between leaf nitrogen concentration and number of tillers at 112 DAP

5.7.10.2 Phosphorus content (%) in the leaf with TVD

There media x fertiliser application rate interaction on phosphorus content (%) in the leaf with TVD of primary tiller was significant (Figure 56). The leaf P content of sugarcane plants grown in the pig manure + pine bark and filter cake + pine bark was more than filter cake only and the ZSAES soil media of plants that were applied nutrient solution, 312.5 mg/l, 937.5 mg/l and 1562.5 mg/l blend fertilizer. In contrast, leaf N content of plants grown in filter cake + pine bark was more than other media tested, in plants that were applied 2187.5 mg/l blend fertlizer (Figure 56). There was a strong positive relationship between leaf phosphorus content and the number of tillers (Figure 57). Also the relationship between leaf phosphorus content and Brown rust incidence was strongly positive (Figure 58).

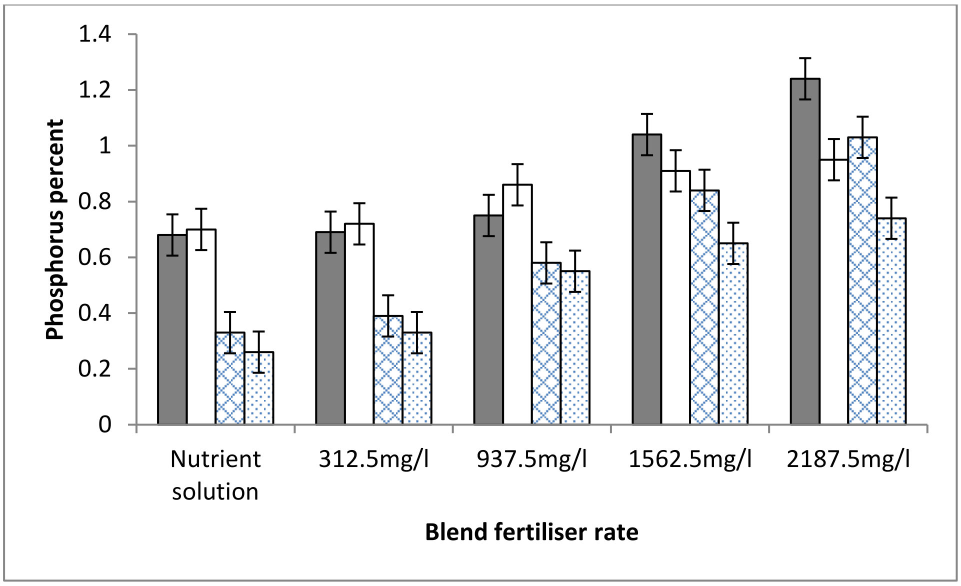

Figure 56: Phosphorus content on the leaf with TVD of primary tillers grown in different media (⊠ filter cake only, ■ filter cake + pine bark, □ pig manure + pine bark, ⊡ ZSAES soil medium) and applied different blend fertiliser application rates (nutrient solution, 312.5 mg/l, 937.5 mg/l, 1562.5 and 2187.5 mg/l) measured at 112 DAP in January 2018 (level of significance **)

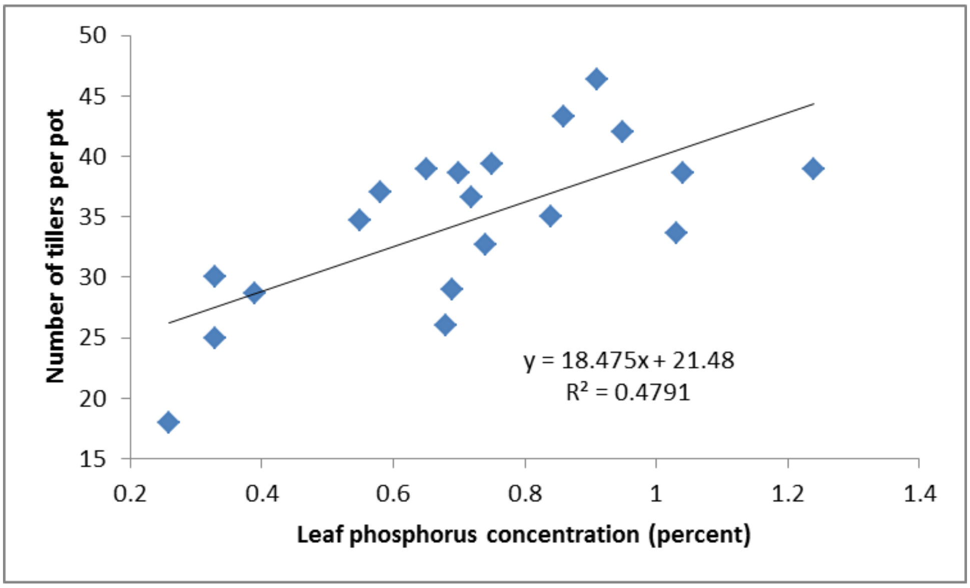

Figure 57: Relationship between leaf phosphorus concentration and number of tillers at 112 DAP

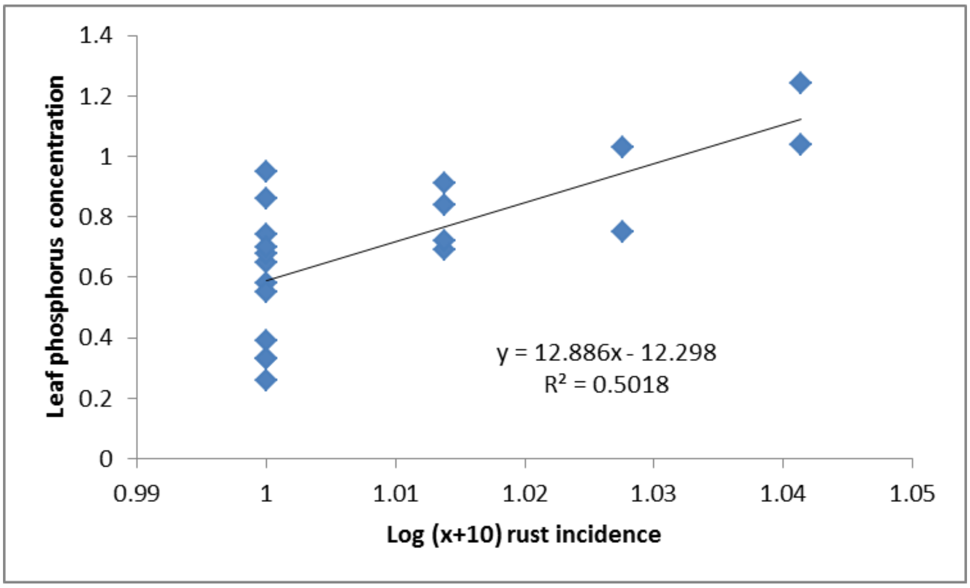

Figure 58: Relationship between leaf phosphorus concentration and Brown rust incidence

5.7.10.3 Potassium content (%) in the leaf with TVD

There was interaction between media and fertiliser application rate on K content (%) in the leaf with TVD of primary tiller (Figure 59). The leaf K content of sugarcane plants grown in the pig manure + filter cake and ZSAES soil media was more than other media in plants that were applied nutrient solution, 312.5 mg/l and 1562.5 mg/l blend fertilizer. In contrast, leaf K content of plants grown in the the ZSAES soil medium was more than the other media, of plants that were applied 937.5 mg/l (Figure 59). There was no significant difference between media in leaf K content of plants that were applied 2187.5 mg/l blend fertilizer (Figure 59).

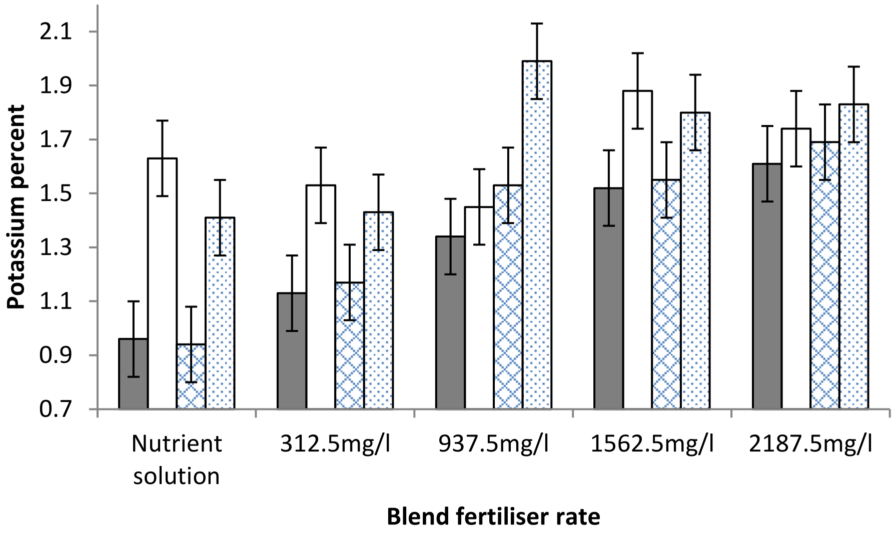

Figure 59: Potassium content on the leaf with TVD of primary tillers grown in different media (⊠filter cake only, ■filter cake + pine bark, □pig manure + pine bark,⊡ ZSAES soil medium) and applied different blend fertiliser application rates (nutrient solution,312.5 mg/l,937.5 mg/l, 1562.5 and 2187.5 mg/l) measured at 112 DAP in January 2018 (level of significance *)

5.7.10.4 Magnesium content (%) in the leaf with TVD

There was no interaction between media and fertilizer application rate on leaf Mgcontent (data not shown). Also, there were no significant differences between blend fertiliser rates in in leaf Mg content (data not shown). However, there were significant differences among the media (Figure 60). Plants grown in the ZSAES soil medium had the lowest leaf magnesium concentration of all the media tested (Figure 60). There was no significant difference in leaf magnesium concentrations between filter cake + pine bark or filter cake onlyand pig manure + pine bark (Figure 60).

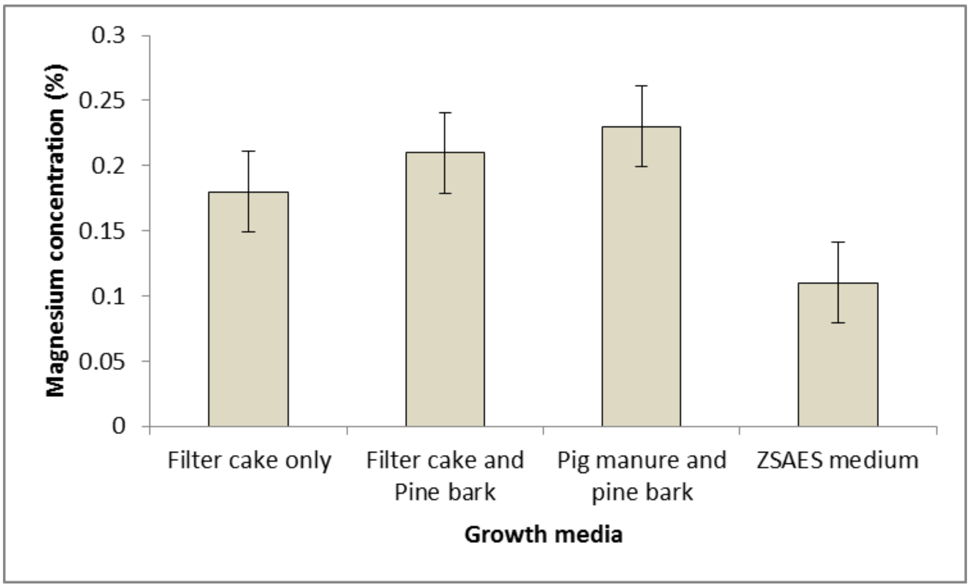

Figure 60: Magnesium content on the leaf with TVD of primary tillers grown in different media (filter cake only, filter cake + pine bark, pig manure + pine bark, ZSAES soil medium) measured at 112 DAP in January 2018 (level of significance *)**

5.7.10.5 Calcium content (%) in the leaf with TVD

There was interaction between media and fertiliser application rate on Ca content (%) in the leaf with TVD of primary tiller (Figure 61). The leaf Ca content of sugarcane plants grown in all media was significantly equal in plants that were applied nutrient solution. In contrast, leaf Ca content of plants grown in the filter cake + pine bark, pig manure + pine bark and filter cake only was more than the ZSAES soil medium of plants that were applied 312.5 mg/l (Figure 61). Leaf Ca content of plants grown in the pig manure + pine bark was more than other media of plants that were applied 937.5 mg/l (Figure 61).The leaf Ca content of plants grown in the filter cake + pine bark and filter cake only was more than pig manure + pine bark and the ZSAES soil media of plants that were applied 1562.5 mg/l and 2187.5 mg/l blend fertilizer (Figure 61).

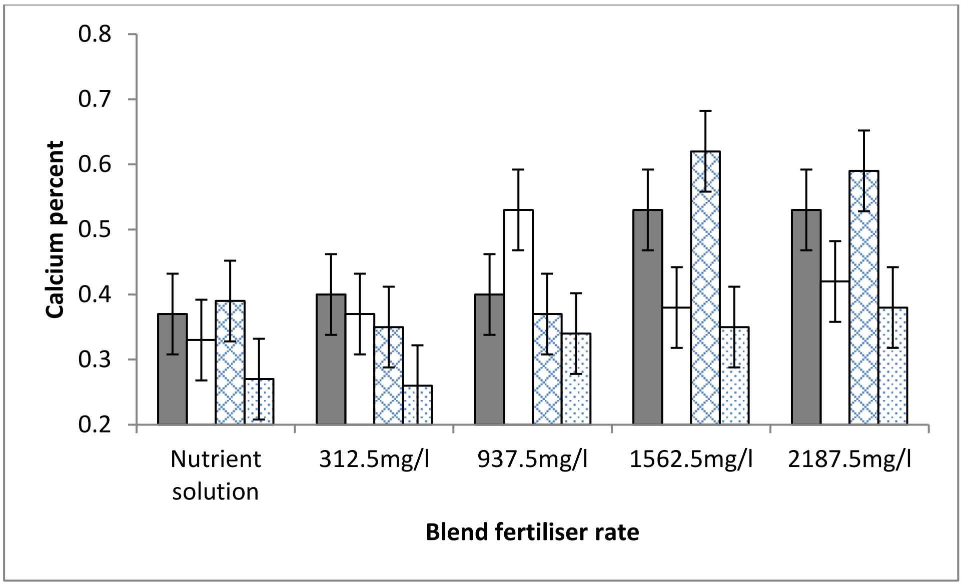

Figure 61: Calcium content on the leaf with TVD of primary tillers grown in different media (⊠ filter cake only, ■ filter cake + pine bark, □ pig manure + pine bark, ⊡ ZSAES soil medium) and applied different blend fertiliser application rates (nutrient solution, 312.5 mg/l, 937.5 mg/l, 1562.5 and 2187.5 mg/l) measured at 112 DAP in January 2018 (level of significance *)

5.7.11 Principal component analysis based on total plant dry mass (TPDM) and foliar leaf nutrient content

The first principal component (F1) had the highest Eigen value of 2.743, contributing 54.87 % and was followed by the second principal component (F2) with 1.495, which contributed 29.90 % (Figure 62). Of all the principal components analysed, principal components F5 (0.041) and F4 (0.160) contributed the least Eigen values (Figure 62). The score plot between first principal component (horizontal axis) and second principal component (vertical axis) showed that leaf nitrogen concentration contributed the highest score to TPDM in the first principal component (F1) when compared to other leaf nutrients (Figure 63). Leaf potassium concentration contributed the highest score to TPDM relative to other leaf nutrients in second principal component (F2).

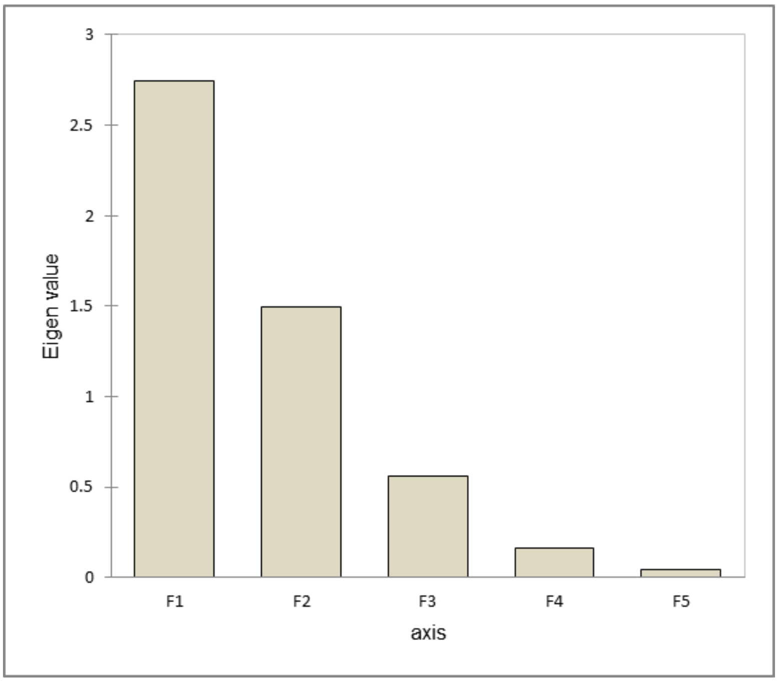

Figure 62: Scree plot showing Eigen values of five principal components

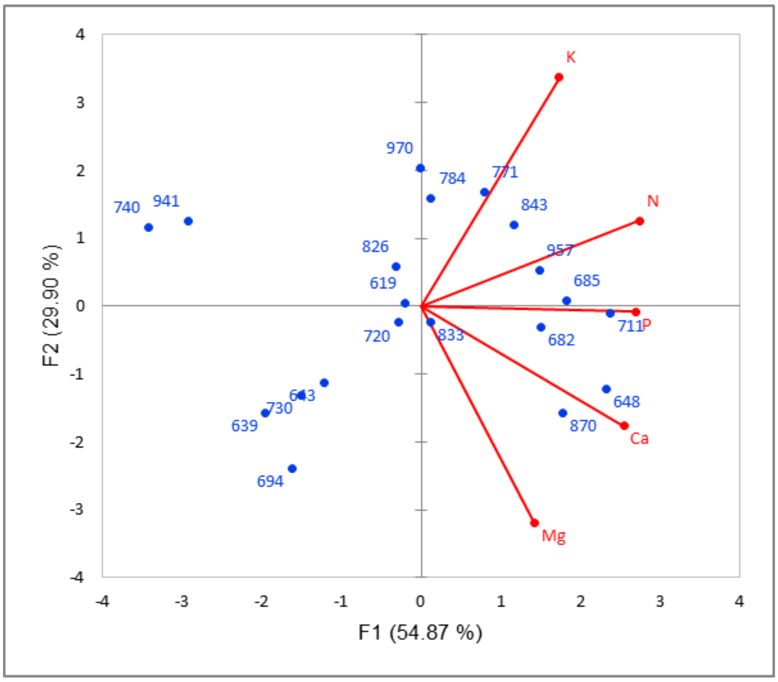

Figure 63: Box plot for first and second components

5.8 Discussion

5.8.1 Effects of interactions of blend fertiliser application rates and growth media on plant growth

During early growth of sugarcane plants (≤67 DAP), the effects of the media were more dominant on plant growth than fertilizer application rate (Table 22). Stem height and tillering of plants grown in pig manure + pine bark were higher than other media during early growth and this may be attributed to more available nitrogen content in this medium (Table 9). Most of the nitrogen content in pig manure is in the inorganic form (Bertora et al., 2008). Among the mineral elements required by sugarcane plants, nitrogen influence plant growth most than any other element. According to da Silva (2018), nitrogen is the second demanded element after potassium, in growth of plants. Nitrogen is important in plant growth as it participates in several cellular components such as amino acids, chlorophyll and nucleic acids (Taiz et al., 2017).

As the plants grew (>67 DAP), the stem height of plants grown in pig manure + pine bark declined (Table 22), but tillering remained prolific (Table 23). This may be attributed to competition between the tillers for water, nutrients and space in the container. Tillering of sugarcane can take up resources meant for stem elongation. In this study, the relationship between number of tillers and stem height was negative (Figure 43and Figure 51). Assuero and Tognetti (2010) revealed that tillering of grasses like sugarcane is affected by environmental factors and endogenous, which interact. The endogenous factors include plant hormones, ontogenic control and assimilate availability. Assimilate availability suggests that tiller production is associated with environmental conditions that promote carbon fixation over use such as high light intensity and high nitrogen availability. The environmental factors include light, temperature, photoperiod, water and mineral nutients. Among the mineral elements that affect tillering is nitrogen. Nitrogen is said to trigger increase of leaf appearance rate causing more tillering (Lemaire and Chapman, 1996). Kapur et al. (2011) and Kang et al. (2013) reported that tillers can compete for resources like water, nutrients, light and space which may reduce stalk elongation of sugarcane plants.

At 108 DAP, the interaction between media and fetiliser application rate showed that sugarcane plants grown in the ZSAES soil medium applied nutrient solution and 312.5 mg/l. were taller than other media (Figure 41 and Figure 49). This may be explained by low nitrogen inherent in the ZSAES soil medium. Also there was low nitrogen content in nutrient solution and 312.5 mg/l than other fertilizer application rates. Low nitrogen content in the ZSAES soil medium and nutrient solution or 312.5 mg/l blend fertilizer may have resulted in fewer tillers per container in this treatment. Fewer tillers per container suggest that there was low competition for water nutrients and space among tillers and thus promoting stem elongation. At high fertilizer application rates, the differences between media in stem elongation was insignificant except of plants grown in pig manure + pine bark due to profilic tillering in this medium. Assuero and Tognetti (2010) have reported that low nitrogen availability on grasses such as sugarcane reduce tiller production. There was inverse relationship between number of tillers and stem elongation in sugarcane (Kapur et al., 2011) and Kang et al., 2013).

Conversly, at 108 days after planting, the plants grown in pig manure + pine bark had more tillers per container when applied nutrient solution and 312.5 mg/l. The differences between media in number of tillers per container diminished as fertilizer application rate increases. This may be explained by high nutrition in pig manure + pine bark which promoted tillering. As the fertilizer application rate increases, this reduced the effects of pig manure + pine bark on tillering since high blend fertilizer rates availed more nitrogen, phosphorus and potassium. Nitrogen and phosphorus are the two most important elements that promote tillering (Assuero and Tognetti, 2010). However, potassium has also been found to promote tiller production in grasses, if N is adequate (Duble, 2004). Similarly, leaf SPAD index of plants grown in pig manure + pine bark and filter cake only was more than other media that were applied nutrient solution. The differences between media in leaf SPAD index decreased as the fertilizer application rate increased. This is explained by high N content in pig manure + pine bark and filter cake only than other media and the effect was more where nutrient solution was used since the content of nitrogen was low in the latter. Nitrogen has a strong influence on leaf SPAD index of sugarcane plants (Rigon et al., 2013; IIkaee et al., 2016 and Dinh et al., 2017).

Brown rust incidence levels were high in plants grown in filter cake + pine bark than other media. This may be attributed to high concentration of calcium, magnesium and manganese in filter cake + pine bark than other media (Table 9). Brown rust in sugarcane is dependent on plant age, climatic conditions, variety, plant nutrition and soil characteristics (Avellaneda et al., 2015). Mcfarlane et al. (2008) revealed that Brown rust in sugarcane is caused by excessive amounts of K, Ca, Mg and Mn and lower levels of Fe. The study also showed that

Brown rust incidence increased with fertliser application rates. There was a positive relationship between Brown rust incidence and leaf phosphorus content (Figure 58). This suggests that high phosphorus content in blend fertilizer may have caused increased Brown rust incidence where high rates of blend fertilizer (≥1562.5 mg/l) was used. Grisham et al., (2006) showed that high levels of P and S increased levels of Brown rust in sugarcane plants. Ramouthar (2009) reported that over fertilization should be avoided to reduce Brown rust in sugarcane.

Plants grown in pig manure + pine bark and the ZSAES soil media had more dry matter than other media. This is explained by high number of green leaves of plants grown in pig manure + pine bark and ZSAES soil mediathan other media (Table 25). Biomass accumulation in sugarcane plants is primarily driven by the amount of solar radiation intercepted by green leaves and the photosynthetic conversion efficiency (van Heerden et al., 2010). High inherent nitrogen content in pig manure + pine bark may have resulted in more green leaves that that contributed to more dry matter of sugarcane than other media. Principal component analysis showed that nitrogen, followed by potassium, were the most important nutrients in that order in contributing to total plant dry matter (Figure 63). Nitrogen fertilization increased sugarcane biomass because of the role of nitrogen in giving structural function in many organic compounds of the plant and also participates in vital physiological processes (Otto et al., 2009; Prado et al., 2010). Although the nitrogen content of ZSAES soil medium was lower than other media, the medium retained more water (Figure 22). Optimal water condition can increase absorption of nutrients, increasing root growth and biomass of sugarcane plants (Costa et al.., 2016). The constitution of nutrients in total sugarcane biomass is less than one percent, but deficiency of nutrients reduce synthesis of essential amino acids, chlorophyll and the energy needed produce carbohydrates and carbon skeletons, directly reflecting sugarcane dry matter (Taiz et al.,2017). Although plants grown in the ZSAES soil medium had relatively fewer tillers per container, the plants were taller (Figure 41) and thicker (Figure 52) than plants grown in other media thus more shoot and total dry matter.

5.8.2 Interactions of growth medium and fertiliser application rates on tissue N, P, K, Mg and Ca content

Leaf nitrogen concentration of plants grown in the pig manure + pine bark was higher than other media that was applied nutrient solution and 312.5 mg/l blend fertilizer, at 112 DAP. The differences between media in leaf N content diminished as the blend fertilizer application rate increased. This may be explained by high N available for uptake in the pig manure + pine bark than other media (Table 9). Most of the nitrogen content in pig manure is in the available form which can be taken by plants (Bertora et al., 2008). N is a major constituent of proteins, nucleic acids, enzymes and chlorophyll of sugarcane plants (Kingston, 2014). As the fertilizer application rate increased, more N was availed to the sugarcane plants, thus reducing the influence of media on leaf N concentration. Costa et al. (2016) showed that sugarcane plant if applied high rates of N, the maximum of the leaf nitrogen concentration are reached.

Phosphorus content in leaves of plants grown in pig manure + pine bark and filter cake + pine bark was more than other media that was applied any of the fertilizer application rate except 2187.5 mg/l blend fertilizer. This may be attributed to the optimal pH of pig manure + pine bark (6.61) and filter cake + pine bark (7.01) that increased the availability of P for uptake by the plants. The optimal pH (Calcium chloride) for uptake of P by plants is between 5.5 and 7.5 (McCauley et al., 2009). The pH for the ZSAES soil and filter cake only media was respectively, 7.6 and 7.51. At pH greater than 7.5, the phosphate is fixed to calcium as calcium phosphates and this reduces solubility of phosphates for uptake by plants (Kingston, 2014; Barrow, 2016). Also in this study, the inherent content of phosphorus in pig manure + pine bark and filter cake + pine bark was higher than in the ZSAES soil medium (Table 9). P is a constituent of nucleic acids which is important in cell division and heredity transfer. Also phosphorus is important for forming energy-rich bonds such as ADP andATP which can be used in endogenic reactions in plants (Kingston, 2014).

There was more leaf potassium of plants that were grown in pig manure + pine bark and ZSAES soil media than other media tested, and applied nutrient solution, 312.5 mg/l and 1562.5 mg/l blend fertilizer. Potassium in sugarcane plants have several uses that include activation of enzymes involved in starch synthesis; bonding of transferRNA to ribosomes in protein synthesis; maintanence of pH gradient for ATP synthesis during photosynthesis and osmoregulation for uptake and efficient us of water (Kingston, 2014). Potassium content in pig manure + pine bark and ZSAES soil media was higher than filter cake + pine bark (Table 9), thus may have contributed to more K in the former. Sugarcane plants, luxuriously take up potassium from the rooting medium (Ridge, 2013; Costa et al., 2016). Potassium content in the filter cake only was relatively higher than filter cake + pine bark, but leaf K content of plants grown in filter cake was lower than the latter. On one hand, potassium may have been fixed by materials found in filter cake only medium. Potassium availability for uptake by plants can be reduced by K fixation to materials such as silicates in the growth medium (Etesami et al., 2017). On another hand, high content of magnesium and calcium in filter cake only may have interferred with uptake and utilization of potassium by sugarcane plants resulting in low leaf K content of plants grown in filter cake only (Kingston, 2014).

Plants grown in the ZSAES soil medium had low leaf magnesium content when compared to pig manure + pine bark, filter cake + pine bark and filter cake only media. This may be attributed to very low content in the ZSAES soil medium when compared to other media (Table 9). Composited pig manure and filter cake manure has high content of organic matter rich in magnesium which can be easily taken by plants (Bertora et al., 2008; Prado et al., 2013; Ridge, 2013). Ridge (2013) reported that generally soils have low Mg content, therefore, sugarcane plants responded well after applying magnesium. However, sugarcane plants do not require magnesium in large quantities when compared to nitrogen, potassium and phosphorus (Kingston, 2013). No statistical difference between fertilizer application rates on leaf Mg can be explained by little or no magnesium concentration in the fertilizer application rates that was used in this study.

There was no difference in leaf Ca content in plants grown in all media except ZSAES soil medium, that were applied nutrient solution and 312.5 mg/l blend fertliser. Leaf Ca content was higher in sugarcane plants grown in filter cake and pine bark and filter cake only than other media applied 1562.5 mg/l and 2187.5 mg/l blend fertilizer. This is explained by high calcium content in filter cake only and filter cake + pine bark media when compared to other media (Table 9; Bertora et al., 2008; Prado et al., 2013). Calcium is important for stabilizing and strengthening cell walls of plants (Kingston, 2014). The increased rate of fertilizer application may have influenced the uptake of calcium by sugarcane plants. High concentration of potassium may cause more calcium or/ and magnesium to be taken by sugarcane plants by mass flow of the transpiration flow (Santo et al. 2000).

5.9 Conclusions

At ≤67 DAP, stem elongation and tillering were more pronounced in plants grown in pig manure + pine bark than in the other media. Beyond 67 DAP, plants grown in pig manure +pine bark tillered profusely but their stem elongation was reduced. Stem elongation and internodes length were more pronounced in plants grown in the ZSAES soil medium and applied nutrient solution and 312.5 mg/l blend fertliser. Number of tillers per container was higher in plants grown in pig manure + pine bark and increased with fertilizer application rate coupled with stunting of stem height, and this was not desirable. Plants grown in filter cake + pine bark were susceptible to Brown rust, also when high blend fertiliser rates (>937.5 mg/l) were used. Plants grown in pig manure + pine bark and ZSAES soil media had higher shoot and total plant dry matter than other media. Green leaf area of plants that were applied nutrient solution and 312.5 mg/l was smaller when compared to other fertilizer application rates. Where nutrient solution and 312.5 mg/l blend fertilizer was applied, leaf N, P K was higher in plants grown in pig manure + pine bark than other media. Plants grown in the ZSAES soil medium had low leaf magnesium and calcium. The recommendation is to use 937.5 mg/l blend fertilizer using any of the media except pig manure + pine bark.

CHAPTER 6

ASSESSING CONTAINER SIZE FOR SUITABILITY OF GROWING SUGARCANE PLANTS

6.1 Abstract

There is inadequate information on optimal container size for growing sugarcane plants with minimal stress. An experiment was done at the Zimbabwe Sugar Association Experiment Stationin the 2017/18 season to assess container size for suitability of growing sugarcane plants. A Completely Randomised Design consisting of three levels of container size, three media in factorial arrangement and three replications was used. The respective depths and diameters of the three container sizes tested in the experiment were: Small (25.5 cm x 31.3 cm), Medium (45 cm x 54 cm) and Large (90 cm x 54 cm). The three media used were filter cake only, filter cake + pine bark and the ZSAES soil medium. Sugarcane variety that was used in this experiment was ZN8. Plants grown in the ZSAES soil medium were taller, thicker with more internodes than it was in the filter cake + pine bark or filter cake only. Stem height, green leaf area and number of leaves increased with container size. Leaf SPAD index and tillering increased in plants grown in filter cake + pine bark or filter cake only than in the ZSAES soil medium. Also there was more tillering and leaf SPAD index of plants grown in large and medium sized containers over small containers. Plants grown in filter cake + pine bark or filter cake only had more dry matter than ZSAES soil medium in large containers. Internodes lengths were longer for plants grown in ZSAES soil medium and filter cake + pine bark than filter cake only. There were no differences amongst media or container sizes in leaf calcium, magnesium, phosphorus and potassium concentrations, although they were all above the critical levels for deficiency. Therefore, sugarcane can be grown in large containers with pine bark + filter cake for greater plant growth.

Key words: sugarcane, container size, media, growth and nutrition.

6.2 Introduction and background

One of the factors that affect plant growth in pots is the size of the container (Yang et al., 2010). Much of the research on container size has focused on forestry and horticultural plants (Carlson and Endean, 1976; Kharkina et al. 1999. Little if any attention has been paid to the effect of container size on sugarcane plant growth (Carlson and Endean, 1976; Al-Debei and Mugnai, 2011). Researchers working on sugarcane in containers have used containers of variable sizes (Morris and Tai, 2004; Zhao et al., 2010). The size of the container determines the volume of the medium to be used (NeSmith and Duval, 1998). Small containers have less substrate volume and generally supply less water and nutrients to the plants (Poorter et al., 2012a). The limited water holding capacity of small pots causes containers to dry out quickly after irrigation, thus increasing the risk of water-deficit stress to plants (Ray and Sinclair, 1998). Water-deficit stress increases leaf shedding and stalk senescence in sugarcane plants (Inman-Bamber and De Jager 1988; Inman-Bamber, 2004). It also reduces stomatal conductance and photosynthesis of sugarcane leaves, which ultimately shrinks cane and sugar yields (Basnayake et al., 2012; Inman-Bamber et al., 2012).

Reduced total nutrient content has been observed in small containers when compared to large pots (Poorter et al., 2012a). As plants grow in small containers, they demand ever-increasing amounts of nutrients from a limited root volume. Reduced total nutrient content in small containers may cause nutrient stress in plants. Poorter et al. (2012b) reported that increased root mass fraction in containers is a sign of the nutrient stress of plants in pots. As with water stress, nutrient stress in sugarcane plants limits the stomatal conductance and photosynthesis of plants. Decreased photosynthetic rates of plants can reduce sugar and cane yields (Dinh et al., 2017).

Small containers also restrict space required by plants for root growth (Yang et al., 2010). Krizek et al. (1985) reported that root growth restriction due to container size can mimic the effects of water-deficit stress even when sufficient moisture is supplied to the crop. More-so, space restriction can reduce root volume, making it difficult for plants to take up water and nutrients (McConnaughay and Bazzaz, 1991). The restriction of space in small containers causes roots to compete for resources resulting in oxygen deficiency and imbalance of hormones, thus impeding shoot growth (Peterson et al., 1991b; Shi et al., 2007). Oxygen deficiency can cause the respiration of roots to decrease and, consequently, reduce the uptake of essential mineral nutrients required for shoot growth. Paul and Pellny (2003) reported that when root growth is impeded by pot size, it sends a negative feedback of photosynthesis, thereby reducing leaf area and shoot growth (Cantliffe, 1993; Peterson et al., 1991).

Container size is a function of height and diameter and both affect plant growth. Container height is important as it influences the depth of the root plug of a plant (Landis et al., 2014). Usually, deeper containers result in longer root plugs although the depth delays the formation of a firm root plug (Landis et al., 2014). Container height also affects the amount of freely drained substrate in a pot. Tall containers have a higher proportion of freely drained medium than shorter ones (Poorter et al., 2012a). When irrigation water is applied to the container, it moves downward due to gravity until it reaches the bottom and creates a saturated zone. This saturation zone is proportionally greater in containers with limited height, resulting in poor aeration (Luna et al., 2009). A sugarcane plant, just like many other crops, requires sufficient oxygen in the container for the roots to grow optimally (Manik et al., 2019). The diameter of a container dictates the type of plant that should be grown. Containers with larger diameters should be used for broad leaved tree shrubs and herbaceous plants so that irrigation water can penetrate the dense foliage and reach the substrate (Luna et al., 2009). A sugarcane plant emerges from a single eye and consists of a number of tillers that emerge in a sequence of orders typical for that variety, which may require containers with a large diameter (Poorter et al., 2012a).

6.3 Aim

To assess container size for suitability of growing sugarcane plants.

6.4 Specific objectives

6.4.1 To test three container sizes that includes Small (25.5 cm x 31.3 cm), Medium (45 cm x 54 cm) and Large (90 cm x 54 cm) using three media namely filter cake only, filter cake + pine bark andZSAES soil medium (control) on the growth performance (germination percent, stem height, number of tillers, SPAD index, green leaf area, number of leaves, dry matter of above and below ground parts of plants).

6.4.2 To evaluate three container sizes that includes Small(25.5 cm x 31.3 cm), Medium (45 cm x 54 cm) and Large (90 cm x 54 cm) using three growth media namely filter cake only, filter cake + pine bark andZSAES soil medium (control) on leaf nutrient content (N, P, K, Mg and Ca percent) of sugarcane plants.

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6.5 Hypotheses

6.5.1 Container size suitability for growth performance of sugarcane plants depends on growth media.

6.5.2 Container size affects the leaf nutrient concentrations of sugarcane plants to varying extent in different growth media.

6.6 Materials and methods

6.6.1 Study area

The experimental work was conducted from August 2017 to October 2017 at the Zimbabwe Sugar Association Experiment Station (ZSAES). The Station is located at 21º01′S latitude and 28^{o}38′E longitude with an altitude of 430m above sea level. Mean air temperatures range from 16 ^{o}C in winter to 26 ^{o}C in summer. Mean annual rainfall received in the area is 625 mm per annum, much of it falling in the summer months of October to March.

6.6.2 Experimental design and treatments

A Completely Randomised Design consisting of three container sizes and three types of growth media in factorial arrangement with three replications was used. The respective depths and diameters of the three container sizes used in the experiment were: Small (25.5 cm x 31.3 cm), Medium (45 cm x 54 cm) and Large (90 cm x 54 cm). The volumes of substrate in small, medium and large containers were 16, 88 and 176 litres, respectively. The three growth media used were filter cake only, filter cake + pine bark (1:1 v/v), and the ZSAES soil medium (top soil: composted cattle manure: sand, 5 :2 :2 v/v).

6.6.3 Plant culture

The containers were filled with filter cake only, filter cake + pine bark (1:1 v/v), and ZSAES soil medium to within 7.5 cm from the brim leaving space for irrigation water. Prior to planting, the soil-lesswas saturated with water for 72 hours by plugging the drainage holes.The ZSAES soil medium was only saturated for 24 hours prior to planting without plugging drainage holes. Sugarcane setts of ZN8 variety (9 months old) were cut at the base from S1 field using cane knives which were sterilized by immersing them for 5 minutes in diluted Propan-2-ol or isopropanol (JEYES fluid) (0.5 L JEYES fluid per 10 L of water). One eyed setts were cut from the remaining stalk before dipping them for 5 minutes in Triadimenol (Shavit) (1ml Shavit / 1000 ml of water) to prevent ratoon stunting disease. Five one eyed cane setts were planted 40 mm deep at the centre of each container on 26 October

2017. Upon emergence, plants were thinned to one plant per container. Blend fertiliser (Triple 16) was applied at the rate of 937.5mg/l of medium at 14 DAP and, thereafter, fortnightly until 56 DAP. One litre of water per day per container was applied to the plants in the first 14 DAP for germination and early growth in all pot sizes. Thereafter, the pots were irrigated at the rate of 160 mLof water per litre volume of medium until the end of the experiment (108 days after planting). Weeds were pulled out by hand from each container from planting to harvesting. Fipronil (Regent) at the rate of 135 ml Regent /15L of water was sprayed at the base of each container and around the experimental area to control termites and aphids. The plants were grown for 112 days before termination of the experiment.

6.6.4 Measurements and data analysis

The data that was collected for the experiment is presented in Table 26. Fisher’s Analysis of Variance was performed on the data using Genstat statistical software (Genstat 14th edition, VSN International Ltd., Hemel Hempstead, UK. The separation of treatment means was done using Least Significant Difference or Standard Error Difference test at 5% level (Steel and Torie, 1984).

Table 26: Parameters that were measured from plants, frequency of collecting the data and methods used on experiment that assessed container size for suitability of growing sugarcane planted in October 2017.

Parameter	Frequency	Method
Medium Temperature	At 43 and 92 DAP	Inserted soil digital thermometer (Instrusupply,Rajasthan, India) 20 cm deep into the medium in a container
Stem height (cm)	38 DAP; thereafter fortnightly till 108 DAP	Using a metre rule, from the base of the plant at the surface of the medium to the apex of the primary tiller
Number of tillers	38 DAP; thereafter fortnightly till 108 DAP	Counting all tillers in a container
SPAD index	38 DAP; thereafter fortnightly till 108 DAP	Measured on leaf with the topmost visible dewlap leaf (LTVD) using chlorophyll meter (Minolta SPAD-502, Minolta Co., Osaka, Japan) (Zhao et al., 2010)
Dry Matter	Done once at harvest 112 DAP	All tillers were excised at the base to separate shoots and roots. The roots were washed with water. The shoots were separated into different components of trash and leaves. The roots and components of shoots were placed in a forced air oven at 105 ºC for 72 hours and then weighed
Green leaf area	Done once at harvest 112 DAP	The leaf area of all green leaves was measured usingleaf area meter (Delta-T Devices Ltd., Burwell, Cambridge, UK)
Number of green leaves	Done once at harvest 112 DAP	All mature green leaves were counted
Number of internodes	Done once at harvest 112 DAP	Number of internodes on the primary tillers was counted.
Stem girth	Done once at harvest 112 DAP	Was measured on primary tiller at the base (first internode) using a Dial calliper 150 mm
Leaf calcium concentration	Done once at harvest 112 DAP	EDTA method (Derderian, 1961)
Leaf potassium concentration	Done once at harvest 112 DAP	EDTA method (Derderian, 1961)
Leaf magnesium concentration	Done once at harvest 112 DAP	EDTA method (Derderian, 1961)
Leaf nitrogen concentration	Done once at harvest 112 DAP	Kjedahl digestion method (Persson et al., 2008)
Leaf phosphorus concentration	Done once at harvest 112 DAP	Vanado-molydo phosphate method (Bray and Kurtz, 1945)

6.7 Results

6.7.1 Temperature of growth medium

For the filter cake + pine bark or filter cake only, the temperatures of the media at 43 DAP were markedly higher in the medium and larger containers whereas it was lower in the ZSAES soil medium (Figure 64). Notably, there were no differences between the medium and larger containers in the temperature of the growth media.

At 92 DAP, the temperatures of the growth media increased markedly with increase in container size, however, this pattern of response was especially more pronounced in both filter cake media than it was in the ZSAES soil medium (Figure 65).

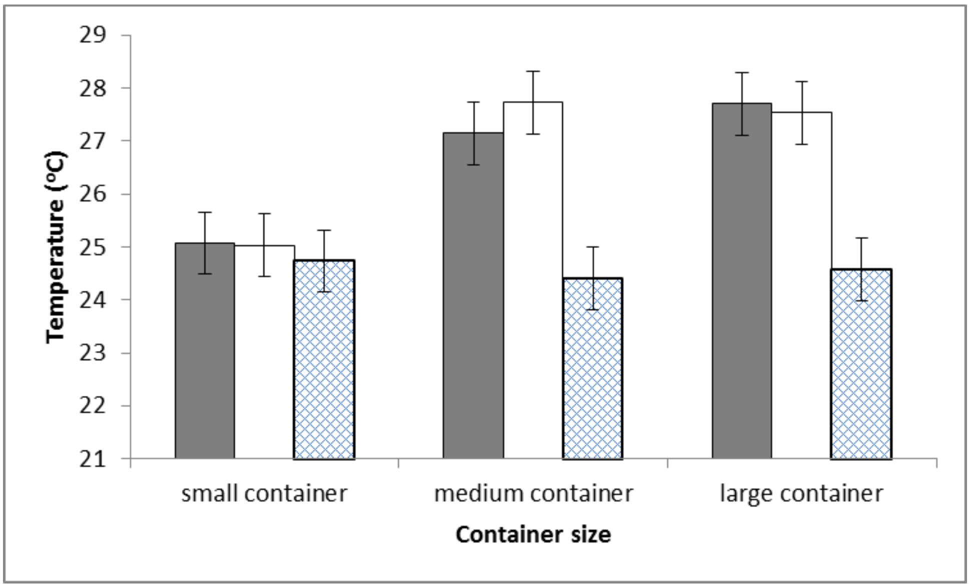

Figure 64: Medium temperature at the depth of 20 cm of sugarcane tillers grown in ■ filter cake + pine bark, □filter cake only, ⊠ZSAES soil medium using different container sizes (small, medium and large) measured at 43 days after planting (level of significance **)

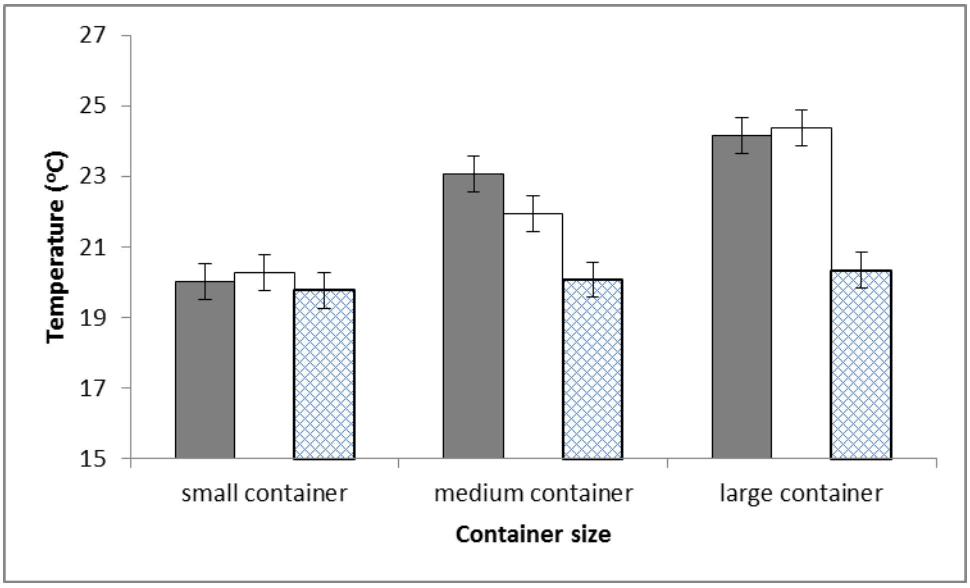

Figure 65: Medium temperature at the depth of 20 cm of sugarcane tillers grown in ■ filter cake + pine bark, □filter cake only, ▨ZSAES soil medium using different container sizes (small, medium and large) measured at 92 days after planting (level of significance *)**

6.7.2 Stem heights of primary tiller

Initially, there were no differences in stem height among the media tested until 67 DAP (Table 27). At ≥81 DAP, the primary tiller of plants grown in the ZSAES soil medium was taller than it was in the filter cake + pine bark or filter cake only (Table 27). The addition of pine bark to the filter cake did not influence the height of the primary tiller of sugarcane plants (Table 27). There were no significant differences between the container sizes until 67 days after planting (Table 27). As plants aged (≥95 DAP), the length of primary tillers increased in proportion to container size, with those in the large containers growing tallest.

Table 27: Stem height of sugarcane primary tillers grown in filter cake + pine bark, filter cake only, ZSAES soil medium using different container sizes (small, medium and large) measured from 38 to 108 days after planting

Media	**38 DAP**	**53 DAP**	**67 DAP**	**81 DAP**	**95 DAP**	**108 DAP**
Filter cake + pine bark	14.44	22.67	27.33	34.58a	40.56a	52.4a
Filter cake only	15.78	23.36	29.22	33.22a	37.33a	49.6a
ZSAES soil medium	14.33	23.06	30.92	40.00b	49.22b	68.5b
P value	0.523	0.886	0.083	0.005	<0.001	<0.001
LSD	NS	NS	NS	3.984	4.592	8.03
Container size						
Small container	14.61	20.99	27.94	31.28a	33.33a	35.0a
Medium container	14.28	23.50	28.24	36.92b	44.50b	60.9b
Large container	15.67	24.59	31.29	39.61b	49.28c	74.6c
P value	0.588	0.054	0.073	0.001	<0.001	<0.001
LSD	NS	NS	NS	3.984	4.592	8.03
CV (%)	19.8	12.9	10.9	11.1	10.9	14.2

6.7.3Number of sugarcane tillers per container

Amongst the growth media tested, the plants grown in the filter cake + pine bark and filter cake only media had more tillers than ZSAES soil medium at 38 DAP and from 81 to 108 days after planting (Table 28). There was no significant differences between container sizes on number of tillers per container from 38 to 67 DAP. From 81 to 108 DAP, the number of tillers in small containers trailed behind medium and large containers (Table 28). There were no significant differences between large and medium container sizes on number of tillers per container (Table 28). The relationship between number of tillers per container and stem height showed that the number of tillers per container increased with stem height to a peak before it declined (Figure 66).

Table 28: Number of tillers per container of plants grown in filter cake + pine bark, filter cake only, ZSAES soil medium using different container sizes (small, medium and large) measured from 38 to 108 days after planting

Media	**38 DAP**	**53 DAP**	**67 DAP**	**81 DAP**	**95 DAP**	**108 DAP**
Filter cake + pine bark	1.00b	5.11	14.33b	23.89b	34.7b	44.7b
Filter cake only	1.00b	4.78	14.22b	21.89b	30.6ab	41.2b
ZSAES soil medium	0.00a	3.89	8.67a	17.33a	25.1a	33.6a
P value	0.006	0.213	<0.001	0.003	0.016	0.002
LSD	0.02587	NS	2.650	3.442	6.20	5.53
Container size						
Small container	0.56	4.56	12.67	18.22a	24.7a	31.1a
Medium container	0.78	4.67	12.67	22.44b	33.7b	44.9b
Large container	0.67	4.56	11.89	22.44b	32.0b	43.4b
P value	0.776	0.983	0.777	0.029	0.016	<0.001
LSD	NS	NS	NS	3.44	26.20	5.53
CV (%)	98.5	31.7	21.5	16.6	20.7	14.0

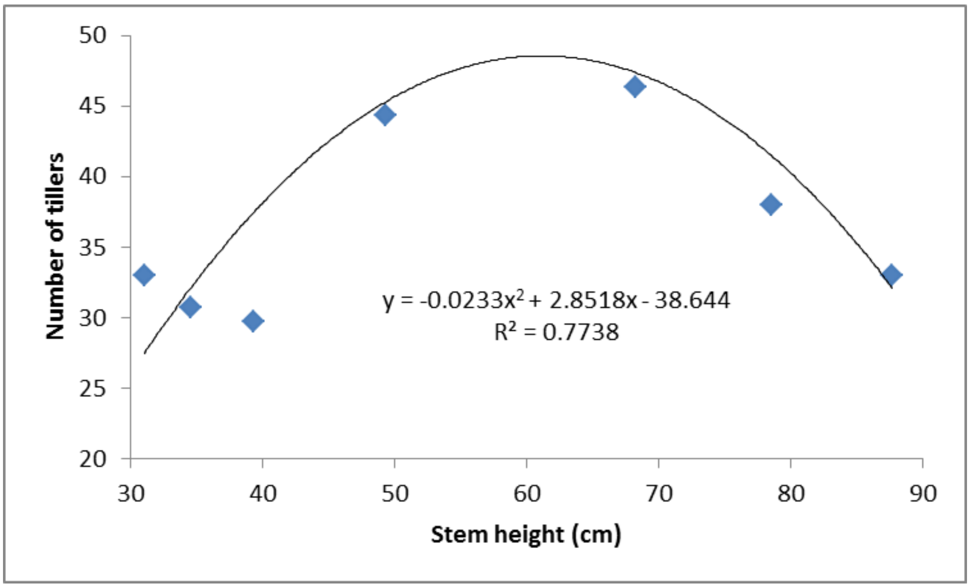

Figure 66: Relationship between number of tillers and stem height of sugarcane plants

6.7.4SPAD index of leaf with TVD of primary tillers

There was interaction between media and container size on leaf SPAD index (Figure 67). Leaf SPAD index of plants grown in filter cake only was lower than filter cake + pine bark and the ZSAES soil media, in small containers. In contrast, leaf SPAD index of plants grown in filter cake only was higher than filter cake + pine bark and the ZSAES soil media, in large containers (Figure 67). Leaf SPAD index of plants grown in any of the media was significantly the same, in medium container.

At 53 DAP, the leaf SPAD index of plants grown in the ZSAES soil and filter cake only was higher than filter cake + pine bark (Table 29). There was no difference between media in leaf SPAD index at 67 and 95 DAP. At 108 DAP, leaf SPAD index of plants grown in the filter cake + pine bark and filter cake only media was higher than in the ZSAES soil medium (Table 29. There was no difference between container sizes in leaf SPAD index at 53 and 67 DAP. At ≥95 DAP, leaf SPAD index of plants grown in medium and large containers was higher than small containers (Table 29).

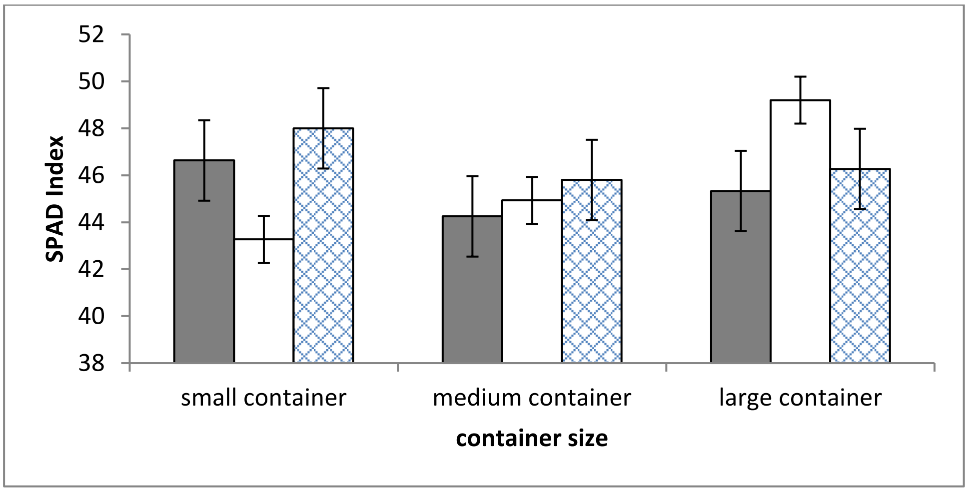

Figure 67: SPAD index of leaf with TVD of primary tillers in ■filter cake + pine bark, ☐filter cake only, ▨ZSAES soil medium using different container sizes (small, medium and large) measured at 81 days after planting (level of significance *)

Table 29: SPAD index of leaf with TVD of primary tillers grown in filter cake + pine bark, filter cake only, ZSAES soil medium using different container sizes (small, medium and large) measured from 38 to 108 days after planting

Media	**53 DAP**	**67 DAP**	**95 DAP**	**108 DAP**
Filter cake + pine bark	45.45a	47.14	44.18	48.26b
Filter cake only	46.49ab	48.18	44.39	48.18b
ZSAES soil medium	48.78b	48.32	46.06	46.57a
P value	0.039	0.413	0.485	0.033
LSD	2.550	NS	NS	1.388
Container size				
Small container	46.37	47.99	41.33a	46.52a
Medium container	46.57	47.49	46.47b	47.58ab
Large container	47.78	48.16	46.82b	48.90b
P value	0.467	0.771	0.007	0.008
LSD	NS	NS	3.529	1.388
CV (%)	5.5	4.2	7.9	2.9

6.7.5 Dry matter of sugarcane plants

There was interaction between growth media and container size in dry matter comprising stalk, sheath and tops of tillers (Figure 68). The dry matter comprising stalk, sheath and tops of tillers grown in the ZSAES soil medium was more than filter cake only and filter cake + pinebark media, in small container. In contrast, dry matter comprising stalk, sheath and tops of tillers grown in the filter cake only and filter cake + pinebark media was more than in the ZSAES soil medium in large container. Dry matter comprising stalk, sheath and tops of tillers grown in any of the media was significantly the same, in medium container (Figure 68).

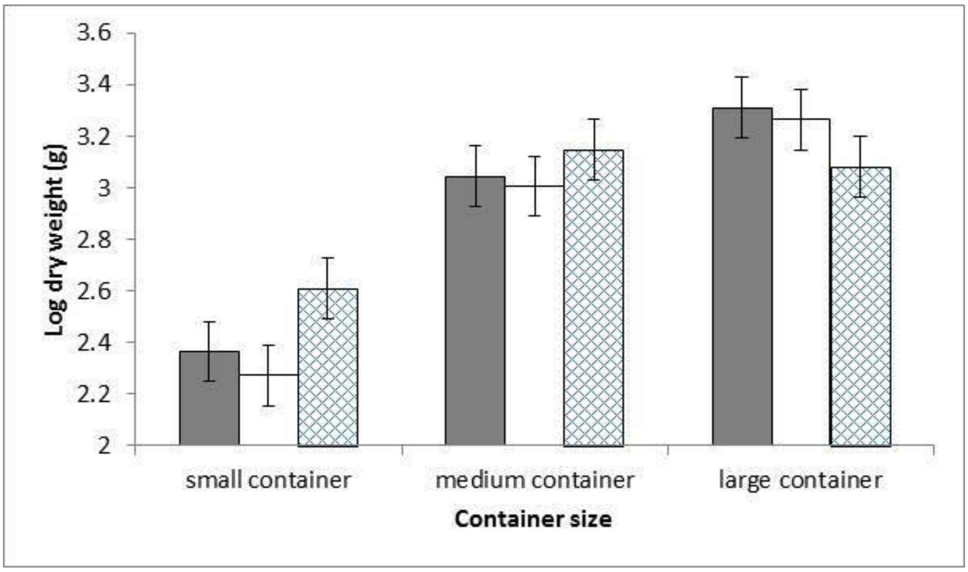

Figure 68: Dry matter of stalk, sheath and tops of tillers grown in ■filter cake + pine bark, □filter cake only, ▨ZSAES soil medium using different container sizes (small, medium and large) measured at 112 days after planting (level of significance *)

Interaction between growth media and container size on root dry matter was significant (Figure 69). Root dry matter of plants grown in any of the media was significantly the same, in small and medium containers (Figure 69). However, root dry matter of plants grown in filter cake + pine bark and filter cake only media was more than in the ZSAES soil medium, in large containers (Figure 69). The relationship between the number of tillers and the total plant dry matter (TPDM) (Figure 70A), stem height and TPDM (Figure 70B), media temperature and TPDM (Figure 70C), dry matter of stems, sheath and tops and TPDM (Figure 70D) showed a strong positive relationship.

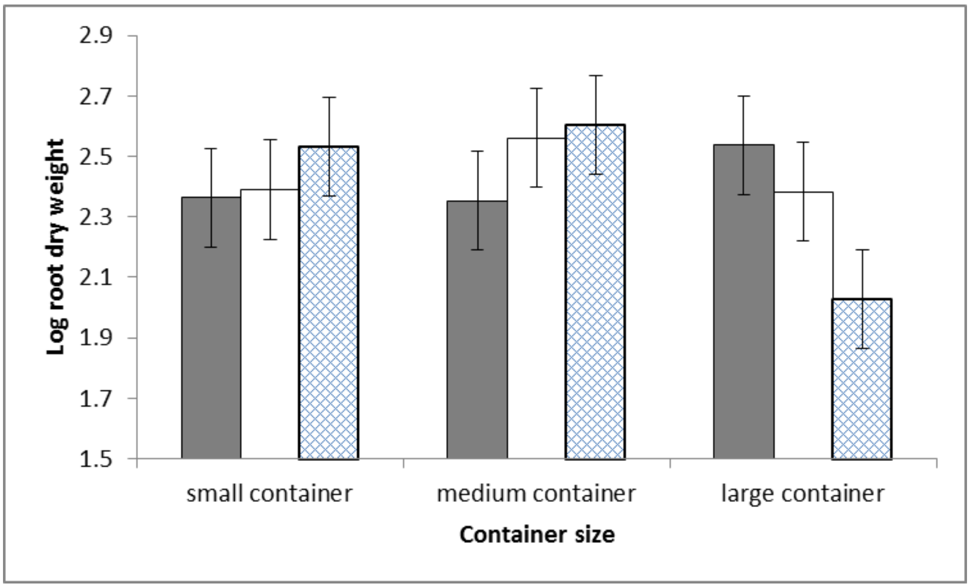

Figure 69: Dry matter of roots of sugarcane tillers grown in ■filter cake + pine bark, □ filter cake only, ▨ZSAES soil medium using different container sizes (small, medium and large) measured at 112 days after planting (level of significance *)

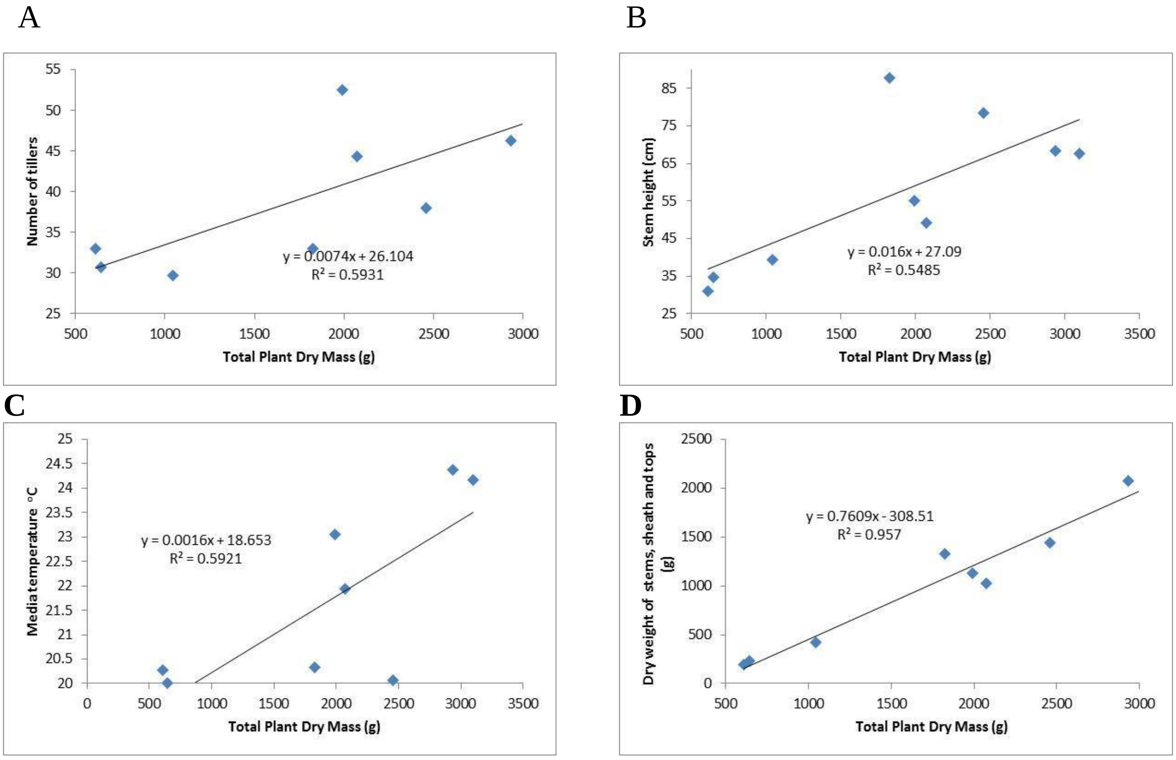

Figure 70: Relationship between number of tillers and TPDM (A), stem height and TPDM (B), media temperature and TPDM (C), dry matter of stems, sheath and tops and TPDM (D)

6.7.6 Green leaf area and number of green leaves of sugarcane plants

The green leaf area and the number of green leaves were greater in the medium and large containers than in small containers, but there was no further advantage of growing the plants in large containers compared with the medium sized container (Table 30). The relationship between green leaf area and total plant dry matter (TPDM) and the relationship between number of leaves and TPDM showed a strong positive relationship (Figure 71).

Table 30: Green leaf area and number of green leaves of sugarcane tillers grown in different container sizes (small, medium and large) measured at 112 days after planting

Container size	**Log Green Leaf Area (mm^2)**	**Log number of green leaves**
Small container	5.981a (970093)	2.108a (128.7)
Medium container	6.562b (3667174)	2.428b (271.4)
Large container	6.502b (3701713)	2.385b (252.1)
P value	<0.001	<0.001
LSD	0.1783	0.0789
CV (%)	2.8	3.4

Means followed by the same letter, within a column, do not differ significantly at the 5% level. Figures in brackets are the original means.

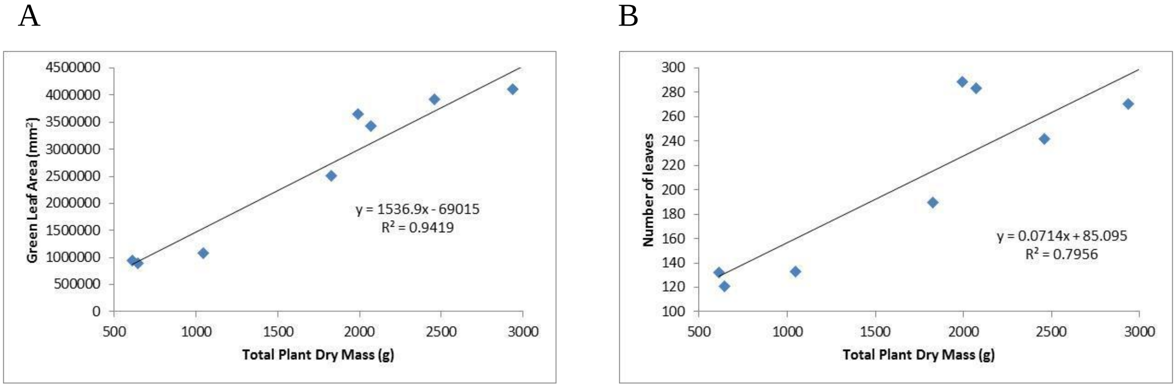

Figure 71: Relationship between green leaf area and total plant dry matter (A) as well as number of leaves and total plant dry matter (B)

6.7.7 Number of internodes and stem diameter (cm) of sugarcane primary tillers

The number of internodes on primary tiller was higher in the ZSAES soil medium than in the filter cake + pine bark or filter cake only (Table 31). There was greater stem diameter of primary tiller grown in the ZSAES soil medium, although it was not significantly different from plants grown in filter cake + pine bark. The number of internodes and the stem diameters of primary tillers were significantly higher for plants grown in medium and large containers than small containers (Table 31).

Table 31: Number of internodes and stem diameters of sugarcane tillers grown in filter cake + pine bark, filter cake only, ZSAES soil medium using different container sizes (small, medium and large) measured at 112 days after planting

Media	Number of internodes	Stem diameter (cm)
Filter cake with pine bark	8.89a	2.583ab
Filter cake only	9.00a	2.344a
ZSAES soil medium	10.33b	2.733b
P value	0.018	0.025
LSD	1.061	0.2727
Container size		
Small container	8.11a	2.367a
Medium container	9.89b	2.572ab
Large container	10.22b	2.722b
P value	0.001	0.043
LSD	1.061	0.2727
CV (%)	11.3	10.7

6.7.8 Internode lengths (cm) of sugarcane primary tillers

The first four internodes of cane grown in the ZSAES soil medium were longer than in filter cake only or filter cake + pine bark (Table 32). The lengths of the fifth to the eight internodes of cane grown in the ZSAES soil medium and filter cake + pine bark were equal and longer than those of cane grown in filter cake only (Table 32). Average internodelength increased significantly by 211 % as the size of the container increased from small to large (Table 32).

Table 32: Internodes length (cm) of sugarcane primary tillers grown in filter cake + pine bark, filter cake only, ZSAES soil medium using different container sizes (small, medium and large) measured at 112 days after planting

Media	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**Average**
Filter cake + pine bark	1.87a	2.44a	2.96a	3.43a	3.82ab	4.58b	5.84b	6.46b	3.92ab
Filter cake only	1.91a	2.64a	2.96a	3.12a	3.44a	3.34a	3.72a	4.26a	3.17a
ZSAES soil medium	2.70b	3.70b	4.30b	4.57b	4.74b	5.09b	5.48b	6.26b	4.60b
P value	0.056	0.086	0.006	0.003	0.029	0.001	0.010	0.037	0.006
LSD	N/A	N/A	0.869	0.770	0.949	0.849	1.361	1.805	0.804
Container size									
Small container	1.24a	1.56a	1.80a	2.07a	1.89a	1.74a	2.11a	2.38a	1.84a
Medium container	2.04b	2.72b	3.39b	3.67b	4.36b	4.84b	5.77b	6.29b	4.14b
Large container	3.19b	4.51c	5.02c	5.39c	5.77c	6.42c	7.17c	8.30c	5.72c
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD	0.755	1.194	0.869	0.770	0.949	0.849	1.361	1.805	0.804
CV (%)	15.6	17	25.6	20.9	23.8	19.7	27.2	31.8	20.7

6.7.9 Foliar analysis of leaf with TVD leaf of sugarcane primary tillers

Growth medium and container size had no significant influence on leaf N, P, K, Mg and Ca concentrations at 112 DAP (data not shown).

6.8 Discussion

Temperatures of filter cake + pine bark and filter cake only media were higher than the ZSAES soil substrate in medium and large sized containers than in small containers (Figure 64 and Figure 65). Perhaps, more organic content in the soil less media (filter cake + pine bark and filter cake only) in large containers elevated the temperature. Fang et al. (2005) reported that organic matter content increases water holding capacity of the medium and gives a dark colour. Increased water holding capacity and dark colour increases the absorption of heat that increases the temperature of the growth medium. Temperature of the growth medium depends on the ratio of the energy absorbed to that lost from the medium (Martias and Musil, 2012). Medium temperature fluctuates daily, depending on air temperature and solar radiation. Medium temperature influences the plant growth since it affects water and nutrient retention, root development and other factors (Onwuka and Mang, 2018).

Plants grown in the ZSAES soil medium were taller (Table 27), thicker with more internodes (Table 31) than it was in the filter cake + pine bark or filter cake only. This is attributed to low competition for resources between tillers grown in ZSAES soil medium since they were fewer than the soil less media (Table 28). Kang et al. (2013) reported that sugarcane tillers can compete for resources like water, nutrients, light and space. Stem height of plants increased with container size and this is attributed to adequacy of resources such as water, nutrients and space that promoted plant growth in large containers than small and medium sized containers. Large containers have more substrate volume and generally supply more water and nutrients to the plants than small container (Poorter et al., 2012a). The limited water holding capacity of small pots causes containers to dry out quickly after irrigation, thus increasing the risk of water-deficit stress to plants (Ray and Sinclair, 1998).

There were more tillers in large and medium sized containers than in small containers (Table 28) due to more space that allowed the plants to tiller without limitation. Masukume (2016) reported of more tillering with wide than narrow spacing, as sugarcane plants compensate. Proportionally, large and medium sized containers had more nutrients and water than in small containers and this may have promoted tillering in medium and large containers than small containers. Container space restriction can reduce root volume, making it difficult for plants to take up water and nutrients (McConnaughay and Bazzaz, 1991). More water and nutrients in large containers increase the leaf appearance rate which is linked to more tillering (Matsuoka and Stolf, 2012).

Leaf SPAD index of plants grown in filter cake only was higher than filter cake + pine bark and ZSAES soil media when grown in large containers and not in small containers (Figure 67). This suggests that plants grown in filter cake only were stressed more than in filter cake + pine bark and ZSAES soil media when small containers are used. SPAD index of leaves is a physiological indicator of water stress in sugarcane plants (Reyes et al., 2020). At termination (108 DAP), leaf SPAD index of plants grown in filter cake + pinebark and filter cake only was higher than in the ZSAES soil medium (Table 29) suggesting better plant growth in soil-less media than ZSAES soil medium. Similarly, leaf SPAD index of plants grown in medium and large sized containers were higher than in small containers. This is attributed to less stress of plants grown in large containers than small containers.Yang et al. (2010) reported of less competition for nutrients, space, water and other requirements between roots. Nitrogen uptake and assimilation is increased in large containers than small containers (Whitefield et al., 1996; Ronchi et al., 2006; Zhu et al., 2006; Yang et al., 2007; Yang et al., 2010).

Plants grown in filter cake + pine bark and filter cake only had more dry matter comprising stalk, sheath and tops of tillers than the ZSAES soil medium grown in large containers (Figure 68). This trend was also similar for the root dry weight (Figure 69). This may by explained by optimal conditions for sugarcane plant growth that prevailed in soil-less media when large containers were used. Perhaps the physical and chemical properties of filter cake + pine bark and filter cake only may have created conducive conditions for growth of sugarcane plants (Majsztrik et al., 2011; Majsztrik et al., 2017). In addition, the limitation of space in small containers causes roots to compete for resources resulting in oxygen deficiency and imbalance of hormones, thus reducing shoot growth (Peterson et al., 1991b; Shi et al., 2007). Oxygen deficiency reduces respiration of roots and this decrease the uptake of essential mineral nutrients required for shoot growth. Paul and Pellny (2003) reported that when root growth is limited by pot size, it sends a negative feedback of photosynthesis, thereby reducing leaf area and shoot growth (Cantliffe, 1993; Peterson et al., 1991). This is also supported by higher green leaf area and number of green leaves per container of plants grown in large and medium sized containers than small containers (Table 30).

Plants grown in the ZSAES soil and filter cake + pine bark media had longer internodes length than filter cake only. This is attributed to less tillering of plants grown in ZSAES soil medium when compared to other media. Decreased number of tillers increases stem elongation in sugarcane, as there will be less competition for resources among tillers (Kapur et al., 201; Kang et al., 2013). Filter cake + pine bark medium was able to give optimal conditions for plant growth interms of water, nutrients, porosity despite supporting more tillers per container than other media(Majsztrik et al., 2011; Majsztrik et al., 2017).

There were no differences between media or container size with respect to contents of leaf calcium, magnesium, phosphorus and potassium. All the containers in the experiment were fertilized with blend fertiliser fortnightly, thereby reducing chances of nutrient deficiency. The mean leaf calcium content of all media tested was in the range of 0.32 % in filter cake only to 0.41 % in filter cake + pine bark, a range well above the 0.15 to 0.2 % reported to be the critical range for deficiency for sugarcane in a number of countries (Table 20 of Chapter 4).

Magnesium concentration in the leaves of plants in all media tested was between 0.12 % in filter cake + pine bark and 0.22 % in filter cake only, thus ranging from marginal to sufficiency, according to the 0.08 to 0.12 % range reported to be critical for deficiency for sugarcane in a number of countries (Table 20 of Chapter 4). Leaf magnesium concentration in plants grown in the container sizes tested ranged from 0.12 % (large) to 0.23 % (small), also showing adequacy in the supply of magnesium to plants in all container sizes.Leaf potassium concentrations ranged from 1.23 % in filter cake + pine bark to 1.67 % in the ZSAES soil medium, thus ranging from marginal to sufficiency, according to the range 0.9 to 1.25 % (Table 20), which has been reported to be the critical level for deficiency for sugarcane. Leaf potassium concentrations in cane grown in all container sizes ranged from 1.22 % to 1.61 % in the medium containers, a range above the 0.9 to 1.25 % reported to be critical for deficiency for sugarcane in a number of countries (see Table 20 of Chapter 4).

Leaf nitrogen concentrations in plants grown in all the media tested ranged from 2.16 % in the ZSAES soil medium to 2.86 % in filter cake + pine bark, which was above the 1.6 to 1.95 % range reported to be critical for deficiency (Table 20). Leaf nitrogen of cane grown in all container sizes ranged from 2.14 % in the medium containers to 2.84 % in the small pot, a range also above the 1.6 to 1.95 % reported to be critical for deficiency (Table 20). As for leaf P concentrations, they ranged from 0.20 % to 0.76 % in plants grown inall media, which was superior to the critical level of 0.16 % (Table 20 of Chapter 4). The leaf P concentrations in cane grown in all container sizes ranged from 0.20 % to 0.69 %, indicating that phosphorus was sufficient since it was above the critical level of 0.16 % (see Table 20 of Chapter 4).

6.9 Conclusions

Plants grown in the ZSAES soil medium were taller, thicker with more internodes than it was in the filter cake + pine bark or filter cake only. Stem height, green leaf area and number of leaves increased with container size. Leaf SPAD index and tillering increased in plants grown in filter cake + pine bark or filter cake onlythan in the ZSAES soil medium. Also there was more tillering and leaf SPAD index of plants grown in large and medium sized containers over small containers. Plants grown in filter cake + pine bark or filter cake only had more dry matter than ZSAES soil medium in large containers. Internodes lengths were longer for plants grown in ZSAES soil medium and filter cake + pine bark than filter cake only. There were no differences amongst media or container sizes in leaf calcium, magnesium, phosphorus and potassium concentrations, although they were above the critical levels for deficiency.

CHAPTER 7

EVALUATION OF TOLERANCE TO WATER-DEFICIT STRESS OFRELEASED SUGARCANE VARIETIES IN ZIMBABWE

7.1 Abstract

The negative effects of climate change and variability on the sugarcane industry can be minimised by screening commercially grown varieties for their tolerance to drought. The objective of the experiment was to assess the growth response of 14 sugarcane varieties released for production in Zimbabweto water-deficit stress. A 14 x 2 factorial arrangement in Completely Randomised Design with 3 replications was used to screen the varieties at the Zimbabwe Sugar Experiment Station (ZSAES). The first factor was the sugarcane varieties ZN1, ZN2, ZN3, ZN4, ZN5, ZN6, ZN7, ZN8, ZN9, ZN10, CP72-1312, NCo376, N14 and CP72-2086. The second factor comprised of two levels of irrigation namely well-watered (100% by volume) and water-deficit stressed (30% by volume). The parameters measured in this study such as number of tillers, leaf SPAD index, total plant dry mass, photosynthetic rate and leaf temperature were found to be too weak for screening sugarcane varieties for their tolerance to water-deficit stress. Water deficit stressed varieties ZN1, ZN8, ZN10 and N14 had the tallest stalks compared to the rest. CP72-2086, ZN2, ZN5, CP72-1312, ZN4, ZN6 and ZN9 varieties showed stunting, thus proving to be drought-sensitive. Leaf vapour pressure deficit of varieties ZN8, ZN10 and N14 was higher in water-stressed plants than in the well-watered ones. The vapour pressure deficit of NCo376 of well-watered plants was higher than that of water-stressed plants. Furthermore, the stomatal conductance of water-stressed NCo376 plants was greater than that of the other varieties tested. All things considered, sugarcane varieties that can be grown by cane famers when faced with drought instigated by climate change are NCo376, ZN1, ZN8, ZN10 and N14.

Key words: climate change, sugarcane, drought tolerance, varieties, screening

7.2 Introduction and background

Despite the importance of the Zimbabwe's sugarcane industry, its survival is threatened by the adverse effects of climate change and variability. Marin et al. (2013) warn that climate change is projected to have adverse effects on rainfall patterns, resulting in droughts and floods across the planet. Whereas a sugarcane plant requires a substantial amount of water to complete its lifecycle (Gonçalves et al., 2010), it is predicted that, in Southern Africa, climate change will cause more frequent droughts (Brown et al., 2012). In Zimbabwe, frequent droughts are likely to curtail the production of sugarcane. A number of dams, including Mutirikwi, Manyuchi, Manjirenji, Bangala, Siya and the recently commissioned Tokwe Mukosi, supply irrigation water to the sugarcane industry (USAID, 2016). However, erratic rainfall due to climate change and variability may result in poor replenishment of these dams, leading to a shortage of irrigation water (Benebere, 2017).

Some of the mitigation and adaptation strategies for climate change in sugarcane production in Zimbabwe include investing in irrigation infrastructure, increasing irrigation efficiency and drainage systems, improving cultural and management practices, and planting drought tolerant varieties (Chandiposha, 2013). The degree of tolerance to water-deficit stress varies among sugarcane genotypes (Wolfe et al., 1988; Aguilera et al., 1999; Silva et al., 2007; Inman-Bamber et al., 2012). However, in Zimbabwe, selection criteria for sugarcane genotypes released in the industry do not include water-deficit stress tolerance. The selection of genotype varieties in the Zimbabwe sugarcane industry is mainly based on high cane and sugar yields, tolerance to smut and ratoon stunting disease, and ability to resist sugarcane stalkborer (*Eldana saccharina*), among others (Clowes and Breakwell, 1998). Screening sugarcane genotypes for water-deficit stress tolerance in the field may be costly due to substantial requirements, such as seed cane, water, fertilisers, herbicides and other inputs. Also, controlling irrigation and other sources of water in the field is difficult. Instead of screening the sugarcane varieties in the field, the selection can be done in containers. Screening sugarcane varieties in containers enables the researcher to control variables such as irrigation, nutrition and substrate. Using containers in screening sugarcane varieties is also likely to reduce costs since the area required is small, which means fewer inputs for growing the plants. According to Ferreira et al. (2017), the most important stage of sugarcane sensitive to water-deficit stress is the tillering and stem elongation phase. Therefore, the screening of sugarcane varieties for tolerance to water-deficit stress can be done in containers in the first few months of growth.

Water-deficit stress alters the physiological and morphological processes of sugarcane plant growth and, can thus be used in screening genotypes for tolerance (Silva et al., 2008; Rodrigues et al., 2009; Jangpromma et al., 2010; Medeiros et al., 2013). Physiological processes that are sensitive to water-deficit stress include stomatal conductance and photosynthetic rate (Silva et al., 2007; Centritto et al., 2009; Galmes et al., 2011). Another physiological characteristic that can be used in screening of sugarcane genotypes is SPAD index. According to Silva et al. (2011), sugarcane genotypes that have SPAD index of less than 40 are susceptible to water-deficit stress. Low SPAD index is tantamount to reduced chlorophyll content and this may result in decreased photosynthetic rates (Torres et al., 2005). Relative Water Content (RWC) is another parameter that can be used in selecting genotypes tolerant to water-deficit stress (Silva et al., 2007; Silva et al., 2013). Sugarcane genotypes with RWC of above 80% are tolerant to water-deficit stress (Graca et al., 2010; Silva et al., 2011). Leaf temperature of sugarcane plants is another physiological parameter that can also be used to differentiate between tolerant and sensitive genotypes to water-deficit stress (Silva et al., 2007). Leaf temperature of sugarcane plants tends to increase in susceptible genotypes (Colom and Vazzana, 2003; Silva et al., 2007). Morphological parameters that are ordinarily affected by water-deficit stress include sugarcane leaf and stem elongation, root development and biomass (Inman-Bamber, 2004; Inman-Bamber and Smith, 2005; Inman-Bamber et al., 2008).

7.3 Aim

To screen sugarcane varieties released in Zimbabwe for their tolerance to water-deficit stress.

7.4 Specific Objectives

7.4.1 To test 14 sugarcane varieties ZN1, ZN2, ZN3, ZN4, ZN5, ZN6, ZN7, ZN8, ZN9, ZN10, CP72-1312, NCo376, N14 and CP72-2086 on two levels of irrigation namely well-watered (100% by volume) and water-deficit stressed (30% by volume) on stem height, number of tillers, SPAD index, leaf temperature, photosynthetic rate, transpiration, stomatal conductance, vapour pressure deficit, relative water content, dry matter, green leaf area and stem girth.

7.5 Hypothesis

Sugarcane varieties differ in their response to water-deficit stress in terms of growth performance.

7.6 Materials and methods

7.6.1 Study area

The study was done at the Zimbabwe Sugar Association Experiment Station (ZSAES) located in the South Eastern Lowveld of Zimbabwe (21^{o}01’S: 28^{o}38’N; 430m above sea level). The area experiences an average rainfall of 625mm per annum, much of which falls in summer (October to March). The mean air temperatures range from 16^{o}C in June to July to 26^{o}C in October to January.

7.6.2 Experimental design and treatments

A Completely Randomised Design (CRD) consisting of 14 varieties and two water application rates in factorial arrangement with three replications was used. The 14 sugarcane varieties used in the experiment were ZN1, ZN2, ZN3, ZN4, ZN5, ZN6, ZN7, ZN8, ZN9, ZN10, CP72-1312, NCo376, N14 and CP72-2086. The two levels of irrigation tested were well-watered (100%) and water stress (30% of daily water volume applications).

7.6.3 Plant culture and experimental procedure

The protocol outlined in Chapter 6, subsection 6.10 was used to study the effects of water deficit stress on the 14 sugarcane varieties. Sugarcane setts of varieties ZN1, ZN2, ZN3, ZN4, ZN5, ZN6, ZN7, ZN8, ZN9, ZN10, CP72-1312, NCo376, N14 and CP72-2086 varieties (12 months old) were cut at the base from S2 field using cane knives which were sterilized by immersing them for 5 minutes in diluted Propan-2-ol or isopropanol (JEYES fluid) (0.5 L JEYES fluid per 10 L of water).Three internodes from the base and top of the stalk were discarded using a cane knife. One eyed setts were cut from the remaining stalk before dipping them for 5 minutes in Triadimenol (Shavit) (1ml Shavit / 1000 ml of water) to prevent ratoon stunting disease. Three sterilised single eyed sections of ZN1, ZN2, ZN3, ZN4, ZN5, ZN6, ZN7, ZN8, ZN9, ZN10, CP72-1312, NCo376, N14 and CP72-2086 were planted 40 mm deep close to the centre of a container (54 cm diameter and 90 cm depth) in a filter cake + pine bark (1:1 v/v) medium on 20 September 2018. Thinning of emerged plants was done 14 DAP, leaving one plant per container. Triple 16 blend fertiliser was applied to the surface of the media in containers at the rate of 937.5mg/l at 14 DAP and, thereafter, fortnightly until 70 DAP. The plants were irrigated with one litre per container per day for the first 14 DAP for germination. Subsequently, the containers were supplied with 160 mL and 48 mL per litre volume of medium for well-watered and water stress treatments, respectively, till the end of experiment on 21 January 2019 (153 days after planting). Weeds were controlled by hand pulling. Spraying Regent insecticide at the base of the containers and around the experimental site controlled termites and aphids. White grubs were controlled at planting using carbrayl 85 WP (1- naphthol N-methylcarbamate) at the rate of 200 g carbrayl in 200 L of water which was applied every fortnightly.

7.6.4 Measurements and data analysis

During the experimental period, seasonal meteorological data that included rainfall amount, aerial temperature, and evaporation was measured at the ZSAES Automatic Weather Station, which was approximately 100 m to the experimental site. The data that was measured in this experiment is presented in Table 33. The data was subjected to Fisher's Analysis of Variance using Genstat Version 14th edition software. The separation of treatment means was done using Least Significant Difference and Standard Error Difference tests at 5% level (Steel and Torie, 1984).

Table 33: Parameters and methods usedin testing of tolerance to water-deficit stress of all released sugarcane varieties in Zimbabwe measured at 150 DAP

Parameter	Method
Stem height (cm)	Using a metre rule, from the base of the plant at the surface of the medium to the apex of the plant
Number of tillers	Counting all tillers in a container
SPAD index	Measured on the leaf with the topmost visible dewlap (TVD) using chlorophyll meter (Minolta SPAD-502, Minolta Co., Osaka, Japan) (Zhao et al., 2010).
Physiological parameters (leaf temperature, photosynthesis, transpiration, stomatal conductance and vapour pressure deficit.	A portable photosynthetic system (CIRAS 3 model, PP systems, Amesbury, United States of America) was used on leaf with TVD of primary tillers between 0700 and 1000 hours.
Relative Water Content	Using leaf with TVD of primary tiller as according toTurner, 1981).
Dry Matter	All tillers were excised at the base to separate shoot and roots. The roots were washed with water. The shoot was separated into different components of trashand leaves. The roots and components of shoots were placed in a forced air oven at 105 ^{o}C for 72 hours and weighed.
	The leaf area of all green leaves was measured usingleaf area meter (Delta-T Devices Ltd., Burwell, Cambridge, UK).
Number of green leaves	All mature green leaves were counted.
Number of internodes	Number of internodes on the primary plant was counted.

7.7 Results

7.7.1 Seasonal meteorological data

Rainfall started very late in November 2018, which amounted to only 26.9 mm and reached a peak of 107.1 mm in December 2018 before declining sharply to 14.4 mm in January 2019 (Figure 72). Similarly, the temperatures started off quite low in August (21.4 ^{o}C) and gradually increased to reach the highest in December 2018 (27.9 ^{o}C) and in January 2019 (25.9 ^{o}C). The average monthly evaporation was generally high with an average of 6.6 mm per day throughout the experimental period (Figure 72).

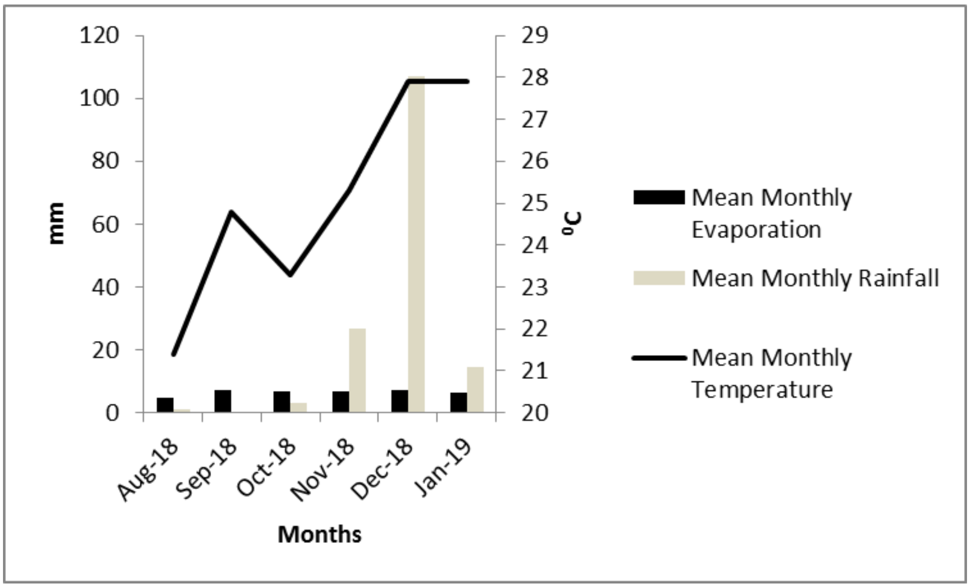

Figure 72: Average monthly temperature, rainfall and evaporation at ZSAES for August 2018 to January 2019 period

7.7.2 Stem height of primary tillers

There was a significant interaction between sugarcane variety and water application rate on stem height at 150 DAP (Figure 73). Stem height was not significantly affected by water application rate in the varieties ZN1, ZN3, ZN5, CP72-1312, NCo376 and CP72-2086 (Figure 73). In contrast, stem height decreased in the water stressed treatment in the varieties ZN2, ZN6, ZN7, ZN8, ZN9, ZN10 and N14 (Figure 73).

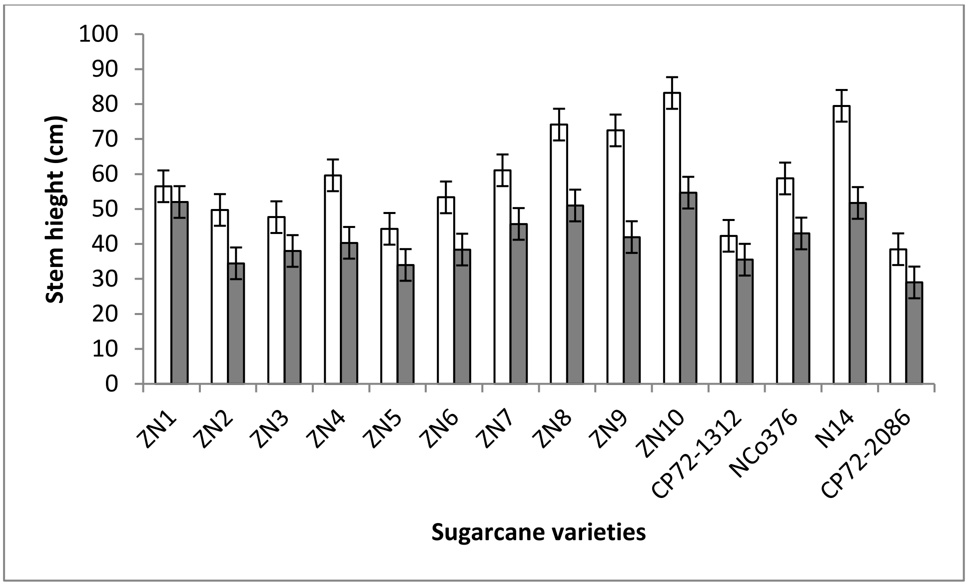

Figure 73: Stem height of primary tiller of 14 commercial sugarcane varieties grown in filter cake + pine bark in large containers and either ☐ well-watered or ▨ water-stressed measured at 150 DAP (level of significance *)**

7.7.3 Number of sugarcane tillers per container

There was a no interaction between sugarcane variety and water application rate on number of tillers per container. Variety ZN2 had more tillers per compared than other varieties tested. Sugarcane varieties ZN3, ZN1, ZN4, ZN5, ZN6, ZN7, ZN8, ZN9 and N14 had fewer tillers per container when compared to the rest (Figure 74). Plants that were grown under water-stressed conditions had more tillers than well-watered plants (Figure 75).

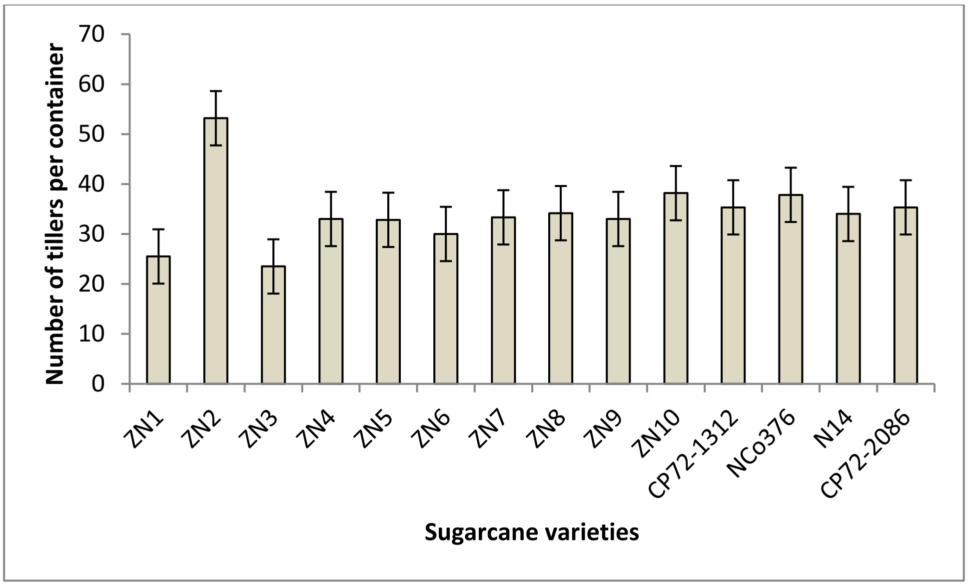

Figure 74: Number of tillers per container of 14 commercial sugarcane varieties grown in pine + filter cake in large containers measured at 150 DAP (level of significance ***)

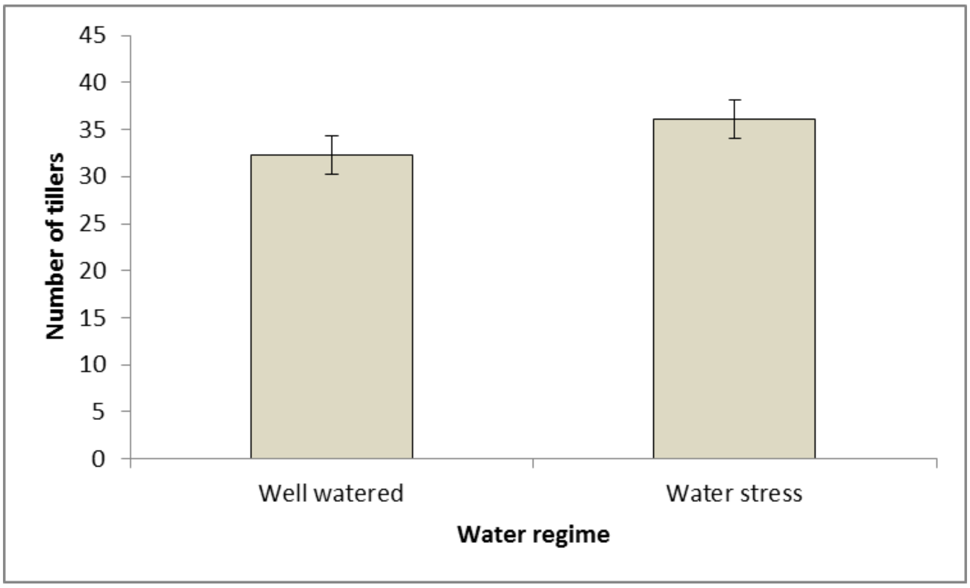

Figure 75: Number of tillers per container grown in pine + filter cake in large containers and either well-watered or water-stressed measured at 150 DAP (level of significance ***)

7.7.4SPAD index of leaf with TVD of primary tillers

Interaction betwen variety and water application rate on leaf SPAD index was not significant. Variety ZN3 had the highest significant SPAD index of leaf with TVD of primary tillers of all the varieties that were tested (Figure 76). Variety ZN4 had the lowest leaf SPAD index, although it did not differ significantly from the rest of varieties except ZN1, ZN4 and ZN10 (Figure 76).

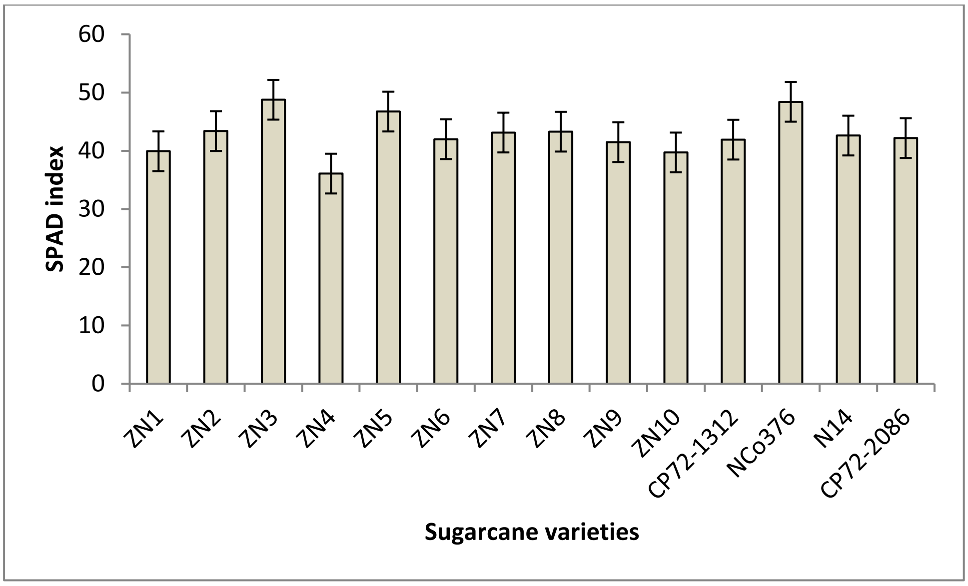

Figure 76: SPAD index of leaf with TVD of primary tiller of 14 commercial sugarcane varieties grown in pine + filter cake in large containers measured at 150 DAP (level of significance *)**

7.7.5Vapour pressure deficit of leaf with TVD of primary tillers

There was a significant interaction between sugarcane variety and water application rate on vapour pressure deficit of leaf with TVD of primary tillers. Leaf vapour pressure deficit was not significantly affected by water application rate in the varieties ZN1, ZN2, ZN3, ZN4, ZN5, ZN6, ZN7, ZN9, CP72-1312 and CP72-2086 (Figure 77). In contrast, leaf vapour pressure deficit increased in the water stressed treatment in the varieties ZN8, ZN10 and N14 (Figure 77). Leaf vapour pressure deficit decreased in the water-stressed treatment in the variety NCo376 only (Figure 77).

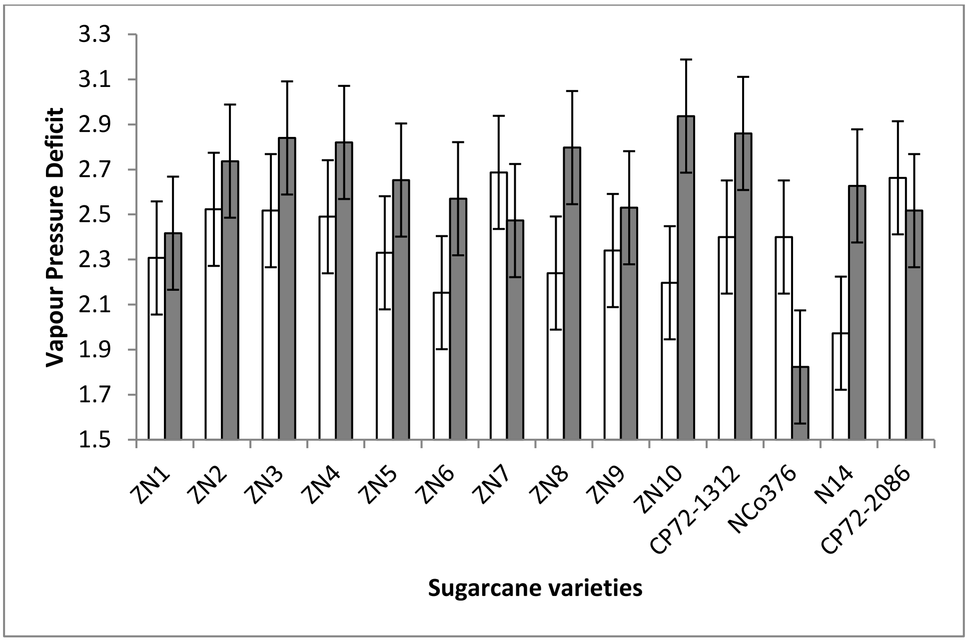

Figure 77: Vapour pressure deficit of leaf with TVD of primary tillers of 14 commercial sugarcane varieties grown in pine + filter cake in large containers and either ☐ well-watered or ▨ water-stressed, measured at 150 DAP (level of significance *)

7.7.6 Relative water content, photosynthetic rate and temperature of leaf with TVD of primary tillers

There was no interaction between variety and water application rate on relative water content, photosynthetic rate and leaf temperature. Of all the varieties tested, only ZN2 and ZN10 had relative water content of <80% (Table 34). Well-watered plants had 4.9 % more relative water content than water-stressed plants. Similarly, the photosynthetic rate of well-watered plants was higher than that of water-stressed plants by 46.8 % (Table 34).

Table 34: Relative water content, photosynthetic rate and temperature of leaf with TVD of primary tillers of 14 commercial sugarcane varieties grown in pine + filter cake in large containers and either well-watered or water-stressed, measured at 150 DAP

Variety	**Relative Water Content (%)**	**Photosynthetic rate (µmol CO2 m^{-2} s^{-1})**	**Leaf Temperature (°C)**
ZN1	85.02	9.9	37.15
ZN2	78.62	10.7	36.12
ZN3	84.81	15.4	37.35
ZN4	88.48	13.1	37.43
ZN5	85.03	18.0	36.97
ZN6	86.64	11.7	36.47
ZN7	84.90	10.9	36.45
ZN8	84.14	17.2	37.22
ZN9	82.26	10.8	36.15
ZN10	79.81	9.7	37.65
CP72-1312	82.01	20.5	37.38
NCo376	82.41	12.5	36.32
N14	84.52	16.8	36.18
CP72-2086	83.34	10.6	36.28
P value	0.457	0.657	0.684
LSD	NS	NS	NS
Water application rate			
Well-watered	85.68a	16.0a	36.91
Water-stressed	81.7b	10.9b	36.67
P value	0.006	0.018	0.484
LSD	2.746	4.21	NS
CV (%)	7.5	71.7	4.2

7.7.7 Stomatal conductance (gs) of leaf with TVD of primary tillers

There was interaction between variety and water application rate on stomatal conductance at 150 DAP. Stomatal conductance was not significantly affected by water application rate in the varieties ZN1, ZN2, ZN3, ZN4, ZN5, ZN6, ZN7, ZN9, CP72-1312 AND CP72-2086 (Figure 78). In contrast, stomatal conductance increased in the water stressed treatment in the variety NCo376 only (Figure 78). Stomatal conductance decreased in the water-stressed treatment in the varieties ZN8, ZN10 and N14 (Figure 78).

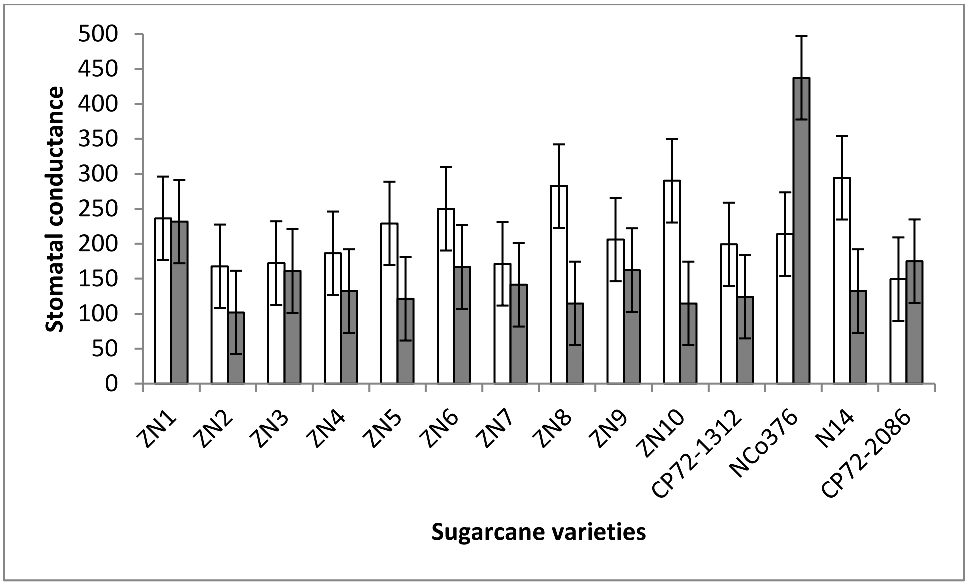

Figure 78: Stomatal conductance of leaf with TVD of primary tillers of 14 commercial sugarcane varieties grown in pine + filter cake in large containers and either □ well-watered or ■ water-stressed at 150 DAP (level of significance **)

7.7.8 Transpiration rate of leaf with TVD of primary tillers

Interaction between variety and water application rate on transpiration rate was significant at 150 DAP. Stomatal conductance was not significantly affected by water application rate in the varieties ZN1, ZN2, ZN3, ZN4, ZN6, ZN7, ZN9, CP72-1312, NCo376 and CP72-2086(Figure 79). In contrast, transpiration rate decreased in the water-stressed treatment in the varieties ZN5, ZN8, ZN10 and N14 (Figure 79).

There was inverse linear relationship between transpiration rate and vapour pressure deficit (Figure 80A) as well as between stomatal conductance and vapour pressure deficit (Figure 80B). In contrast, there was a linear positive relationship between transpiration rate and vapour pressure deficit (Figure 80C).

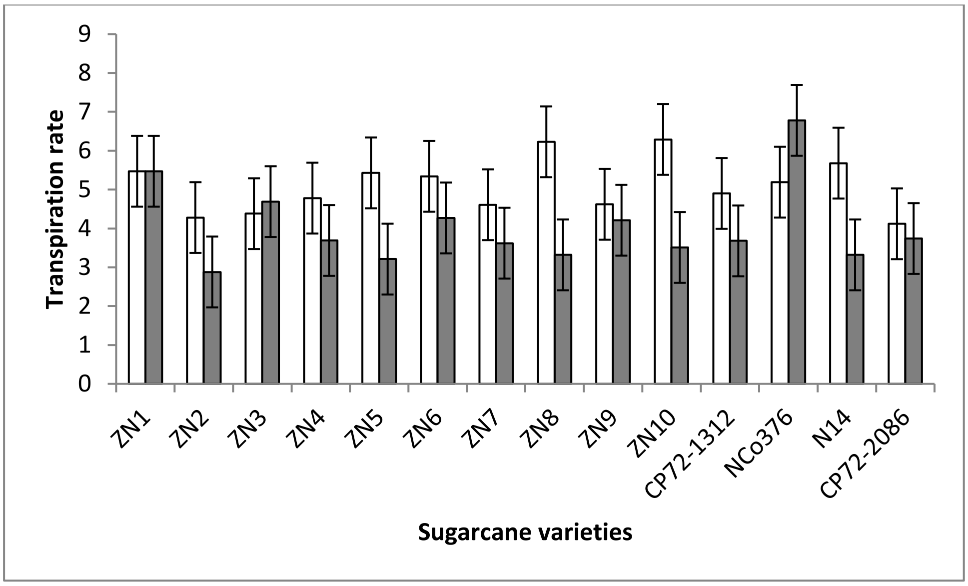

Figure 79: Transpiration rate of leaf with TVD of primary tillers of 14 commercial sugarcane varieties grown in pine + filter cake in large containers and either ☐ well-watered or ■ water-stressed, measured at 150 DAP (level of significance *)

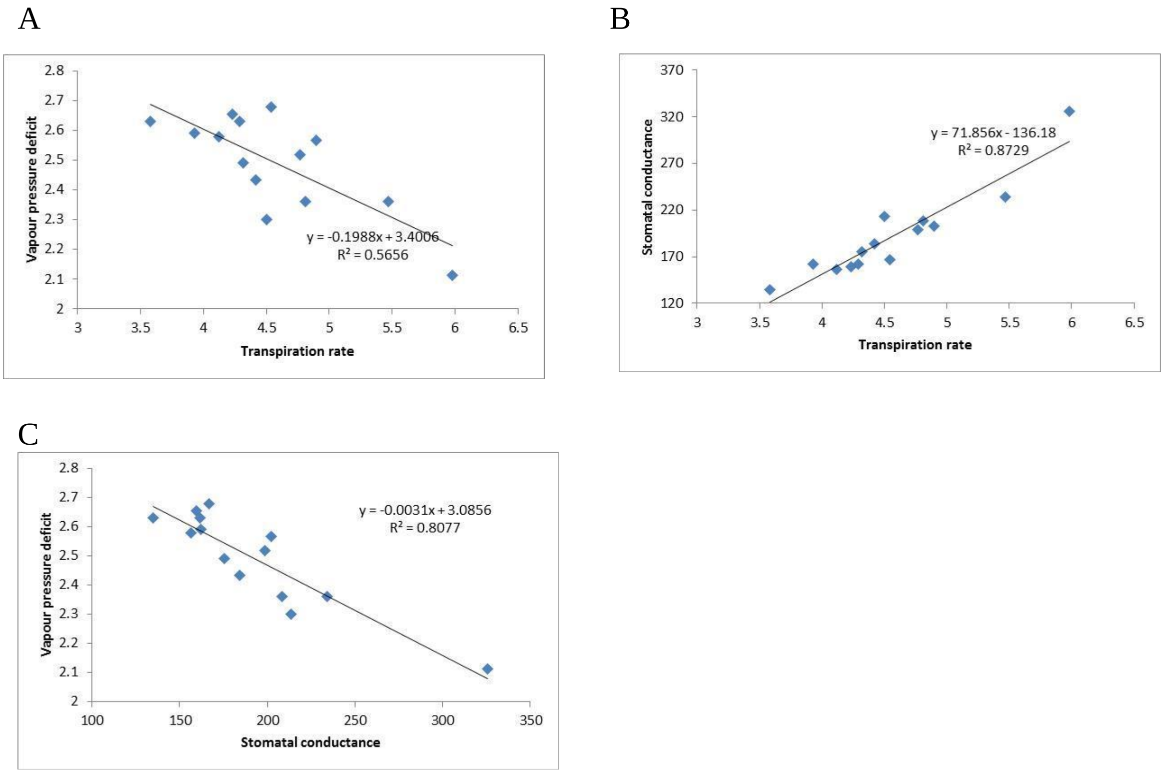

Figure 80: Relationship between transpiration rate and vapour pressure deficit (A), transpiration rate and stomatal conductance (B), stomatal conductance and vapour pressure deficit (C)

7.7.9 ***Number of Internodes and internodelengths of primary tillers***

Overally, there were more internodes in well-watered plants than in water-stressed plants. At 150 DAP, variety N14 had more internodes than the other varieties, although it was not significantly different to ZN10, ZN9, ZN8 and ZN7 (Table 35). Variety CP72-2086 had the least number of internodes, but was not different to ZN6 and ZN2 (Table 35).

Variety ZN3 had the longest internodes from the first (base) to the eighth internode (top most) as well as the average internodes length, closely followed by ZN6, ZN10 and N14 (Table 35). In contrast, ZN2 had the shortest internodes length from the first (base) to the eighth (top most) internode as well as the average internode length, with the ZN4, ZN5, ZN7 and CP72-2086 varieties not faring much better (Table 35). From the first to the eighth internode, the internodes length of well-watered plants increased more than that of water-stressed plants (Table 35). There was a 75 % decrease in the average internodes length of water-stressed plants (Table 35).

Table 35: Number and length of internodes (cm) of primary tillers of 14 commercial sugarcane varieties grown in pine bark + filter cake in large containers and either well-watered or water-stressed, measured at 150 DAP

Variety	Number of internodes	1st	4th	5th	6th	8th	Average
		Internodes lengths (cm)					
ZN1	10.3cd	3.7d	4.6bcd	4.6cde	3.7abc	3.4bc	4.1bcd
ZN2	8.7ab	1.7a	2.7a	2.8a	2.8a	1.0a	2.6a
ZN3	9.7bc	3.2cd	4.5bc	4.8de	5.3d	5.6ef	4.8de
ZN4	10.2cd	2.1abc	3.3a	3.4ab	2.9a	4.4cde	3.1ab
ZN5	10.2cd	2.1abc	2.9a	2.7a	2.6a	2.7b	2.6a
ZN6	8.0a	2.9bcd	4.9cd	5.7e	4.9cd	6.3f	4.6de
ZN7	11.2de	2.2abc	3.6ab	3.5abc	3.5ab	3.8bcd	3.3abc
ZN8	11.8e	2.3abc	4.4bc	4.3bcd	4.1bcd	3.8bcd	3.8bcd
ZN9	11.3de	2.1abc	4.6bcd	4.1bcd	4.2bcd	3.6bcd	3.8bcd
ZN10	11.3de	2.7abcd	5.6d	4.9de	4.5bcd	4.2cd	4.5de
CP72-1312	9.5bc	1.9bab	3.6ab	4.1bcd	4.7bcd	4.9de	3.8bcd
NCo376	10.0bcd	3.0bcd	4.5bc	4.2bcd	4.4bcd	4.8de	4.3cd
N14	12.5e	3.1cd	4.7cd	4.6cd	4.1bcd	3.5bcd	4.0bcd
CP72-2086	7.7a	1.9ab	3.1a	2.8a	2.7a	3.2bc	3.2ab
P value	<0.001	0.031	<0.001	<0.001	<0.001	<0.001	<0.001
LSD	1.498	1.17	1.03	1.16	1.21	1.39	1.08
Water application rate							
Well-watered	12.5a	3.1a	5.3a	5.3a	5.2a	5.6a	4.9a
Water stress	7.9b	1.9b	2.9b	2.8b	2.5b	2.3b	2.8b
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD	0.566	0.44	0.39	0.44	0.46	0.53	0.41
CV (%)	12.7	40.8	21.8	24.9	27	30.4	24.2

7.7.10 Number of green leaves and green leaf area

Varieties ZN2, ZN8, ZN10, NCo376 and N14 had the highest number green leaves per container than other varieties. In contrast, varieties ZN1, ZN2, ZN3, ZN4, ZN5, ZN6, ZN7, ZN9, CP72-1312 and CP72-2086 had the fewest green leaves per container (Table 36). Well-watered had more green leaves and green leaf area per container than water-stressed plants (Table 36). There were no differences among varieties tested in green leaf area.

Table 36: Number of green leaves and green leaf area per container of 14 commercial sugarcane varieties grown in pine + filter cake in large containers and either well-watered or water-stressed measured at 150 DAP.

Variety	Number of green leaves	Green leaf area (mm^2)
ZN1	155.3a	4191543
ZN2	221.5d	4485643
ZN3	147.2a	3396611
ZN4	174.2abc	4619779
ZN5	161.0ab	3829739
ZN6	146.7a	5413365
ZN7	142.8a	4486153
ZN8	198.3bcd	3293166
ZN9	146.7a	4741248
ZN10	218.8d	4075877
CP72-1312	175.2abc	4981720
NCo376	203.2cd	3403077
N14	216.3d	4445341
CP72-2086	172.2abc	5228614
P value	<0.001	0.158
LSD	37.87	NS
Water application rate		
Well-watered	201.1a	5786164a
Water stress	153.0b	2869818b
P value	<0.001	<0.001
LSD	14.32	592856.3
CV (%)	18.5	31.3

7.7.11Dry matter of roots, total plant dry matter and Shoot: Root ratio

Variety ZN5 had greater root dry matter than the other varieties tested, although it was comparable to varieties ZN2 and N14 (Table 37). The sugarcane variety with the highest Shoot: Root ratio was ZN9, although it did not differ significantly from ZN1, ZN3, ZN4, ZN6, ZN7, ZN8, ZN10, CP72-1312, NCo376 and CP72-2086 (Table 37). Variety ZN7 had the greatest total plant dry matter amongst the varieties tested, even though it did not differ significantly from ZN4, ZN5, ZN6, ZN8, ZN9, ZN10, CP72-1312, N14 and CP72-2086 (Table 37). Well-watered plants had higher root, total plant dry matter and Shoot: Root than water-stressed plants (Table 37).

Table 37: Dry matter of roots, total plant dry matter and Shoot : Root ratio per container of 14 commercial sugarcane varieties grown in pine + filter cake in large containers and either well-watered or water-stressed measured at 150 DAP.

Variety	Root dry matter (g)	Total plant dry matter (g)	Shoot: Root
ZN1	493ab	1859a	3.63abc
ZN2	801.7c	2342d	1.93a
ZN3	358.8a	1919ab	4.38bc
ZN4	477.9a	2077abcd	3.29abc
ZN5	829.2c	2256cd	1.80a
ZN6	529.8ab	2158bcd	3.93bc
ZN7	470.2ab	2352d	3.93bc
ZN8	466.5ab	2081abcd	3.38abc
ZN9	397.6ab	2331d	5.05c
ZN10	472.4ab	2136abcd	3.63abc
CP72-1312	376.5a	2139abcd	4.88c
NCo376	385.9a	2038abc	4.40bc
N14	624.3bc	2275cd	2.85ab
CP72-2086	473.6ab	2279cd	3.73abc
P value	<0.001	0.014	0.046
LSD	227.1	286.4	1.999
Water application rate			
Well-watered	636a	3072a	4.82a
Water stress	387b	1248b	2.51b
P value	<0.001	<0.001	<0.001
LSD	85.9	108.3	0.755
CV (%)	38.4	11.5	47.2

7.8 Discussion

The varieties ZN2, ZN6, ZN7, ZN8, ZN9, ZN10 and N14 had much more reduced plant height (Figure 73) under water stress conditions than ZN1, ZN3, ZN5, CP72-1312, NCo376 and CP72-2086. These results suggests that varieties ZN1, ZN3, ZN5, CP72-1312, NCo376 and CP72-2086 were tolerant to water stress than ZN2, ZN6, ZN7, ZN8, ZN9, ZN10 and N14 with respect to stem height. With respect to average internodes length, ZN1, ZN3, ZN5, CP72-1312, NCo376 and CP72-2086 had longer internodes length than other varieties (Table 35). This may be explained by genetic differences that existed between sugarcane varieties in extraction of water that influences stem elongation (Ferreira et al. 2017). Water-deficit stress reduces stem elongation of sugarcane plants by decreasing cell elongation as a result of poor cell turgor pressure (Hsaio, 1973). Water-deficit stress may also cause a decline in cell division, resulting in poor stem growth (Hsaio, 1973; Machado et al., 2009; Rossler, 2013). Gomathi et al. (2011) reported that stalk height and internode length are important factors that dictate the yield of sugarcane; therefore, any decline in these parameters will reduce the final yield.

Variety and water application rate did not interact on number of tillers. This may suggest that there is no variation among sugarcane genotypes in tillering when subjected to different water watering regime. This corroborates with the observation by Ryes et al. (2020) that tiller production was not different among genotypes. Tillering is a complex physiological process which is affected by a wide array of factors that include environmental, endogeneous and biotic with their interactions (Assuero and Tognetti, 2010). Tiller number in grasses is controlled by quantitive trait loci that have additive and not dominant effects (Tang et al., 2001). For example, quantitive trait loci that affects tillering identified at early stages of plant growth of sugarcane is undetectable at maturation stage (Yan et al., 1998). Although there was no interaction between variety and water application rate, main effects were significant. Variety ZN2 had more tillers than other varieties. This is attributed to genetic variation among sugarcane genotypes on tiller production. Ryes at al. (2020) also reported of differences in ten sugarcane genotypes on tiller count. The study also revealed more tillering of plants under water-deficit stress than well-watered plants. Water deficit-stress can promote tillering as a way of compensating for the reduced assimilation production during drought (Robertson et al., 1999)

No interaction between water application rate and variety on leaf SPAD index, seem to suggest that leaf SPAD index is a weak parameter for screening varieties for tolerance to water-deficit stress, especially in the formative stage of sugarcane growth. This in contrary to the findings by Silva et al (2007) and Zhao et al. (2013), that leaf SPAD index can be used to screen sugar varieties on their tolerance to water deficit-stress. The results showed that, NCo376, CP72-2086, ZN3 and ZN5 had the highest SPAD index while ZN4, ZN10, ZN9 and CP72-1213 had the least. Perhaps the differences could be attributed mainly to genotypic variation across the varieties tested in nitrogen extraction. There is a strong correlation between nitrogen uptake and leaf SPAD index of sugarcane plants (Rigon et al., 2013; IIkaee et al., 2016 and Dinh et al., 2017).

Varieties ZN8 ZN10 and N14 had higher leaf vapour pressure deficits than the other varieties under water-deficit stress (Figure 77). Higher vapour pressure deficit in sugarcane causes the sugarcane leaves to close their stomata conserving water under drought (Oren, 1999). This assertion is confimed by negative relationship between vapour pressure deficit and stomatal conductance (Figure 80A) or transpiration rate (Figure 80C). In this study, stomatal conductance and transpiration rate of ZN8, ZN10 and N14 was significantly lower in water stressed plants (Figure 78 and 79). This suggested that varieties ZN8, ZN10 and N14 conserved more water than the other genotypes tested under drought (Rossler, 2013). Varieties ZN8, ZN10 and N14 were among varieties with higher total plant dry matter (Table 37). Sugarcane varieties with low stomatal conductance but higher dry matter are said to conserve water under drought and are tolerant to water deficit stress using dehydration avoidance mechanism (Kooyers, 2015; Ferreira et al., 2017). In contrast, variety NCo376 had lower leaf vapour pressure deficit than other varieties under water-deficit stress (Figure 77). In addition, the stomatal conductance of NCo376 variety was higher in water stressed plants (Figure 78). NCo376 variety was among varieties with higher total plant dry mass (Table 37). These results suggested that NCo376 has a greater dehydration tolerance mechanism of accumulating dry matter under water-deficit stress than other varieties tested. Dehydration tolerance is referred to as any mechanisms, such as high stomatal conductance, that permit plants to tolerate stress and maintain plant functions under water-deficit conditions (Blum, 2005). Sugarcane varieties with dehydration tolerance mechanism under water-deficit stress are important for mild and moderate water stress (Ferreira et al., 2017).

ZN8, ZN10, N14 and NCo376 were among varieties with the highest shoot: root ratio (Table 37). This confirms the tolerance of ZN8, ZN10, N14 and NCo376 to water-deficit stress when compared to other genotypes. Under water deficit stress, plants enhance their root system as a tactic to extract more water, therefore, reduce shoot: root ratio (Xu et al., 2010). Under drought conditions, plants re-allocate assimilates from shoot growth to root growth and this increases root length (Rich and Watt, 2013). Lemoine et al. (2013) reported that mild water deficit stress restricts shoot growth with little effect on root growth.In addition, ZN8, ZN10, N14 and NCo376 were among varieties with more green leaves than other varieties (Table 36). This supports the assertion that water deficit stress did not affect the shoot growth of ZN8, ZN10, N14 and NCo376.

There was no interaction between water application rate and variety or significant differences among varieties on relative water content, photosynthetic rate and leaf temperature (Table 34). This suggests that relative water content; photosynthetic rate and leaf temperature are paremeters not suitable for use in screening sugarcane varieties to water deficit-stress. This is in contrast to results by Silva et al. (2011) and Marchiori et al. (2017), who reported that sugarcane varieties can be screened of their tolerance to water deficit-stress using relative water content; photosynthetic rate and leaf temperature. Although, there were no significant differences between varieties, ZN2 and ZN10 had relative water contents of <80% (Table 24), which shows high sensitivity to water-deficit stress (Graca et al., 2010; Silva et al., 2011). Water-deficit stressed plants had a reduced photosynthetic rate relative to well-watered plants. Oskabe et al. (2014) reported that during drought, plant cells accumulate abscisic acid in the guard cells triggering stomatal closure which ultimately reduce photosynthesis. Similar results of water deficit-stress reducing photosynthesis in sugarcane plants have been reported (Chaves et al. 2009; Ferreira et al., 2017).

There was no interaction between variety and water application rate or differences among varieties on green leaf area (Table 36). This meant that the green leaf area of sugarcane varieties was not affected by water-deficit stress.In contrast, Castro-Nava et al. (2016) noted significant differences between sugarcane genotypes in terms of green leaf area in their response to water-deficit stress, and this was conspicuous as the plant aged. The green leaf area of sugarcane in this study was determined at 150 DAP, which might have been too early to note the differences between varieties in their response to water-defict stress.

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7.9 Conclusions

The ZN1 and NCo376 varieties were more tolerant to water-deficit stress than the other genotypes tested with respect to stem and internode elongation, while CP72-2086, ZN2, ZN5, CP72-1312, ZN4, ZN6 and ZN9 showed stunting, suggesting that they are drought sensitive varieties. The parameters measured in this study, such as number of tillers per container, leaf SPAD index, total plant dry matter, photosynthetic rate and leaf temperature, were weak parameters for screening sugarcane varieties for their tolerance to water-deficit stress. ZN8, ZN10 and N14 were more tolerant than other varieties, as they conserved water and accumulate more biomass during drought. Stomatal conductance and transpiration rate of water stressed plants of ZN8, ZN10 and N14 were lower. The vapour pressure deficit of well-watered plants of NCo376 variety was higher than that of water-stressed plants. Furthermore, the stomatal conductance of water-stressed NCo376 plants was greater than that of the other varieties tested. NCo376 was a tolerant variety that may be using dehydration tolerance mechanism. Overally, sugarcane varieties that are recommended to cane farmers when faced with drought are NCo376, ZN1, ZN8, ZN10 and N14.

CHAPTER 8

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

8.1 Introduction

This study examined sources of stress for sugarcane plants grown in containers, mainly water availability, nutrient availability and space restriction (Poorter et al., 2012a; Costa et al., 2016). The first objective was to develop a protocol for growing sugarcan plants with minimum stress. A protocol for growing minimum stress sugarcane plants in containers was achieved by manipulating water application, growth medium, fertiliser rate and container size. A further objective was to use the protocol to evaluate the tolerance of 14 sugarcane varieties to water-deficit stress.

8.2 Protocol for growing research sugarcane plants in containers

8.2.1 Water application

An initial experiment evaluated the suitability of 0.25; 0.5; 1.0; 1.5; 2.0; 2.5 and 3.0 L of water per container per day for growing sugarcane plants in containers. The study showed that sugarcane plants grown in containers require high water application rates (≥2.5 L per container per day) for vegetative growth after the cane setts had germinated. High water application rates (≥2.5 L per container per day), however, reduced germination of cane setts and root dry matter in the ZSAES soil medium when compared to the soil-less media (Chapters 3 and 4). In order to maximise the germination of the cane setts in the ZSAES soil medium, a lower application rate of one litre per container per day was found to be optimal.

8.2.2 Growth media

The second experiment assessed filter cake only, filter cake + pine bark, pig manure + pine bark and the ZSAES soil media (control) suitability for growing sugarcane plants in containers. Plants grown in pig manure + pine bark were found to be restricted in internode length and stem elongation than other media tested (Chapter 4 and 5). This reduces the suitability of using pig manure + pine bark when growing sugarcane plants in containers. The ZSAES medium had aeration constraints that curtailed the germination of cane setts and tillering (Chapters 4 and 5). It also had problems of nutrient availability, particularly calcium and nitrogen (Chapter 5). Plants grown in filter cake + pine bark and filter cake only had deficiency of potassium and nitrogen (Chapter 4). If nutrient inadequacy, especially nitrogen and potassium were addressed, filter cake + pine bark and filter cake only could become suitable growth media for sugarcane (Chapter 5).

8.2.3 Fertliser application regime

The third experiment evaluated Triple 16 Blend fertiliser application rates (312.5 mg/l of medium, 937.5 mg/l of medium, 1562.5 mg/l of medium, 2187.5mg/l of medium (Triple 16 blend fertiliser) and 100 % Hoagland nutrient solution) for suitability of growing sugarcane plants in containers. The application of ≥937.5 mg/l Triple 16 Blend fertiliser resulted in nutritional adequacy in all the four media tested but reduced stem elongation. Combining the use of Hoagland nutrient solution and Triple 16 Blend fertiliser rates <937.5 mg/l caused potassium and nitrogen inadequacy in filter cake + pine bark or filter cake only and in the ZSAES soil medium (Chapter 5). Combining the use of Hoagland nutrient solution and low rates of Triple 16 Blend fertiliser did not cause any nutritional inadequacy in pig manure + pine bark. The use of high blend fertiliser application rates (>937.5 mg/l) may not be suitable in containers since it reduced stem elongation and increased susceptibility of sugarcane plants to Brown rust (*Puccinia melanocephala*). Application of 937.5 mg/l of medium Triple 16 blend fertilizer, applied at 14 DAP and, thereafter, fortnightly until 56 DAP is recommended when growing sugarcane plants in containers.

8.2.4 Container size

The fourth experiment assessed suitability of container sizes *viz* small (25.5 cm depth x 31.3 cm diameter), medium (45 cm depth x 54 cm diameter) and large (90 cm depth x 54 cm diameter) for growing sugarcane plants. Large containers were found to be the most suitable container size because of good aeration, as well as water and nutrient availability (Chapter 6). The use of filter cake + pine bark in large containers resulted in better vegetative growth than the other media and container sizes tested. Small containers (25.5 cm depth x 31.3 cm diameter) were not suitable because of poor aeration and restricted space. Use of the ZSAES soil medium in large containers exacerbated the problems of poor drainage and restricted oxygen supply inherent in soil-based media (Chapter 6).

8.3 Responses of 14 sugarcane varieties to water-deficit stress

The last experiment evaluated 14 sugarcane varieties for tolerance to water-deficit stress. The most sensitive varieties to water-deficit stress were CP72-2086, ZN2, ZN3, ZN5, CP72-1312, ZN4, ZN6 and ZN9, which showed the most stunting and the lowest stomatal conductance and transpiration rates in a water-stressed environment (Chapter 7). Of all the varieties that were tested, NCo376 was found to be the most tolerant to water-deficit stress as its plants developed elongated stems and high stomatal conductance and transpiration rates in water-stressed conditions (Chapter 7). Varieties ZN1, N14, ZN8 and ZN10 were also tolerant to water-deficit stress as they showed higher stem elongation and water conservation with increased total plant dry matter than the rest of the other varieties tested. Therefore, sugarcane varieties that can be grown by cane farmers in the South Eastern Lowveld of Zimbabwe when faced with drought are NCo376, ZN1, ZN8, ZN10 and N14.

8.4 Conclusions

This study was the first of its kind to develop a container protocol that minimizes the stress associated with growing sugarcane plants in containers. This information will help those who would want to do sugarcane research using rapid and cost-effective methods, such as containerised production. The study also showed that it was possible to screen varieties for their tolerance to water-deficit stress using containers. The following conclusions were derived from the study:

- High water application rates (≥2.5 L per container per day) increased vegetative growth of sugarcane (stem height, tiller numbers and dry matter) in all soil-less mediabut led to reduced germination of cane setts and root dry matter in the ZSAES soil medium.
- Growing plants in filter cake + pine bark and filter cake only could become suitable growth media for sugarcane if adequate nutrients are applied.
- The application of 937.5mg/l Triple 16 Blend fertiliser, fortnightly until 56 DAP resulted in nutritional adequacy in all four media tested.
- Use of filter cake + pine bark in large containers resulted in thicker and taller stems with increased total plant dry matter when compared to other treatments.
- Varieties ZN1, N14, ZN8 and ZN10, and NCo376 had tolerance to water-deficit stress than other genotypes tested.

8.5 Recommendations for future research

This study has revealed several information gaps that need to be turned into opportunities for further research. The following is a list of such information gap-based research opportunities.

- Determination of water and fertiliser application rates, medium and container size for sugarcane plants grown in containers with minimal stress needs to be done in a single experiment since these factors interact closely with each other.
- The screening of genotypes in containers should include the use of molecular fingerprinting techniques such as x, y and z to increase precision in identifying drought tolerant varieties.
- There is need to include all released and unreleased genotypes at the Zimbabwe Sugar Association Experiment Station (ZSAES) in the screening of varieties to identify tolerant varieties for use in future breeding programs.

REFERENCES

Abdel-Rahman EM and Ahmed FB (2008) The application of remote sensing techniques to sugarcane (*Saccharum spp*. hybrid) production: a review of the literature. International Journal of Remote Sensing 29 (13): 3753-3767.

Abid M, Ali S, Qi LK, Zahoor R, Tian Z, and Jiang D (2018) Physiological and biochemical changes duringdrought and recovery periods at tillering and jointing stages in wheat (*Triticum aestivum* L.). Scientific Reports8:4615.

Afghan S, Ghous G, Ali K, Hussain K, Hasnain Z and Mushtaq MS (2004) Impact of blended vs straight fertiliser on growth, yield and quality of sugarcane. Sugar Cane International 22: 10-13.

Aguilera C, Stirling CM and Long SP (1999) Genotypes variation within Zea mays for susceptibility to and rate of recovery from chill-induced photoinhibition of photosynthesis. Physiologia plantarum106:429-436.

Ahmad I, Larher F and Steward GR (1979) Sorbitol, A compatible osmotic solute in *Plantago maritime*. New Phytologist 82: 671-678.

Alam MN, Nath UK, Karim K, Ahmed MM and Mitul RY (2017) Genetic Variability of Exotic Sugarcane Genotypes. Scientifica 2017: 5202913.

Al-Debei H and Mugnai S (2011) Starch accumulation in the leaves of root-restricted pepper affects plant growth by a feedback-inhibition of the photosynthesis. Advances in Horticultural Science 25(4): 253-259.

Al-Shammary AAG, Kouzani AZ, Kkaynak A, Khoo SY, Norton M and Gates W (2018) Soil Bulk Density Estimation Methods: A Review. Pedosphere 28(4): 581–596.

Altland JE, Locke JC, and Krause CR (2014) Influence of Pine Bark Particle Size and pH on Cation Exchange Capacity. HortTechnology 24 (5): 554-559.

Argo WR (1998a) Root medium chemical properties. HortTechnology 8: 486-494

Argo WR (1998b) Root medium physical properties. HortTechnology 8: 481-495

Ashraf M and Fooland MR (2007) Roles of glycine betaine and proline in improving plant abiotic stress resistance. Environmental and Experimental Botany 59: 206-216.

Assuero SG and Tognetti JA (2010) Tillering regulation by endogenous and environmental factors and its agricultural management. The Americas Journal of Plant Science and Biotechnology 4: 35–48.

Avellaneda MC, Hoy JW and Pontif MJ (2015) Screening for resistance to sugarcane brown rust with controlled-conditions inoculation. PlantDisease 99:1633-1639.

Azevedo-Neto AD, Prisco JT, Enéas-Filho J, Lacerda CF, Silva JV, Costa PHA and Gomes-Filho E. (2004) Effects of salt stress on plant growth, stomatal response and solute accumulation of different maize genotypes. Brazilian Journal of Plant Physiology16: 31-38.

Bailey D, Bilderback T and Bir D (1999) Water considerations for container production of plants. NC State University Department of Horticultural Science Horticulture Information Leaflet 557. Pp 11.

Barrett GE, Alexandera PD, Robinsonb JS and Braggc NC (2016)Achieving environmentally sustainable growing media for soil less plant cultivation systems – A review. Scientia Horticulturae 212: 220-234.

Barrow NJ (2016) The effects of pH on phosphate uptake from the soil. Plant and Soil 410: 401- 410.

Basnayake J, Jackson PA, Inman-Bamber NG and Lakshmanan P (2012) Sugarcane for water-limited environments. Genetic variation in cane yield and sugar content in response to water stress.Journal of Experimental Botany 63 (2): 695- 709.

Basserau D (1988) Sugarcane. In: Plant Analysis as a Guide to the Nutrient Requirements of Temperate and Tropical Crops. Martin-Prevel P, Gagnard J and Gautier P (Editors). Lavoisier Publishing Inc., New York. pp 513-525.

Bauerle WL, Post CJ, McLeod MF, Dudley JB, and Toler JE (2002) Measurement and modeling of the transpiration of a temperate red maple container nursery. Agricultural and Forest Meteorology114:45- 57.

Begcy K, Mariano ED, Gentile A, Lembke CG, Zingaretti SM, Souza GM and Menossi M (2012) A novel stress-induced sugarcane gene confers tolerance to drought, salt and oxidative stress in transgenic tobacco plants. PLoS One 7:e44697.

Bell MJ, Garside AL and Magarey RC (2000) Effect of breaks on sugarcane growth: Relations between glasshouse and field studies. Proceedings of the Australian Society of Sugar Cane Technologists22: 68- 76.

Benebere P, Asante F and Appiah DO (2017) Hindrances to adaptation to water insecurity under climate variability in peri-urban Ghana. Cogent Social Sciences 3:1.

Bertora C, Alluvione F, Zavattaro L, van Groenigen JW, Velthof G, Grignani C (2008) Pig slurry treatment modifies slurry composition, N_2O, and CO_2 emissions after soil incorporation. Soil Biology and Biochemistry 40: 1999- 2006.

Bilderback TE (2002) Water management is key in reducing nutrient runoff from container nurseries. HortTechnology 12:541- 544.

Bilderback TE, Owen JS, Warren SL, and Albano JP (2007) Non-organic amendments can extend media life: with limited breakdown, they are good additions to bark and peat. Nursery Management and Production. pp 37- 42.

Blum A (2005) Drought resistance, water-use efficiency, and yield potential—are they compatible, dissonant, or mutually exclusive? Crop and Pasture Science56: 1159- 1168.

Bollen WB (1969) Properties of tree barks in relation to their agricultural utilization. USDA Forest Service research. Paper PNW 77.

Bonnett GD, Hewitt ML and Glassop D (2006) Effects of high temperature on the growth and composition of sugarcane internodes. Australian journal of agricultural research57(10): 1087-1095.

Boodley JW and Sheldrake R Jr (1977) Cornell peat-lite mixes for commercial plant growing. Cornell Information Bulletin Number 43. pp 17.

Bray RH and Kurtz LT (1945). Determination of total, organic, and available forms of phosphorus in soils. Soil science 59: 39-45.

Broschat TK (2005) Rates of ammonium nitrogen, nitrate nitrogen, phosphorus, and potassium from two controlled release fertilisers under different substrate environments. HortTechnology 15:332- 335.

Brown D, Chanakira R, Chatiza K, Dhliwayo M, Dodman D, Masiiwa M, Muchadenyika D, Mugabe P, and Zvigadza S (2012).Climate change impacts, vulnerability and adaptation in Zimbabwe. IIED Climate Change Working Paper No. 3, October 2012.

Buamscha MG, Altland JE, Sullivan DM, Horneck DA and Cassidy J (2007) Chemical and Physical Properties of Douglas Fir Bark Relevant to the Production of Container Plants. HortScience 42 (5): 1281-1286.

Buckley TN (2005) The control of stomata by water balance. New Phytologist168 (2): 275-292.

Cabrera RI (2003) Nitrogen balance for two container-grown woody ornamental plants. Scientia Horticulturae97:297-308.

Calcino DV, Kingston G, and Haysom MBC (2000) Nutrition of the plant. In: Manual of Cane Growing. Hogarth DM and Allsopp PG (Editors.). Bureau of Sugar Experiment Stations, Indooroopilly. pp 153-193.

Cantliffe DJ (1993) Pre- and postharvest practices for improved vegetable transplant quality. HortTechnology 3: 415-417.

Calheiros A S, Oliveira MW, Ferreira VM, Barbosa GVS, Costa JPV, Lima GSA and Aristides EVS (2011). Acúmulo de nutrientes e produção de sacarose de duas variedades de cana-de-açúcar na primeira rebrota, em função de doses de fósforo. STAB. Açúcar, Álcool and Subprodutos, 29(1): 26-29.

Carlile WR and Coules A (2009) International Symposium on growing media. Acta horticulturae 819.

Carlson LW and Endean F (1976) The effect of rooting volume and container configuration on the early growth of white spruce seedlings. Canadian Journal of Forest research 6(2): 221-224.

Castro-Nava,Huerta AJ, Cruz JMP,1 and Mireles-Rodríguez E (2016) Leaf Growth and canopy development of three sugarcane genotypes under high temperature rainfed conditions in northeastern Mexico. International Journal of Agronomy 2016.

Centritto M, Lauteri M, Monteverdi MC andSerraj R (2009) Leaf gas exchange, carbon isotope discrimination, and grain yield in contrasting rice genotypes subjected to water-deficits during the reproductive stage. Journal of experimental botany60: 2325-2339.

Chandiposha M (2013). Potential impact of climate change in sugarcane and mitigation strategies in Zimbabwe. African Journal of Agricultural Research 8(23): 2814-2818.

Chandiposha M, Kunedzimwe N, Munyaradzi G and Chiriman'ombe D (2014) Comparisons of sugar blend 1 plus fertiliser over straight fertiliser as basal application on growth and yield of sugarcane (*Saccharum officinarum* L). International Journal of Agronomy and Agricultural Research 4 (4): 89-93.

Cha-um S and Kirdmanee C (2009) Effect of osmotic stress on proline accumulation, photosynthetic abilities and growth of sugarcane plantlets (*Saccharum officinarum* L.). Pakistan Journal of Botany 40:2541-2552.

Chaves MM, Flexas J and Pinheiro C (2009) Photosynthesis under drought and salt stress: regulation mechanism from whole plant to cell. Annals of Biological Research 103: 551-560.

Chidoko C and Chimwai L (2011) Economic challenges of sugarcane production in the Lowveld of Zimbabwe. International Journal of Economics and Research 2(5): 1-13.

Choudhary M, Bailey D and Grant CA (1995) Review of the use of swine manure in crop production: Effects on yield and composition and on soil and water quality. Waste Management and Research 14: 581- 595.

Clowes MJ and Breakwell WL (1998) Zimbabwe Sugarcane Production Manual. Zimbabwe Sugar Association, Chiredzi, Zimbabwe.

Colom MR and Vazzana C (2003) Photosynthesis and PSII functionality of drought-resistant and drought sensitive weeping love grass plants. Environmental and Experimental Botany49:135-144.

Comin JJ, Loss A, Da Veiga M, Guardini R, Schmitt DE, Oliveira PAV, Filho PB, Couto RR, Benedet L and Múller Júnior VM (2013) Physical properties and organic carbon content of a Typic Hapludult soil fertilized with pig slurry and pig litter in a no-tillage system. Soil research51: 459- 470.

Costa ARFC, Rolim MM, Bonfim-Silva EM, Neto DES, Pedrosa ERM and Silva EFF (2016) Accumulation of nitrogen, phosphorus and potassium in sugarcane cultivated under different types of water management and doses of nitrogen. Australian Journal of Crop Science 10(3): 362-369.

da Silva VSG, Oliveira MW, Ferreira VM, Oliveira TBA and Galvão ER (2018) Nutritional Requirement of Sugarcane Cultivars. Journal of Agricultural Science 10 (4): 361- 369.

de CastroREN, de AlvesRM, do Nascimento CAO,and Giudici R (2019) Assessment of sugarcane-basedethanol production. In Fuel Ethanol Production from Sugarcane; Peixoto Basso T and Carlos Basso L Eds. IntechOpen. London, United Kingdom.

de Oliveira MW, Macêdo GAR, Martins JA, da Silva VSG and de Oliveira AB (2017) Mineral nutrition and fertilization of sugarcane. In Sugarcane-Technology and Research. IntechOpen. Rijeka, Croatia.

Derderian MD (1961)Determination of Calcium and Magnesium in Plant Material with EDTA. Analytical Chemistry 33(12): 1796-1798.

Dimkpa CO and Bindraban PS (2016). Fortification of micronutrients for efficient agronomic production: a review. Agronomy for Sustainable Development36:7.

Dinh TH, Watanabe K, Takaragawa H, Nakabaru Mand Kawamitsu Y (2017) Photosynthetic response and nitrogen use efficiency of sugarcaneunder drought stress conditions with different nitrogen application levels. Plant Production Science 20(4): 412-422.

Drzal MS, Fonteno WC and Cassel DK (1999) Pore fraction analysis: A new tool for substrate testing. Acta horticulturae481: 43-54.

Du CW, Zhou JM and Shaviv A (2006) Release characteristics of nutrients from polymer-coated compound controlled-release fertilisers. Journal of Polymers and the Environment14:223–230.

Duble RL (2004) Turf grasses: Their management and use in the Southern zone (2nd ed.). Texes A and M University press, USA. Pp 323.

Endres L, Silva JV, Ferriera VM and Barbosa GV (2010) Photosynthesis and water relations in Brazilian sugarcane. The Open Agriculture Journal 4: 31-37.

Etesami1 H, Emami S and Alikhani HA (2017) Potassium solubilizing bacteria (KSB): Mechanisms, promotion of plant growth, and future prospects - A review. Journal of Soil Science and Plant Nutrition 17: 897- 911.

Fang CM, Smith P and Monorieff JB (2005) Similar response of cabile and resistant soil organic matter pools to changes in temperature. Nature 436:881- 883.

Ferreira THS, Tsunada MS, Bassi D, Araújo P, Mattiello L, Guidelli GV, Righetto GL, Gonçalves VR, Lakshmanan P and Menossi M (2017) Sugarcane Water Stress Tolerance Mechanisms and Its Implications on Developing Biotechnology Solutions. Frontiers in Plant Science 8: 1077.

Freire F, Almeida E, Betânia M, Galvão M, de Oliveira R and Campelo A (2010) Growth indices of eleven sugarcane varieties grown under full irrigation environments in Brazil. World Congress of Soil Science, Soil Solutions for a Changing World. 1 –6 August 2010, Brisbane, Australia.

Freitas AS, Silva ARA, Bezerra FML, Ferreira CS and Andrade RR (2012) Vegetative growth of sugar cane (*Saccharum officinarum* L.) irrigated with water from treated domestic sewage. Conexões Ciência e Tecnologia. 6(1): 27-43.

Galmés J, Ribas-Carbó M, Medrano H and Flexas J (2011) Rubisco activity in Mediterranean species is regulated by the chloroplastic CO_2 concentration under water stress. Journal of Experimental Botany 62: 653-665.

Gascho GJ and Shih SF (1983) Sugarcane. In: Teare IDand Peet MM (eds), Crop Water Relations.John Wiley & Sons, New York. Pp 445-479.

Geissen V, Wang S, Oostindie K. Huerta E, Zwart KB, Smit A, Ritsema CJ, Moore D (2013) Effects of topsoil removal as a nature management technique on soil functions Catena 101: 50 -55.

Ghannoum O (2009) C_4 photosynthesis and water stress. Annals of Botany 103 (4): 635- 644.

Gomathi R and Rakkiyapan P (2011) Comparative lipid peroxidation, leaf membrane thermostability and antioxidant system in four sugarcane genotypes differing in salt tolerance. Plant Physiology and Biochemistry 3: 67- 74.

Gonçalves ER, Ferreira VM, Silva JV, Endres L, Barbosa TP and Duarte WG (2010) de. Trocas gasosas e fluorescência da clorofila a em variedades de cana de açúcar submetidas á deficiência hídrica. Revista Brasileira de Engenharia Agrícola e Ambiental, Campina Grande 14(4): 378-386.

Graça JP, Godrigues FA, Farias JRB, Oliveira MCN, Hoffmann-Campo CB and Zingaretti SM (2010) Physiological parameters in sugarcane cultivars submitted to water-deficit. Brazilian Journal of Plant Physiology 22:189-197.

Grisham MP, Johnson RM and Richard EP (2006) Effect of soil properties on sugarcane brown rust incidence and severity and associated yield loss. Phytopathology. 96: 543.

Gwenzi R (2018) Ethanol saves Zimbabwe $26,5 million. Equity axis.

Hanan JJ (1998) Greenhouses: Advanced technology for protected horticulture. CRC Press, Boca Raton, FL.

Handreck K and Black N (2002) Growing media for ornamental plants and turf. 3rd ed. UNSW Press, Sydney, Australia.

Haworth M, Killi D, Materassi A, Raschi A and Centritto M (2016) Impaired stomatal control is associated with reduced photosynthetic physiology in crop species grown at elevated [CO_2]. Frontiers in Plant Science7:1568.

Haynes JR and Naidu R (1998) Influence of lime, fertiliser and manure applications on soil organic matter content and soil physical conditions: a review. Nutrient Cycling in Agroecosystems 5: 1123- 1137.

Hemaprabha G, Nagarajan R and Alarmelu S (2004) Response of sugarcane genotypes to water-deficit stress. Sugar Tech 6: 165-168.

Himmel ME, Ding, SY, Johnson, DK, Adney WS, Nimlos MR, Brady JW and Foust TD (2007) Biomass recalcitrance engineering plants and enzymes for biofuels production. Science 315: 804-807.

Hoagland DR and Arnon DI (1950) The water-culture method for growing plants without soil. Berkeley, Calif.: University of California, College of Agriculture, Agricultural Experiment Station.

Hsiao TC (1973). Plant responses to water stress. Annual Review of Plant Physiology 24: 519-570.

Huett DO, and Gogel BJ (2000) Longevities and nitrogen, phosphorus, and potassium release patterns of polymer-coated controlled-release fertilisers at 30 ^{o}C and 40 ^{o}C. Communications in Soil science and Plant analysis31:959-973.

Ilkaee MN, Shomeili M, Banitorfizadeh M, Mirshekarnejad B, Golzardi F, Ashrafi SKH and Baghdadi A (2016) Study the affiliation of SPAD and leaf nitrogen with total chlorophyll in Sugarcane. International Journal of Advanced Life Sciences 9 (1) 19-23.

Ingram DL, Henley RW and Yeager TH (1993) Growth media for container grown ornamental plants. Bulletin 241, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

Inman-Bamber NG (2004) Sugarcane water stress criteria for irrigation and drying off. Field Crops Research 89: 107-122.

Inman-Bamber N, Bonnett G, Spillman M, Hewitt M and Jackson J (2008). Increasing sucrose accumulation in sugarcane by manipulating leaf extension and photosynthesis with irrigation. Australian Journal of Agricultural Research59: 13-26.

Inman-Bamber NG and De Jager JM (1988) Effect of water stress on sugarcane stalk and quality. Proceedings of the South African Sugar Technologists' Association. Pp 140- 144.

Inman-Bamber NG and Smith MD (2005) Water relations in sugarcane and response to water-deficits. Field Crops Research92: 185- 202.

Inman-Bamber NG, Lakshmanan P and Park S (2012) Sugarcane for water-limited environments: Theoretical assessment of suitable traits. Field Crops Research 134: 95-104.

Insausti P, Grimoldi AA, Chaneton EJ and Vasellati V (2001) Flooding induces a suite of adaptive plastic responses in the grass Paspalum dilatatum. New Phytologist 152: 291-299.

IPCC (2007) Fourth Assessment Report. Intergovernmental Panel on Climate Change Secretariat. Geneva, Switzerland.

Iskandar HM, Casu RE, Fletcher AT, Schmidt S, Xu J, Maclean DJ, Manners JM and Bonnett GD (2011) Identification of drought-response genes and a study of their expression during sucrose accumulation and water-deficit in sugarcane culms. BMC Plant Biology 11: 12.

Jaleel CA, Manivannan P, Wahid A, Farooq M, Somasundaram R and Panneerselvam R (2009) Drought stress in plants: A review on morphological characteristics and pigments composition. International Journal of Agriculture and Biology 11: 100- 105.

Jangpromma N, Songsri P, Thammasirirak S and Jaisil P (2010) Rapid assessment of chlorophyll content in sugarcane using a SPAD chlorophyll meter across different water stress conditions. Asian Journal of Plant Sciences 9: 368- 374.

Jones BJ (2016) A practical guide for the soil less grower Second edition. CRC press. Pp 20.

Jones HG (2004) Application of thermal imaging and infrared sensing in plant physiology and ecophysiology. Advances in Botanical Research 41:107- 163.

Kang SA, Noor M, Khan FA and Saeed F (2013) Divergence analysis and association of some economical characters of sugarcane (*Sacchurum officinarum* L) Journal of Plant Breeding and Genetics 1: 1-6.

Kapur R, Duttamajumder SK, Krishna RK (2011) A breeder's perspective on the tiller dynamics in sugarcane. Current Science 100(2): 183- 189

Kavi Kishor PB, Sangam S, Amrutha RN, Sri Laxmi P, Naidu KR, Rao KRSS, Sreenath Rao Reddy KJ, Theriappan P, Sreenivasulu N (2005) Regulation of proline biosynthesis, degradation, uptake and transport in higher plants: its implications in plant growth and abiotic stress tolerance. Current Science 88:424- 438.

Kawaletz H, Mölder I, Annighöfer P, Terwei A, Zerbe S and Ammer C (2014) Pot experiments with woody species – a review, Forestry: An International Journal of Forest Research 87 (4):482-491.

Kariniki RK and Sahoo SN (2019) Use of meteorological data for identification of drought. ISH Journal of Hydraulic Engineering 2019:1–7.

Khaled KA, El-Arabi NI, Sabrey NM, El-Shrbing S (2018) Sugarcane genotypes assessment under drought conditions using amplified fragment length polymorphism. Biotechnology 17(3): 120- 127.

Khan MA and Ungar IA (1984) The effect of salinity and temperature on the germination of polymorphic seeds and growth of *Atriplex triangularis* Willd. American Journal of Botany 71: 481- 489.

King LD, Westerman PW, Cummings GA, Overcash MR and Burns JC (1985) Swinelagoon effluent applied to ‘costal’ bermudagrass: II. Effects on soil. Journal of Environmental Quality 14: 14-21.

Kingston G (2014) Mineral nutrition of sugarcane. In Sugarcane: Physiology, Biochemistry, and Functional Biology (editors Mooreand P H and Botha FC). John Wiley and Sons. Oxford. Pp 85-120.

Knox JW, Díaz, JAR., Nixon DJ and Mkhwanazi M (2010) A preliminary assessment of climate change impacts on sugarcane in Swaziland. Agricultural Systems 103: 63-72.

Kohout P, Sykorova Z, Bahram M, Hadincová V, Albrechtová J, Tedersoo L and Vohník M (2011) Ericaceous dwarf shrubs affect ectomycorrhizal fungal community of the invasive *Pinus strobus* and native *Pinus sylvestris* in a pot experiment. Mycorrhiza 21: 403- 412.

Kooyers NJ (2015). The evolution of drought escape and avoidance in natural herbaceous populations. Plant Science 234: 155-162.

Korndörfer GH and Anderson DL (1997) Use and impact of sugar alcohol residues vinasse and filter on sugarcane production in Brazil. Sugar y Azucar 92(3): 26-35.

Kowalski Z, Makara A and Fijorek K (2013) Changes in the properties of pig manure slurry. Acta Biochimica Polonica 60(4): 845-850.

Kozlowski TT and Pallardy SG (1984). Effects of flooding on water, carbohydrate and mineral relations. In Flooding and plant growth. T T Kozlowski (ed). Academic Press Inc., Orlando, Florida , pp. 165-193.

Krizek DT, Carmi A, Mirecki RM, Snyder FW and Bunce JA (1985) Comparative effects of soil moisture stress and restricted root zone volume on morphogenetic and physiological responses of soybean (*Glycine max* (L.) Merr.). Journal of Experimental Botany 36: 25-38.

Ku CSM and Hershey DR (1997). Growth response, nutrient leaching and mass balance for potted poinsettia I. Nitrogen. Journal of the American Society for Horticultural Science122:452-458.

Kwong KF (2002). The effects of potassium on growth, development, yield and quality of sugarcane. In: Pasricha, Bansal (Ed.), Potassium for Sustainable Crop Production, Proceedings of the International Symposium on the Role of Potassium in Nutrient Management for Sustainable Crop Production in India. Potash Research Institute of India (PRII) and International Potash Institute (IPI), Horgen, Switzerland. pp430-444.

Kwong RNGK (2005) Status of sugar industry in Mauritius: Constraints and future research strategies. Sugar Tech 7(1): 5-10.

Landis TD, Luna T and DumroeseRK (2014) Containers. In:Tropical nursery manual Wilkinson KM, Landis TD, Hasse DL, Daley BF, and Dumroese RK (Editors). Washington, DC, United States of America. pp 123- 139.

Laser M, Schulman D, Allen SG, Lichwa J, Antal MJ and Lynd LR (2002) A comparison of liquid hot water and steam pretreatments of sugar cane bagasse for conversion to ethanol. Bioresource technology 81:33-44.

Lawlor DW (2002) Carbon and nitrogen assimilation in relation to yield: mechanisms are the key to understanding production systems. Journal of Experimental Botany 53(370):773–787.

Lawlor DW and Tezara W. (2009) Causes of decreased photosynthetic rate and metabolic capacity in water-deficient leaf cells: a critical evaluation of mechanisms and integration of processes. Annals of botany 103: 561-579.

Lea-Cox, JD and Ross DS (2001). A review of the Federal Clean Water Act and the Maryland Water Quality Improvement Act: The rationale for developing a water and nutrient management planning process for container nursery and greenhouse operations. Journal of Environmental of Horticulture 19:226-229.

Leite JM, Ciampitti IA, Mariano E, Vieira-Megda MX and Trivelin PCO (2016) Nutrient partitioning and stoichiometry in unburnt sugarcane ratoon at varying yield levels. Frontiers in Plant Science 7: 1-14.

Lemaire G and Chapman D (1996) Tissue flows in grazed plant communities. In Hodgsun J and Illins AW (Eds) The ecology and management of grazing systems. CAB International Wallingford, UK. Pp 3-37.

Lemoine R, Camera SL, Atanassova R, De´dalde´champ F, Allario T, Pourtau N, Bonnemain JL, Laloi M, Coutos-The´venot P, Maurousset L, Faucher M, Girousse C, Lemonnier P, Parrilla J and Durand M (2013) Source-to-sink transport of sugar and regulation by environmental factors. Frontiers in Plant Science 4:272

Lens P, Hamelers B, Hoitink H and Bidlingmaier W (2004) Resource recovery and reuse in organic solid waste management. IWA Publishing. pp 249-261.

Liberato MAR, Gonçalves JFC, Chevreuil LR, Nina Junior AR, Fernandes AV and Santos JUM. (2006) Leaf water potential, gas exchange and Chlorophyll a fluorescence in acariquara seedlings (*Minquartia guianensis* Aubl.) under water stress and recovery. Brazilian Journal of Plant Physiology 18:315-323.

Lima-Melo Y, Alencar VTCB, Lobo AKM, SousaRHV, Tikkanen M, AroEM, Silveira, JAG andGollan PJ (2019) Photoinhibition of Photosystem I provides oxidative protection during imbalanced photosyntheticelectron transport in *Arabidopsis thaliana*. Frontiers of Plant Science 10: 916.

Long SP, Humphries S and Falkowski PG (1994) Photoinhibition of photosynthesis in nature. Annual Review of Plant Physiology and Plant Molecular Biology 45:633-662.

Luna T, Landis TD and Dumroese RK. (2009) Containers. In: Nursery manual for native plants: A guide for tribal nurseries - Volume 1: Nursery management. Agriculture Handbook 730. Dumroese RK, Luna T, Landis TD (Editors). Washington, D.C.: U.S. Department of Agriculture, Forest Service. pp 99-111.

Machado R, Ribeiro R, Marchiori P, Machado D, Machado E, Landell M (2009) Biometric and physiological responses to water-deficit in sugarcane at different phenological stages. Pesqui Agropecu Bras 44: 1575- 1582.

Majsztrik JC, Ristvey AG and Lea-Cox JD (2011) Water and Nutrient Management in the Production of Container-Grown Ornamentals.Horticultural Reviews 38: 253-298.

Majsztrik JC, Fernandez RT, Fisher PR (2017) Water Use and Treatment in Container-Grown Specialty Crop Production: A Review. Water, Air and Soil Pollution 228: 151.

Malavolta E (1994) Nutrient and Fertiliser Management in Sugarcane. IPI Bulletin No. 14. International Potash Institute, Switzerland.

Manik SMN, Pengilley G, Dean G, Field B, Shabala S and Zhou M (2019) Soil and Crop Management Practices to Minimize the Impact of Waterlogging on Crop Productivity. Frontiers in Plant Science 10:140.

Marchiori PER, Ribeiro RV, da Silva L, Machado RS, Machado EC, Scarpari MS (2010) Plant growth, canopy photosynthesis, and light availability in three sugarcane varieties. Sugar Tech. 12: 160-166.

Marchiori PER, Machado EC, Sales CRG, Espinoza-Núñez E, Magalhães Filho JR, Souza GM and Ribeiro RV (2017) Physiological plasticity is important for maintaining sugarcane growth under water deficit. Frontiers in Plant Science 8: 2148.

Mariano E, Leite JM, Megda MXV, Ciampitti IA, Vitti AC and Faroni CE (2016) Biomass and nutrient content by sugarcane as affected by fertiliser nitrogen sources. Crop Science 56(3): 1234-1244.

Marin F R, Jones JW, Singels A, Royce F, Assad ED, Pellegrino GQ, and Justino F (2013) Climate change impacts on sugarcane attainable yield in Southern Brazil. Climatic Change 117(1-2): 227-239.

Martias AD and Musil S (2012) Temperature and thermal diffusivity within a range land soil near Oracle, Arizona. Journal of the Arizona–Nevada academy of science 44(1):15–21.

Matsuoka S and Stolf R (2012) Sugarcane tillering and ratooning: key factors for a profitable cropping. In Sugarcane: Production, Cultivation and Uses (eds Goncalves JF and Correia KD. Nova Science Publishers, Inc. Hauppauge, Newyork. Pp 137-157.

McCauley A, Jones C, Jacobsen J (2009) Commercial fertilisers and soil amendments. In: Nutrient Management Module No 10. Nutrient Manegement a self-study course from MSU Extension Continuing Education Series. Montana State University. Pp 20.

McConnaughay KDM and Bazzaz FA (1991) Is Physical Space a Soil Resource? Ecology 72(1): 94-103.

McCray JM, Rice RW, Ezenwa LW, Lang TA and Baucum L (2009) Sugarcane plant nutrient diagnosis. SS-AGR-128, University of Florida, IFAS Extension.

Mcfarlane SA, Meyer JH, Cadet P and Rutherford RS (2008) Investigation into the effect of nutrition on Brown rust development in sugarcane. Proceedings of The South African Sugar Technologists' Association 81: 388- 392.

McKeague JA (1978) Manual on soil sampling and methods of analysis. 2nd ed. Canada Soil Survey Committee, Ottawa.

Medeiros DB, Da Silva EC, Nogueira RJMC, Teixeira MM and Buckeridge MS (2013) Physiological limitations in two sugarcane varieties under water suppression and after recovering. Theoretical and Experimental Plant Physiology 25(3): 213-222.

Medina NH, Branco MLT, Guazzelli da Silveira MA, Santos RBB (2013) Dynamic distribution of potassium in sugarcane.Journal of Environmental Radioactivity 126: 172-175.

Merhaut DJ, Blythe EK, Newman JP, and Albano JP (2006) Nutrient release from controlled-release fertilisers in acid substrate in a greenhouse environment: I. Leachate electrical conductivity, pH, and nitrogen, phosphorus and potassium concentrations. HortScience 41:780-787.

Meunchang S, Panichsakpatana S, and Weaver RW (2005) Cocomposting of filter cake and bagasse; by-products froma sugar mill. Bioresource Technology 96 (4): 437-442.

Meyer JH, Wood RA, and du Preez P (1971) A nutrient survey of sugarcane in the South African industry with special reference to trace elements. Proceedings of South African Sugar Technologists' Association 45:196-203.

Meyer JH(2013) Sugarcane nutrition and fertilization. In: Meyer JH, Rein P, Turner P, Mathias K (Eds.), Good Management Practices for the Cane Sugar Industry. Verlag Dr. Albert Bartens KG, Berlin. pp 169- 218.

Miserquea O and Pirard E (2004) Segregation of the bulk blend fertilisers. Chemometrics and Intelligent Laboratory Systems 74: 215-224.

Mokhena TC, Mochane MJ, Motaung TE, Linganiso LZ, Thekisoe OM and Songca SP (2017) Sugarcane bagasse and cellulosepolymer composites. In: Sugarcane-technology and research. Intech Open.

Mollard FPO, Striker GG, Ploschuk EL and Insausti P (2010) Subtle topographical differences along a floodplain promote different plant strategies among *Paspalum dilatatum* subspecies and populations. Austral Ecology 35: 189- 196.

Mollard FPO, Striker GG, Ploschuk EL, Vega AS and Insausti P (2008) Flooding tolerance of *Paspalum dilatatum* (Poaceae: Paniceae) from upland and lowland positions in a natural grassland. Flora 203: 548-556.

Morris DR. and Tai PYP (2004) Water table effects on sugarcane root and shoot development. J. American Society of Sugar Cane Technologists 24: 41-59.

Mosaddeghi MR, Mahboubi AA, and Safadoust A (2009) Short-term effects of tillage and manure on some soil physical properties and maize root growth in a sandy loam soil in western Iran. Soil and Tillage Research 104: 173-179.

Muchovej RM, Newman PR Luo Y (2005) Sugarcane leaf nutrient concentrations: with or without midrib tissue. Journal of Plant Nutrition 28(7): 1271-1286.

Naidoo G and Mundree SG (1993). Relationship between morphological and physiological responses to waterlogging and salinity in *Sporobolus virginicus* (L.) Kunth. Oecologia 93: 360-366.

Nash MA and Pokorny FA (1990) Cation exchange capacity of two-component container media predicted from laboratory analysis of components. Communications in Soil Science and Plant Analysis 21:705- 715.

NeSmith DS and Duval RD (1998) The effect of container size. HortTechnology 8(4): 495-498.

Nkomboni D, Sisito G, van Rooyen A, Homann-Kee TS, Sikosana JLN and Ndlovu LR (2014) The potential for increasing cattle productivity in mixed farming systems of Zimbabwe. Livestock Research for Rural Development 26 (6).

Oliveira ECA, Freire JF, Oliveira AC, Neto DE, Rocha AT and Carvalho LA (2011) Produtividade, eficiência de uso da água e qualidade tecnológica de cana-deaçúcar submetida a diferentes regimes hídricos. Pesquisa Agropecuária Brasileira 46(6): 617-625.

O'Neill PM, Shanahan JF and Schepers JS (2006) Use of chlorophyll fluorescence assessments to differentiate corn hybrid response to variable water conditions. Crop Science 46:681-687.

Onwuka B and Mang B (2018) Effects of soil temperature on some soil properties and plant growth. Advances in Plants & Agriculture Research 8(1):34-37.

Oren R, Sperry JS, Katul GG (1999) Survey and synthesis of intraand interspecific variation in stomatal sensitivity to vapour pressure deficit. Plant, Cell and Environment 22: 1515- 1526.

Oregeron AJ (2012) Sugarcane growth, sucrose content and yield response to the ripeners Glyphosphate and Trinexapac-ethyl. Doctor of Philosophy Thesis, Louisiana State University.

Osakabe Y, Osakabe K, Shinozaki K and Tran LP (2014) Response of plants to water stress. Frontiers in Plant Science 5(86): 1- 5.

Owen JS, Warren SL, Bilderback TE, Cassel DK and Albano SP (2008) Physical Properties of Pine Bark Substrate Amended with Industrial Mineral Aggregate. Acta Horticulturae 779:131-138.

Owen JS and AltlandJE (2008) Container height and douglas fir bark texture affect substrate physical properties. HortScience 43: 505- 508.

Otto R, Franco HCJ, Faroni CE, Vitti AC and Trivelin PCO (2009) Sugarcane root and shoot phytomass related to nitrogen fertilization at planting. Pesquisa Agropecuaria Brasileira. 44(4): 398-405.

Paul MJ and Pellny TK (2003) Carbon metabolite feedback regulation of leaf photosynthesis and development. Journal of Experimental Botany 54:539- 547.

Pedro A, Eras JJC, Cabello E, Sagastume A, Hens L and Vandecasteeles C (2010) Residue from sugarcane juice filtration (filter cake): Energy use at the sugar factory. Waste Biomass 1: 407-413.

Persson JA, Wennerholm M and O’Halloran S (2008) Handbook for Kjeldahl Digestion, FOSS, Hilleroed, Denmark.

Peterson TA, Reinscl MD, and Krizek DT (1991). Tomato (*Lycopersicon esculentum* Mill. cv 'Better Bush') plant response to root restriction. Root respiration and ethylene generation. Journal of Experimental Botany 42:1241-1249.

Poorter H, Bühler J, Dusschoten D and Climent J (2012a) Pot size matters: a meta-analysis of the effects of rooting volume on plant growth. Functional Plant Biology 39: 839-850

Poorter H, Niklas KJ, Reich PB, Oleksyn J, Poot P, Mommer L (2012b) Biomass allocation to leaves, stems and roots: meta-analyses of interspecific variation and environmental control. Tansley Review. New Phytologist 193: 30-50.

Prado RM, Franco CF and Puga AP (2010) Macronutrient deficiencies in soybean cv. BRSMG 68 (Vencedora) cultivated in nutritive solution. Computer Science 1(2): 114-119.

Prado RD, Caione G, and Campos CNS (2013) Filter Cake and Vinasse as Fertilisers Contributing to Conservation Agriculture. Applied and Environmental Soil Science 2013: 1-8.

Prapaspongsa T (2010) Sustainable piggery waste management: a study based on examples and cases from Denmark and Thailand Section of Environmental Engineering. Philosophy of Doctorare Dissertation, Aalborg University.

Pedro A, Eras JJC, Cabello E, Sagastume A, Hens L and Vandecasteeles C (2010) Residue from sugarcane juice filtration (filter cake): Energy use at the sugar factory. Waste Biomass 1: 407-413.

Qing ZM, Jing LG and Kai CR (2001) Photosynthesis characteristics in eleven cultivars of sugarcane and their responses to water stress during the elongation stage. Proceedings of International Society of Sugar Cane Technologists 24:642-643.

Queiroz RJB, dos Santos DMM, Ferraudo AS, Carlin SD and Silva MA (2011) Biochemical and physiological responses of sugarcane cultivars to soil water deficiencies. Scientia Agricola 68: 469-476.

Queiroz RJB, Santos DMM, Carlin SD, Marin A, Banzatto DA and Cazetta JO (2008) Effects of osmoprotectors on sugarcane plants growing under different water-deficit levels. Científica 36:107-115.

Rachmilevitch S, Da Costa M and Huang B (2006). Physiological and Biochemical Indicators for Stress Tolerance. In Plant-Environment Interactions (3rd edition) Bingru Huang (Ed.). CRC Press, New York. Pp 321-355.

Ragel P, Raddatz N, Leidi EO, Quintero FJ and Pardo JM (2019) Regulation of K(+) nutrition in plants. Frontiers of Plant Science 10:281.

Rakkiyappan P, Thangavelu S and Bhagyalakshmi KV (2007) Uptake of nitrogen, phosphorus and potassium by some promising mid late maturing sugarcane clones. Sugar Tech 9: 23-27.

Ramesh P (2000) Effect of different levels of drought during the formative phase on growth parameters and its relationship with dry matter accumulation in sugarcane. Journal of Agronomy and Crop Science 185:83-89.

Ramesh P and Mahadevaswamy M (2000) Effect of formative phase drought on different classes of shoots, shoot mortality, cane attributes, yield and quality of four sugarcane cultivars. Journal of Agronomy and Crop Science 185: 249-258.

Raviv M and Lieth JH (2008) Soil less culture: Theory and practice. Elsevier BV, Newyork.

Raviv M, Wallach R, Siber A and Bar-Tal A (2002) Chapter 2: Substrates and their Analysis. In Savvas D and Passam H (Eds), Hydroponic Production of Vegetables and Ornamentals. Embryo Publications. Athens, Greece. Pp 25-101.

Ray JD and Sinclair TR (1998) The effect of pot size on growth and transpiration of maize and soybean during water-deficit stress. Journal of Experimental Botany 49(325): 1381- 1386.

Rayment GE and Higginson FR (1992) Australian Laboratory Handbook of Soil and Water Chemical Method. Reed International Books Australia P/L, Trading as Inkata Press, Port Melbourne. Pp 330.

Reed D (1996) Water, media and nutrition for greenhouse crops. Ball Publishing, Batavia, Illinois, United States of America.

Reyes JAO, Carpentero AS, Santos PJA andDelfin EF (2020) Effects of water regime, genotype, and formative stages on the agro-physiological response of sugarcane (*Saccharum officinarum* L.) to drought. Plants 9(5): 661.

Rhodes R, Rhodes N, Miles N, Miles J and Hughes C (2018) Interactions between potassium, calcium and magnesium in sugarcane grown on two contrasting soils in South Africa. Field Crops Research 223:1-11

Ribeiro KD, Menezes SM, Mesquita MGBF and Sampaio FMT (2007) Propriedades físicas do solo, influenciadas pela distribui¸cão de poros, de seis classes de solos da região de Lavras-MG. Ciência e Agrotecnologia 31: 1167- 1175.

Rich SM and Watt M (2013) Soil conditions and cereal root system architecture: review and considerations for linking Darwin and Weaver. Journal of Experimental Botany 64:1193- 1208.

Ridge R (2013) Fertilizing for High Yield and Quality: Sugarcane. IPI Bulletin No. 21. International Potash Institute, Australia.

Rigon JPG and Capuani S, Neto JFB and Beltrao (2013) Indirect measurements of photosynthetic pigments in the leaves of jatropha curcus. Semina: Ciencias Agrarias Londrina 34(2): 669-674.

Rippy JFM and PV Nelson PV (2007) Cation exchange capacity and base saturation variation among Alberta, Canada, moss peats. HortScience 42:349-352.

Ristvey AG, Lea-Cox JD, and Ross DS (2004) Nutrient uptake, partitioning and leaching losses from container-nursery production systems. Acta Horticulturae 630:321-328.

Robertson MJ, Inman-Bamber NG, Muchow RC and Wood AW (1999) Physiology and productivity of sugarcane with early and mid-season water deficit. Field Crops Research 64: 211- 227.

Rodrigues FA, Laia ML and Zingaretti SM (2009) Analysis of gene expression profiles under water stress in tolerant and sensitive sugarcane plants. Plant Science Journal 176: 286-302.

Ronchi CP, DaMatta FM, Batista KD, Moraes G, Loureiro ME and Ducatti C (2006) Growth and photosynthetic down-regulation in Coffea arabica in response to restricted root volume. Functional Plant Biology 33: 1013-1023.

Ross DS, and Lea-Cox JD (2004) Engineering review of container nursery facilities to implement water and nutrient management. 2004 ASAE/CSAE Annual Intl. Meeting. Ottawa, Ontario, Canada. Paper 04-402.

Rossler RL (2013) Water stress effects on the growth, development and yield of sugarcane. MSc Agric (Agronomy) thesis. University of Pretoria. South Africa.

Ramouthar PV (2009) Studies on Brown rust (Puccinia melanocephala) of sugarcane in South Africa. MSc (Pathology) thesis. University of KwaZulu-Natal, South Africa.

Sahin AW, Zanninia E, Coffey A and Arendtc EK (2019) Sugar reduction in bakery products: Current strategies and sourdough technology as a potential novel approach. Food research International 126.

Samui RP, John G and Kulkarni MB (2003) Impact of weather on yield of sugarcane at different growth stages. Journal of Agricultural Physics 3(1): 119-125.

Sánchez M and González JL (2005) The fertiliser value of pig slurry. I.Values depending on the type of operations. Bioresource technology 96:1117- 1123.

Santana MAE and Teixeira DE (1993) Uso do bagaço de cana-de-açúcar na confecção de chapas de aglomerados. In: Congresso Florestal Brasileiro, 7; Congresso Florestal Pan-americano, 1. Curitiba, São Paulo.

Santo LT, Nakahata MH and Ito GP (2000) Calcium and liming trials from 1994 to 1998 at HC&S. Technical Supplement to Agronomy Report 83. Hawaii Agriculture Research Center, Honolulu, Hawaii. pp. 1–20.

Santos F and Diola V (2015) Chapter 2 – Physiology. In: Sugarcane. Santos F, Borém A and Caldas C (Editors). Academic Press. San Diego, CA. Pp 13- 33.

Santos LC, Coelhoa RD, Barbosa FS, Leal DPV, Júnior EFF, Barros THS, Lizcano JV andRibeiroa NL (2019) Influence of deficit irrigation on accumulation and partitioning of sugarcane biomass under drip irrigation in commercial varieties. Agricultural Water Management 221: 322-333.

Sasidharan R and Voesenek LACJ (2015) Ethylene-Mediated Acclimations to Flooding Stress. Plant Physiology 169: 3-12.

SASRI (2013) Nutrition: 7.17 Guidelines for the interpretation of leaf analyses for sugarcane. South African Sugarcane Research Institute. Information sheet 7.17.

Saunder DH and Metelerkamp HR (1962). Use of an anion-exchange resin-for the determination of available soil phosphorus. Transactions of the International Congress of Soil Science. Pp 847-853.

Schnelle MA and Henderson JC (1991) Containers and media for the nursery. Oklahoma cooperative extension service. Extension facts. Oklahoma State University, Stillwater, OK.

Scoones I, Mavedzenge Band Murimbarimba F (2017) Sugar, People and Politics in Zimbabwe’s Lowveld. Journal of Southern African Studies 43 (3)567-584.

Shi K, Hu WH, Dong DK, Zhou YH and Yu JQ (2007) Low O_2 supply is involved in the poor growth in root-restricted plants of tomato (*Lycopersicon esculentum* Mill.). Environmental and Experimental Botany 61: 181-189.

Shiono K, Ogawa S, Yamazaki S, Isoda H, Fujimura T, Nakazono M and Colmer TD (2011) Contrasting dynamics of radial O2-loss barrier induction and aerenchyma formation in rice roots of two lengths. Annals of Botany: 107: 89- 99.

Shukla SK, Yadav RL, Singh PN and Singh I (2009) Potassium nutrition for improving stubble buds sprouting, dry matter partitioning, nutrient uptake and winter initiated sugarcane (*Saccharum spp*. Hybrid complex) ratoon yield. European Journal of Agronomy 30: 27-33.

Silva EC, Albuquerque MB, Azevedo Neto AD and Silva Junior CD (2013) Drought and its consequences to plants from individual to ecosystem. In Responses of organisms to water stress. Akıncı S (Editor). InTechOpen, Croatia. Pp17-47.

Silva MA, Da Silva JAG, Enciso J, Sharma V and Jifon J (2008) Yield components as indicators of drought tolerance of sugarcane. Scientia Agricola65:620-627.

Silva MA, Jifon JL, Sharma V, Da Silva JAG, Caputo MM and Damaj MB (2011) Use of physiological parameters in screening drought tolerance in sugarcane genotypes. Sugar Tech 13: 178-184.

Silva MA, Jifon JL, Silva JAG and Sharma V (2007) Use of physiological parameters as fast tools to screen for drought tolerance in sugarcane. Brazilian Journal of Plant Physiology 19(3):193-201.

Smit MA (2010) Characterising the factors that affectgermination and emergence in sugarcane. Proceedings of South African Sugar Technologists' Association(2010) 83: 230- 234.

Smith DM, Inman-Bamber, NG and Thornburn PJ (2005) Growth and function of the sugarcane root system. Field Crops Research 92: 163-189.

Spomer LA (1990) Evaluating drainage in container and other shallow-drained horticultural soils. Communications in Soil Science and Plant Analysis 21: 3-4.

Spomer LA, Berry WL, and Tibbitts TW (1997) Plant culture in solid media. In: Plant growth chamber handbook. Langham RW and Tibbitts TW (Editors). Iowa Agriculture and Home Economics Experiment Station Special Report 99.

Srivastava AK and Rai MK (2012) Review: Sugarcane production: impact of climate change and its mitigation. Biodiversitas 13: 214-227.

Steel RGD and Torrie JH (1984) Principles and Procedures of Statistics: A Biometrical Approach. McGraw Hill Book Co., New York.

Striker GG, Insausti P, Grimoldi AA, Ploschuk EL and Vasellati V (2005). Physiological and anatomical basis of differential tolerance to soil flooding of *Lotus corniculatus* L.and *Lotus glaber* Mill. Plant and Soil 276: 301-311.

Taherzadeh MJ and Karimi K (2008) Pretreatment of lignocellulosic wastes to improve ethanol and biogas production: a review. International Journal of Molecular Sciences9: 1621-1651.

Taiz L and Zeiger E (2006) Plant Physiology. 4th ed. Sinauer Associates, Inc. Publishers, Massachusetts.

Taiz L, Zeiger E, Moller IM and Murphy A (2017) Fisiologia e desenvolvimento vegetal 6th ed. Porto Alegre. pp 888.

Tamang BG and Fukao T (2015). Plant adaptation to multiple stresses during submergence and following de submergence. International Journal of Molecular Sciences 16: 30164-30180.

Torres N A, Campostrini E, Oliveira JG and Bressan-Smith RE (2005) Photosynthetic pigments, nitrogen, chlorophyll a fluorescence and SPAD-502 readings in coffee leaves. Scientia Horticulturae104: 199-209.

Trenberth KE (2007) The impact of climate change and variability on heavy precipitation, floods, and droughts.Encyclopedia of Hydrological Sciences. John Wiley and Sons, Ltd.

Trentin R, Zolnier S, Ribeiro S and Neto AJ (2011) Transpiração e temperature foliar da cana-de-açúcar sob diferentes valores de potencial matricial. Engenharia Agrícola. Jaboticabal 31(6): 1085-1095.

Tucker MR (1995) Chemical characteristics for pine bark. Media notes for North Carolina growers. North Carolina Department of Agriculture and Consumer Services. United States of America.

Turner NC (1981) Techniques and experimental approaches for the measurement of plant water status. Plant and Soil 58:339-366.

UNFCCC (2007) Climate change: Impacts, Vulnerabilities and Adaptation in Developing countries. UNFCCC Secretariat. Bonn, Germany.

USDA (2012) The report focuses on the production and usage of sugar in Zimbabwe. USDA Foreign Agricultural Service, United States of America.

USDA (2016) Zimbabwe Sugar Annual: The supply and demand for sugar in Zimbabwe. USDA Foreign Agricultural Service, United States of America.

Usherwood NR and Segars WI (2001) Nitrogen Interactions with Phosphorus and Potassium for Optimum Crop Yield, Nitrogen Use Effectiveness, and Environmental Stewardship. The Scientific World 1: 57-60.

van Heerden PDR, Donaldson RA, Watt DA and Singels A (2010) Biomass accumulation in sugarcane: unravelling the factors underpinning reduced growth phenomena. Journal of Experimental Botany 61(11): 2877- 2887.

Vasantha S, Alarmelu S, Hemaprabha G and Shanthi RM (2005). Evaluation of promising sugarcane genotypes for drought. Sugar Tech 7: 82-83.

Vuyyuru M 1, Sandhu HS, McCray MJ, Raid RN and Erickson JE (2019) Effects of Nitrogen Fertilization and Seed Piece Applied Fungicides on Establishment, Tiller Dynamics, and Sucrose Yields in Successively Planted Sugarcane. Agronomy 9(7): 387.

Wang Y, Uchida Y, Shimomura Y, Akiyama H, and Hayatsu M (2017) Responses of denitrifying bacterial communities to short-term waterlogging of soils. Scientific Reports 7(1): 803.

Whitfield CP, Davison AW and Ashenden TW (1996) Interactive effects of ozone and soil volume on Plantago major. New Phytologist 134: 287-294.

Wiedenfeld RP (1995) Effects of irrigation and N fertiliser application on sugarcane yield and quality. Field Crops Research 43: 101- 108.

Wiedenfeld B and Enciso J (2008) Sugarcane Responses to Irrigation and Nitrogen in Semiarid South Texas. Agronomy Journal 100 (3):665- 671.

Wolfe DW, Henderson DW, Hsaio TC and Alvino A (1988) Interactive water and nitrogen effects on senescence of maize: II. Photosynthetic decline and longevity of individual leaves. Agronomy Journal 80:865-870.

Wood RA (1990) The roles of nitrogen, phosphorus and potassium in the production of sugarcane in South Africa. Fertiliser Research 26:89-98.

Wright RD and Niemiera AX (1987) Nutrition of container-grown woody nursery crops. Horticultural reviews 9:75-101.

Xu Z, Zhou G and Shimizu H (2010) Plant responses to drought and rewatering. Plant Signaling and Behavior. 5(6):649- 654.

Yan JQ, Zhu J, He CX, Benmoussa M and Wu P (1998) Quantitative trait loci analysis for the developmental behavior of tiller number in rice (Oryza sativa. Theoratical and Applied genetics 97: 267- 274.

Yang TY, Zhu LN, Wang SP, Gu WJ, Huang DF, Xu WP, Jiang AL and Li SC (2007) Nitrate uptake kinetics of grapevine under root restriction. Scientia Horticulturae 111: 358-364.

Yang Z, Hammer G, Oosterom E, Rochais D and Deifel K (2010) Effects of Pot Size on Growth of Maize and Sorghum Plants. Proceedings of the 1st Australian Summer Grains Conference, Gold Coast, Australia, 21st - 24th June 2010.

Yamauchi T, Watanabe K, Fukazawa A, Mori H, Abe F, and Kawaguchi K (2014) Ethylene and reactive oxygen species are involved in root aerenchyma formation and adaptation of wheat seedlings to oxygen-deficient conditions. Journal of experimental botany 65: 261-273.

Yordanov I, Velikova V and Tsonev T (2000) Plant responses to drought, acclimation, and stress tolerance. Photosynthetica. 38: 171-186.

Zhang YH and Lynd LR (2004) Toward an aggregated understanding of enzymatic hydrolysis of cellulose: noncomplexed cellulase systems. Biotechnology and Bioengineering 88: 797- 824.

Zhao D, Glaz B and Comstock JC (2010) Sugarcane Response to Water-Deficit Stress during Early Growth on Organic and Sand Soils. American Journal of Agricultural and Biological Sciences 5(3): 403-414.

Zhao D, Glaz B and Comstock JC (2013) Sugarcane Leaf Photosynthesis and Growth Characters during Development of Water-Deficit Stress. Crop science 53: 1066-1075.

Zhao D, Glaz B and Comstock JC (2014) Physiological and growth responses of sugarcane genotypes to nitrogen rate on a sand soil. Journal of Agronomy and Crop Science 200(4): 290-301.

Zhao D and Li YR (2015) Climate Change and Sugarcane Production: Potential Impact and Mitigation Strategies. International Journal of Agronomy 2015: 1- 10

Zhou M (2003) Modelling Variety Differences in Canopy Growth and Development ofSugarcane (*Saccharum officinarum* L.) using CANEGRO model. MSc Agric., Schoolof Applied Environmental Sciences, Faculty of Science and Agriculture, University of Natal, South Africa.

Zhou MM and Shoko MD (2011) Seasonal and varietal effects on tiller population development of sugarcane (*Saccharum officinarum* L). South African Journal of Plant and Soil 28(1) 11-16.

Zhu LN, Wang SP, Yang TY, Zhang CX and Xu WP (2006) Vine growth and nitrogen metabolism of 'Fujiminori' grapevines in response to root restriction. Scientia Horticulturae 107: 143-149.

Zimbabwe Annual Action Programme (2009) Accompanying Measures for Sugar - Sugar Facility – CRIS Decision 021446.

Zingaretti SM, Rodrigues FA, Graça JP, Pereira LM and Lourenço MV (2012). Chapter 13: Sugarcane Responses at Water-deficit Conditions. In: Water Stress. Mofizur R (Editor). IntechOpen.

APPENDICES

Appendices for Chapter 3 on testing the suitability of selected water application rates for growing sugarcane plants in a container with soil-less or ZSAES soil medium

Appendix 1: ANOVA table for the effect of media and water application rate on sugarcane germination percent at 21 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Water application rate	6	3961.9	660.3	0.99	0.451
Medium	1	14485.7	14485.7	21.73	<.001
Water application rate.Medium	6	3847.6	641.3	0.96	0.468
Residual	28	18666.7	666.7		
Total	41	40961.9			

Appendix2: ANOVA table for the effect of media and water application rate on sugarcane germination rate.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Medium	1	11323.5	11323.5	48.24	<.001
Water_regime	6	1164.1	194.0	0.83	0.559
Medium.Water_regime	6	1802.5	300.4	1.28	0.298
Residual	28	6572.7	234.7		
Total	41	20862.8			

Appendix 3: ANOVA table for the effect of media and water application rate on sugarcane plant height at 52 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Medium	1	58.34	58.34	5.52	0.026
Water_regime	6	369.15	61.53	5.82	<.001
Medium.Water_regime	6	197.70	32.95	3.12	0.018
Residual	28	295.83	10.57		
Total	41	921.03			

Appendix 3: ANOVA table for the effect of media and water application rate on sugarcane plant height at 66 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Medium	1	9.054	9.054	0.91	0.347
Water_regime	6	1087.619	181.270	18.31	<.001
Medium.Water_regime	6	525.905	87.651	8.85	<.001
Residual	28	277.167	9.899		
Total	41	1899.744			

Appendix 4: ANOVA table for the effect of media and water application rate on sugarcane plant height at 73 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Medium	1	19.34	19.34	1.72	0.201
Water_regime	6	1854.29	309.05	27.46	<.001
Medium.Water_regime	6	773.95	128.99	11.46	<.001
Residual	28	315.17	11.26		
Total	41	2962.74			

Appendix 5: ANOVA table for the effect of media and water application rate on sugarcane plant height at 86 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Medium	1	3.72	3.72	0.25	0.620
Water_regime	6	6482.14	1080.36	73.04	<.001
Medium.Water_regime	6	1250.57	208.43	14.09	<.001
Residual	28	414.17	14.79		
Total	41	8150.60			

Appendix 6: ANOVA table for the effect of media and water application rate on sugarcane plant height at 107 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Medium	1	0.15	0.15	0.01	0.939
Water application rate	6	23892.00	3982.00	161.82	<.001
Medium.Water application rate	6	3111.48	518.58	21.07	<.001
Residual	28	689.00	24.61		
Total	41	27692.62			

Appendix 7: ANOVA table for the effect of media and water application rate on number of tillers at 107 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Medium	1	267.524	267.524	79.69	<.001
Water application rate	6	414.476	69.079	20.58	<.001
Medium.Water application rate	6	246.476	41.079	12.24	<.001
Residual	28	94.000	3.357		
Total	41	1022.476			

Appendix 8: ANOVA table for the effect of media and water application rate on leaf temperature at 149 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Medium	1	0.0952	0.0952	0.16	0.693
Water application rate	6	29.1962	4.8660	8.14	<.001
Medium.Water application rate	6	17.0648	2.8441	4.76	0.002
Residual	28	16.7400	0.5979		
Total	41	63.0962			

Appendix 9: ANOVA table for the effect of media and water application rate on leaf SPAD index at 149 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Medium	1	474.03	474.03	27.20	<.001
Water application rate	6	2804.62	467.44	26.82	<.001
Medium.Water application rate	6	2038.98	339.83	19.50	<.001
Residual	28	488.06	17.43		
Total	41	5805.69			

Appendix 10: ANOVA table for the effect of media and water application rate on green leaf area at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Medium	1	4.170E+11	4.170E+11	26.28	<.001
Water application rate	6	1.044E+12	1.740E+11	10.96	<.001
Medium.Water application rate	6	1.822E+11	3.037E+10	1.91	0.114
Residual	28	4.443E+11	1.587E+10		
Total	41	2.088E+12			

Appendix 11: ANOVA table for the effect of media and water application rate on number of green leaves at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Medium	1	11800.4	11800.4	36.68	<.001
Water application rate	6	8533.1	1422.2	4.42	0.003
Medium.Water application rate	6	1962.3	327.0	1.02	0.435
Residual	28	9008.7	321.7		
Total	41	31304.5			

Appendix 12: ANOVA table for the effect of media and water application rate on dry matter of green leaves at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Medium	1	7896.7	7896.7	48.59	<.001
Water application rate	6	28125.7	4687.6	28.85	<.001
Medium.Water application rate	6	4879.4	813.2	5.00	0.001
Residual	28	4550.0	162.5		
Total	41	45451.8			

Appendix 13: ANOVA table for the effect of media and water application rate on above ground weight at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Medium	1	294353.7	294353.7	359.98	<.001
Water application rate	6	1317967.3	219661.2	268.64	<.001
Medium.Water application rate	6	255713.5	42618.9	52.12	<.001
Residual	28	22895.4	817.7		
Total	41	1890929.8			

Appendix 14: ANOVA table for the effect of media and water application rate on trash dry matter at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Medium	1	9203.7	9203.7	29.01	<.001
Water application rate	6	20375.0	3395.8	10.71	<.001
Medium.Water application rate	6	10998.1	1833.0	5.78	<.001
Residual	28	8881.7	317.2		
Total	41	49458.5			

Appendix 15: ANOVA table for the effect of media and water application rate on log (x+100) root dry matter at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Water application rate	6	0.231623	0.038604	5.16	0.001
Media	1	0.169624	0.169624	22.67	<.001
Water application rate.Media	6	0.228642	0.038107	5.09	0.001
Residual	28	0.209550	0.007484		
Total	41	0.839439			

Appendix 16: ANOVA table for the effect of media and water application rate on total plant dry matter at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Medium	1	442018.	442018.	86.69	<.001
Water application rate	6	2819106.	469851.	92.15	<.001
Medium.Water application rate	6	404137.	67356.	13.21	<.001
Residual	28	142770.	5099.		
Total	41	3808031.			

Appendix 17: ANOVA table for the effect of media and water application rate on leaf nitrogen concentration percent at 150 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Medium	1		0.44789	0.44789	23.79	<.001
Water application rate	6		0.91245	0.15207	8.08	<.001
Medium.Water application rate	6		0.40584	0.06764	3.59	0.010
Residual	26	(2)	0.48940	0.01882		
Total	39	(2)	1.29104			

Appendix 18: ANOVA table for the effect of media and water application rate on leaf phosphorus concentration percent at 150 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Medium	1		0.0440203	0.0440203	214.60	<.001
Water application rate	6		0.0090709	0.0015118	7.37	<.001
Medium.Water application rate	6		0.0033956	0.0005659	2.76	0.033
Residual	26	(2)	0.0053333	0.0002051		
Total	39	(2)	0.0523900			

Appendix 19: ANOVA table for the effect of media and water application rate on leaf potassium concentration percent at 150 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Medium	1		0.44590	0.44590	14.67	<.001
Water application rate	6		1.89635	0.31606	10.40	<.001
Medium.Water application rate	6		0.67952	0.11325	3.73	0.008
Residual	26	(2)	0.79040	0.03040		
Total	39	(2)	3.76580			

Appendix 20: ANOVA table for the effect of media and water application rate on leaf magnesium concentration percent at 150 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Medium	1		0.0014908	0.0014908	5.15	0.032
Water application rate	6		0.0397389	0.0066231	22.86	<.001
Medium.Water application rate	6		0.0008622	0.0001437	0.50	0.805
Residual	26	(2)	0.0075333	0.0002897		
Total	39	(2)	0.0432975			

Appendix 21: ANOVA table for the effect of media and water application rate on leaf calcium concentration percent at 150 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Medium	1		0.0000374	0.0000374	0.04	0.848
Water application rate	6		0.0375529	0.0062588	6.31	<.001
Medium.Water application rate	6		0.0299345	0.0049891	5.03	0.002
Residual	26	(2)	0.0258000	0.0009923		
Total	39	(2)	0.0765600			

Appendices for Chapter 4 on assessing media for suitability of growing sugarcane plants in containers

Appendix 22: ANOVA table for the effect of media and variety on sugarcane germination percent at 15 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.2222	0.0741	0.33	0.801
Variety	2	0.7222	0.3611	1.62	0.218
Media.Variety	6	1.9444	0.3241	1.46	0.234
Residual	24	5.3333	0.2222		
Total	35	8.2222			

Appendix23: ANOVA table for the effect of media and variety on sugarcane germination rate.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	617.48	205.83	4.40	0.013
Variety	2	188.74	94.37	2.02	0.155
Media.Variety	6	146.67	24.44	0.52	0.786
Residual	24	1123.56	46.81		
Total	35	2076.44			

Appendix 24: ANOVA table for the effect of media and variety on stem height at 25 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	69.688	23.229	5.58	0.005
Variety	2	32.097	16.049	3.86	0.035
Media.Variety	6	30.125	5.021	1.21	0.337
Residual	24	99.833	4.160		
Total	35	231.743			

Appendix 25: ANOVA table for the effect of media and variety on stem height at 32 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	157.410	52.470	6.66	0.002
Variety	2	40.056	20.028	2.54	0.100
Media.Variety	6	39.111	6.519	0.83	0.560
Residual	24	189.167	7.882		
Total	35	425.743			

Appendix 26: ANOVA table for the effect of media and variety on stem height at 47DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	107.35	35.78	2.59	0.076
Variety	2	80.79	40.40	2.92	0.073
Media.Variety	6	87.54	14.59	1.06	0.415
Residual	24	331.50	13.81		
Total	35	607.19			

Appendix 27: ANOVA table for the effect of media and variety on stem height at 61 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	165.81	55.27	1.53	0.233
Variety	2	388.18	194.09	5.36	0.012
Media.Variety	6	155.65	25.94	0.72	0.640
Residual	24	869.17	36.22		
Total	35	1578.81			

Appendix 28: ANOVA table for the effect of media and variety on stem height at 74 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	792.11	264.04	4.00	0.019
Variety	2	380.34	190.17	2.88	0.075
Media.Variety	6	144.53	24.09	0.37	0.894
Residual	24	1582.61	65.94		
Total	35	2899.60			

Appendix 29: ANOVA table for the effect of media and variety on stem height at 86 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	3299.66	1099.89	16.39	<.001
Variety	2	266.47	133.23	1.99	0.159
Media.Variety	6	248.54	41.42	0.62	0.714
Residual	24	1610.09	67.09		
Total	35	5424.76			

Appendix 30: ANOVA table for the effect of media and variety on stem height at 100 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	5426.81	1808.94	23.69	<.001
Variety	2	151.76	75.88	0.99	0.385
Media.Variety	6	109.82	18.30	0.24	0.959
Residual	24	1832.27	76.34		
Total	35	7520.66			

Appendix 31: ANOVA table for the effect of media and variety on stem height at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	5607.97	1869.32	21.09	<.001
Variety	2	197.84	98.92	1.12	0.344
Media.Variety	6	62.39	10.40	0.12	0.993
Residual	24	2127.10	88.63		
Total	35	7995.30			

Appendix 32: ANOVA table for the effect of media and variety on number of tillers at 31 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	12.0000	4.0000	4.24	0.015
Variety	2	12.3889	6.1944	6.56	0.005
Media.Variety	6	4.5000	0.7500	0.79	0.584
Residual	24	22.6667	0.9444		
Total	35	51.5556			

Appendix33: ANOVA table for the effect of media and variety on number of tillers at 46 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	136.222	45.407	12.57	<.001
Variety	2	73.167	36.583	10.13	<.001
Media.Variety	6	31.944	5.324	1.47	0.229
Residual	24	86.667	3.611		
Total	35	328.000			

Appendix 34: ANOVA table for the effect of media and variety on number of tillers at 60 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	441.639	147.213	14.89	<.001
Variety	2	183.389	91.694	9.27	0.001
Media.Variety	6	69.944	11.657	1.18	0.350
Residual	24	237.333	9.889		
Total	35	932.306			

Appendix 35: ANOVA table for the effect of media and variety on number of tillers at 73 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	606.33	202.11	19.72	<.001
Variety	2	288.17	144.08	14.06	<.001
Media.Variety	6	116.50	19.42	1.89	0.123
Residual	24	246.00	10.25		
Total	35	1257.00			

Appendix 36: ANOVA table for the effect of media and variety on number of tillers at 85 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	590.778	196.926	26.45	<.001
Variety	2	352.667	176.333	23.69	<.001
Media.Variety	6	72.889	12.148	1.63	0.182
Residual	24	178.667	7.444		
Total	35	1195.000			

Appendix 37: ANOVA table for the effect of media and variety on number of tillers at 99 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	684.111	228.037	40.84	<.001
Variety	2	396.056	198.028	35.47	<.001
Media.Variety	6	75.722	12.620	2.26	0.072
Residual	24	134.000	5.583		
Total	35	1289.889			

Appendix 38: ANOVA table for the effect of media and variety on number of tillers at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	558.750	186.250	40.39	<.001
Variety	2	317.556	158.778	34.43	<.001
Media.Variety	6	73.333	12.222	2.65	0.041
Residual	24	110.667	4.611		
Total	35	1060.306			

Appendix 39: ANOVA table for the effect of media and variety on log (x+100) SPAD index at 75 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.0013646	0.0004549	4.15	0.017
Variety	2	0.0020116	0.0010058	9.19	0.001
Media.Variety	6	0.0002822	0.0000470	0.43	0.852
Residual	24	0.0026277	0.0001095		
Total	35	0.0062861			

Appendix40: ANOVA table for the effect of media and variety on SPAD index at 87 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	213.49	71.16	6.50	0.002
Variety	2	67.27	33.64	3.07	0.065
Media.Variety	6	112.39	18.73	1.71	0.162
Residual	24	262.94	10.96		
Total	35	656.09			

Appendix41: ANOVA table for the effect of media and variety on SPAD index at 101 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	38.46	12.82	0.65	0.589
Variety	2	51.29	25.65	1.31	0.290
Media.Variety	6	146.28	24.38	1.24	0.321
Residual	24	471.40	19.64		
Total	35	707.43			

Appendix 42: ANOVA table for the effect of media and variety on SPAD index at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	20.02	6.67	0.47	0.706
Variety	2	130.88	65.44	4.61	0.020
Media.Variety	6	59.74	9.96	0.70	0.652
Residual	24	340.85	14.20		
Total	35	551.49			

Appendix 43: ANOVA table for the effect of media and variety on leaf calcium concentration percent at 75 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.067719	0.022573	18.90	<.001
Variety	2	0.012506	0.006253	5.23	0.013
Media.Variety	6	0.014139	0.002356	1.97	0.110
Residual	24	0.028667	0.001194		
Total	35	0.123031			

Appendix 44: ANOVA table for the effect of media and variety on leaf calcium concentration percent at 87 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.144244	0.048081	25.61	<.001
Variety	2	0.005406	0.002703	1.44	0.257
Media.Variety	6	0.017639	0.002940	1.57	0.200
Residual	24	0.045067	0.001878		
Total	35	0.212356			

Appendix 45: ANOVA table for the effect of media and variety on leaf calcium concentration percent at 101 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.180031	0.060010	7.61	<.001
Variety	2	0.037800	0.018900	2.40	0.112
Media.Variety	6	0.073178	0.012196	1.55	0.206
Residual	24	0.189267	0.007886		
Total	35	0.480275			

Appendix 46: ANOVA table for the effect of media and variety on leaf calcium concentration percent at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.169475	0.056492	14.29	<.001
Variety	2	0.016200	0.008100	2.05	0.151
Media.Variety	6	0.022133	0.003689	0.93	0.489
Residual	24	0.094867	0.003953		
Total	35	0.302675			

Appendix 47: ANOVA table for the effect of media and variety on leaf potassium concentration percent at 75 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.57879	0.19293	5.02	0.008
Variety	2	0.48736	0.24368	6.34	0.006
Media.Variety	6	0.07458	0.01243	0.32	0.918
Residual	24	0.92193	0.03841		
Total	35	2.06266			

Appendix 48: ANOVA table for the effect of media and variety on leaf potassium concentration percent at 101 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.70464	0.23488	7.40	0.001
Variety	2	0.29124	0.14562	4.59	0.021
Media.Variety	6	0.15874	0.02646	0.83	0.556
Residual	24	0.76193	0.03175		
Total	35	1.91656			

Appendix 49: ANOVA table for the effect of media and variety on leaf potassium concentration percent at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.49876	0.16625	12.28	<.001
Variety	2	0.31337	0.15669	11.58	<.001
Media.Variety	6	0.25216	0.04203	3.11	0.021
Residual	24	0.32480	0.01353		
Total	35	1.38909			

Appendix 50: ANOVA table for the effect of media and variety on leaf magnesium concentration percent at 75 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.269000	0.089667	14.16	<.001
Variety	2	0.072150	0.036075	5.70	0.009
Media.Variety	6	0.021317	0.003553	0.56	0.757
Residual	24	0.151933	0.006331		
Total	35	0.514400			

Appendix 51: ANOVA table for the effect of media and variety on leaf magnesium concentration percent at 87 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.360500	0.120167	20.99	<.001
Variety	2	0.162156	0.081078	14.16	<.001
Media.Variety	6	0.052533	0.008756	1.53	0.211
Residual	24	0.137400	0.005725		
Total	35	0.712589			

Appendix 52: ANOVA table for the effect of media and variety on leaf magnesium concentration percent at 101 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.243389	0.081130	19.01	<.001
Variety	2	0.113672	0.056836	13.32	<.001
Media.Variety	6	0.062661	0.010444	2.45	0.055
Residual	24	0.102400	0.004267		
Total	35	0.522122			

Appendix 53: ANOVA table for the effect of media and variety on leaf magnesium concentration percent at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.110097	0.036699	9.00	<.001
Variety	2	0.116706	0.058353	14.31	<.001
Media.Variety	6	0.079228	0.013205	3.24	0.018
Residual	24	0.097867	0.004078		
Total	35	0.403897			

Appendix 54: ANOVA table for the effect of media and variety on leaf nitrogen concentration percent at 75 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.60561	0.20187	5.55	0.005
Variety	2	0.06837	0.03419	0.94	0.404
Media.Variety	6	0.09554	0.01592	0.44	0.846
Residual	24	0.87227	0.03634		
Total	35	1.64179			

Appendix55: ANOVA table for the effect of media and variety on leaf nitrogen concentration percent at 87 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.30185	0.10062	2.75	0.065
Variety	2	0.42207	0.21103	5.76	0.009
Media.Variety	6	0.65996	0.10999	3.00	0.025
Residual	24	0.87940	0.03664		
Total	35	2.26328			

Appendix 56: ANOVA table for the effect of media and variety on leaf nitrogen concentration percent at 101 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.38981	0.12994	2.81	0.061
Variety	2	1.01504	0.50752	10.96	<.001
Media.Variety	6	0.33752	0.05625	1.21	0.333
Residual	24	1.11173	0.04632		
Total	35	2.85410			

Appendix 57: ANOVA table for the effect of media and variety on leaf nitrogen concentration percent at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.03096	0.01032	0.41	0.746
Variety	2	0.28987	0.14494	5.79	0.009
Media.Variety	6	0.07833	0.01305	0.52	0.786
Residual	24	0.60080	0.02503		
Total	35	0.99996			

Appendix 58: ANOVA table for the effect of media and variety on leaf phosphorus concentration percent at 75 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.782119	0.260706	58.23	<.001
Variety	2	0.132983	0.066491	14.85	<.001
Media.Variety	6	0.051861	0.008644	1.93	0.117
Residual	24	0.107460	0.004478		
Total	35	1.074423			

Appendix 59: ANOVA table for the effect of media and variety on leaf phosphorus concentration percent at 87 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.70980	0.23660	10.18	<.001
Variety	2	0.03460	0.01730	0.74	0.486
Media.Variety	6	0.32732	0.05455	2.35	0.063
Residual	24	0.55765	0.02324		
Total	35	1.62937			

Appendix 60: ANOVA table for the effect of media and variety on leaf phosphorus concentration percent at 101 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.23920	0.07973	6.38	0.002
Variety	2	0.02735	0.01367	1.09	0.351
Media.Variety	6	0.08287	0.01381	1.11	0.388
Residual	24	0.29989	0.01250		
Total	35	0.64931			

Appendix 61: ANOVA table for the effect of media and variety on leaf phosphorus concentration percent at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.24063	0.08021	5.35	0.006
Variety	2	0.00957	0.00478	0.32	0.730
Media.Variety	6	0.05257	0.00876	0.58	0.739
Residual	24	0.35976	0.01499		
Total	35	0.66253			

Appendix 62: ANOVA table for the effect of media and variety on dry matter of roots at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	8034.3	2678.1	4.04	0.018
Variety	2	10.1	5.1	0.01	0.992
Media.Variety	6	3229.0	538.2	0.81	0.570
Residual	24	15891.7	662.2		
Total	35	27165.2			

Appendix 63: ANOVA table for the effect of media and variety on dry matter of stalk, tops and trash at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	105394.	35131.	4.04	0.019
Variety	2	22240.	11120.	1.28	0.297
Media.Variety	6	74930.	12488.	1.44	0.242
Residual	24	208728.	8697.		
Total	35	411292.			

Appendix 64: ANOVA table for the effect of media and variety on shoot dry matter at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	165516.	55172.	5.53	0.005
Variety	2	28565.	14283.	1.43	0.258
Media.Variety	6	93745.	15624.	1.57	0.200
Residual	24	239242.	9968.		
Total	35	527069.			

Appendix 65: ANOVA table for the effect of media and variety on total plant dry matter at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	245261.	81754.	6.14	0.003
Variety	2	28527.	14264.	1.07	0.359
Media.Variety	6	113514.	18919.	1.42	0.248
Residual	24	319739.	13322.		
Total	35	707041.			

Appendix 66: ANOVA table for the effect of media and variety on dry matter of green leaves at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	9146.4	3048.8	14.29	<.001
Variety	2	1943.0	971.5	4.55	0.021
Media.Variety	6	3844.0	640.7	3.00	0.025
Residual	24	5121.4	213.4		
Total	35	20054.7			

Appendix 67: ANOVA table for the effect of media and variety on log green leaf area at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.34241	0.11414	6.16	0.003
Variety	2	0.02153	0.01077	0.58	0.567
Media.Variety	6	0.29751	0.04958	2.68	0.039
Residual	24	0.44468	0.01853		
Total	35	1.10613			

Appendix 68: ANOVA table for the effect of media and variety on number of green leaves at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	3746.97	1248.99	13.45	<.001
Variety	2	904.06	452.03	4.87	0.017
Media.Variety	6	1997.94	332.99	3.59	0.011
Residual	24	2228.00	92.83		
Total	35	8876.97			

Appendix 69: ANOVA table for the effect of media and variety on first internodes length at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	4.4222	1.4741	3.04	0.048
Variety	2	14.6250	7.3125	15.09	<.001
Media.Variety	6	6.6594	1.1099	2.29	0.069
Residual	24	11.6333	0.4847		
Total	35	37.3400			

Appendix 70: ANOVA table for the effect of media and variety on second internodes length at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	9.500	3.167	2.90	0.056
Variety	2	43.220	21.610	19.81	<.001
Media.Variety	6	5.793	0.966	0.88	0.521
Residual	24	26.187	1.091		
Total	35	84.700			

Appendix 71: ANOVA table for the effect of media and variety on third internodes length at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	10.758	3.586	2.33	0.099
Variety	2	43.722	21.861	14.23	<.001
Media.Variety	6	7.687	1.281	0.83	0.556
Residual	24	36.873	1.536		
Total	35	99.040			

Appendix 72: ANOVA table for the effect of media and variety on fourth internodes length at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	18.672	6.224	5.38	0.006
Variety	2	34.385	17.192	14.87	<.001
Media.Variety	6	5.113	0.852	0.74	0.625
Residual	24	27.740	1.156		
Total	35	85.910			

Appendix 73: ANOVA table for the effect of media and variety on fifth internodes length at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	28.536	9.512	8.41	<.001
Variety	2	15.561	7.780	6.88	0.004
Media.Variety	6	3.939	0.657	0.58	0.742
Residual	24	27.133	1.131		
Total	35	75.170			

Appendix 74: ANOVA table for the effect of media and variety on sixth internodes length at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	72.110	24.037	18.97	<.001
Variety	2	5.040	2.520	1.99	0.159
Media.Variety	6	2.311	0.385	0.30	0.929
Residual	24	30.407	1.267		
Total	35	109.867			

Appendix 75: ANOVA table for the effect of media and variety on seventh internodes length at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	95.8608	31.9536	32.24	<.001
Variety	2	4.1539	2.0769	2.10	0.145
Media.Variety	6	2.1683	0.3614	0.36	0.894
Residual	24	23.7867	0.9911		
Total	35	125.9697			

Appendix 76: ANOVA table for the effect of media and variety on eighth internodes length at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	86.652	28.884	27.46	<.001
Variety	2	2.042	1.021	0.97	0.393
Media.Variety	6	0.722	0.120	0.11	0.994
Residual	24	25.247	1.052		
Total	35	114.663			

Appendix 77: ANOVA table for the effect of media and variety on average internodes length at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	27.4906	9.1635	13.31	<.001
Variety	2	12.3452	6.1726	8.96	0.001
Media.Variety	6	1.4086	0.2348	0.34	0.908
Residual	24	16.5294	0.6887		
Total	35	57.7738			

Appendix 78: ANOVA table for the effect of media and variety on stem diameter at 115 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.10972	0.03657	1.88	0.160
Variety	2	0.37389	0.18694	9.61	<.001
Media.Variety	6	0.33278	0.05546	2.85	0.031
Residual	24	0.46667	0.01944		
Total	35	1.28306			

Appendices for Chapter 5 on assessing rates of a blend fertiliser suitable for growing sugarcane plants in containers

Appendix 79: ANOVA table for the effect of media and blend fertiliser rate on stem height at 38 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	140.379	46.793	5.27	0.004
Fertiliser_rate	4	23.192	5.798	0.65	0.628
Media.Fertiliser_rate	12	62.642	5.220	0.59	0.838
Residual	40	354.833	8.871		
Total	59	581.046			

Appendix 80: ANOVA table for the effect of media and blend fertiliser rate on stem height at 53 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	148.85	49.62	4.15	0.012
Fertiliser_rate	4	54.93	13.73	1.15	0.347
Media.Fertiliser_rate	12	93.38	7.78	0.65	0.785
Residual	40	477.85	11.95		
Total	59	775.01			

Appendix 81: ANOVA table for the effect of media and blend fertiliser rate on stem height at 67 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	61.73	20.58	1.98	0.133
Fertiliser_rate	4	92.89	23.22	2.23	0.083
Media.Fertiliser_rate	12	49.54	4.13	0.40	0.957
Residual	40	416.06	10.40		
Total	59	620.23			

Appendix 82: ANOVA table for the effect of media and blend fertiliser rate on stem height at 81 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	71.900	23.967	3.26	0.031
Fertiliser_rate	4	148.350	37.088	5.04	0.002
Media.Fertiliser_rate	12	157.350	13.113	1.78	0.085
Residual	40	294.333	7.358		
Total	59	671.933			

Appendix 83: ANOVA table for the effect of media and blend fertiliser rate on stem height at 95 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	679.683	226.561	36.94	<.001
Fertiliser_rate	4	532.058	133.015	21.69	<.001
Media.Fertiliser_rate	12	535.775	44.648	7.28	<.001
Residual	40	245.333	6.133		
Total	59	1992.850			

Appendix 84: ANOVA table for the effect of media and blend fertiliser rate on stem height at 108 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	2039.939	679.980	111.07	<.001
Fertiliser_rate	4	1366.138	341.534	55.79	<.001
Media.Fertiliser_rate	12	1880.082	156.674	25.59	<.001
Residual	40	244.880	6.122		
Total	59	5531.039			

Appendix 85: ANOVA table for the effect of media and blend fertiliser rate on number of tillers at 38 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	60.9833	20.3278	27.10	<.001
Fertiliser_rate	4	1.9333	0.4833	0.64	0.634
Media.Fertiliser_rate	12	3.2667	0.2722	0.36	0.969
Residual	40	30.0000	0.7500		
Total	59	96.1833			

Appendix 86: ANOVA table for the effect of media and blend fertiliser rate on number of tillers at 53 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	314.733	104.911	43.41	<.001
Fertiliser_rate	4	2.433	0.608	0.25	0.907
Media.Fertiliser_rate	12	14.767	1.231	0.51	0.896
Residual	40	96.667	2.417		
Total	59	428.600			

Appendix 87: ANOVA table for the effect of media and blend fertiliser rate on number of tillers at 67 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	1144.583	381.528	44.28	<.001
Fertiliser_rate	4	47.067	11.767	1.37	0.263
Media.Fertiliser_rate	12	46.667	3.889	0.45	0.931
Residual	40	344.667	8.617		
Total	59	1582.983			

Appendix 88: ANOVA table for the effect of media and blend fertiliser rate on number of tillers at 81 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	1114.85	371.62	32.13	<.001
Fertiliser_rate	4	90.90	22.72	1.96	0.119
Media.Fertiliser_rate	12	106.57	8.88	0.77	0.679
Residual	40	462.67	11.57		
Total	59	1774.98			

Appendix 89: ANOVA table for the effect of media and blend fertiliser rate on number of tillers at 95 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	807.667	269.222	31.67	<.001
Fertiliser_rate	4	363.400	90.850	10.69	<.001
Media.Fertiliser_rate	12	155.667	12.972	1.53	0.155
Residual	40	340.000	8.500		
Total	59	1666.733			

Appendix 90: ANOVA table for the effect of media and blend fertiliser rate on number of tillers at 108 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	1075.267	358.422	54.58	<.001
Fertiliser_rate	4	1337.767	334.442	50.93	<.001
Media.Fertiliser_rate	12	308.233	25.686	3.91	<.001
Residual	40	262.667	6.567		
Total	59	2983.933			

Appendix 91: ANOVA table for the effect of media and blend fertiliser rate on SPAD index at 54 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	27.528	9.176	1.01	0.400
Fertiliser_rate	4	64.766	16.191	1.77	0.153
Media.Fertiliser_rate	12	70.189	5.849	0.64	0.795
Residual	40	365.047	9.126		
Total	59	527.530			

Appendix 92: ANOVA table for the effect of media and blend fertiliser rate on SPAD index at 68 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	18.553	6.184	0.87	0.466
Fertiliser_rate	4	52.089	13.022	1.83	0.142
Media.Fertiliser_rate	12	62.968	5.247	0.74	0.708
Residual	40	284.940	7.123		
Total	59	418.550			

Appendix 93: ANOVA table for the effect of media and blend fertiliser rate on SPAD index at 82 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	72.25	24.08	1.19	0.327
Fertiliser_rate	4	192.00	48.00	2.37	0.069
Media.Fertiliser_rate	12	86.16	7.18	0.35	0.972
Residual	40	811.36	20.28		
Total	59	1161.77			

Appendix 94: ANOVA table for the effect of media and blend fertiliser rate on SPAD index at 96 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	158.95	52.98	4.01	0.014
Fertiliser_rate	4	75.08	18.77	1.42	0.245
Media.Fertiliser_rate	12	346.31	28.86	2.18	0.032
Residual	40	529.00	13.22		
Total	59	1109.34			

Appendix 95: ANOVA table for the effect of media and blend fertiliser rate on SPAD index at 109 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	80.854	26.951	4.66	0.007
Fertiliser_rate	4	210.694	52.674	9.12	<.001
Media.Fertiliser_rate	12	227.715	18.976	3.28	0.002
Residual	40	231.113	5.778		
Total	59	750.376			

Appendix 96: ANOVA table for the effect of media and blend fertiliser rate on brown rust incidence at 112 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	3.0000	1.0000	10.00	<.001
Fertiliser_rate	4	1.5667	0.3917	3.92	0.009
Media.Fertiliser_rate	12	2.1667	0.1806	1.81	0.081
Residual	40	4.0000	0.1000		
Total	59	10.7333			

Appendix 97: ANOVA table for the effect of media and blend fertiliser rate on root dry matter at 112 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	113459.	37820.	3.54	0.023
Fertiliser_rate	4	8831.	2208.	0.21	0.933
Media.Fertiliser_rate	12	68987.	5749.	0.54	0.877
Residual	40	427901.	10698.		
Total	59	619178.			

Appendix 98 ANOVA table for the effect of media and blend fertiliser rate on dry matter of green leaves at 112 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	9224.6	3074.9	5.87	0.002
Fertiliser_rate	4	15831.9	3958.0	7.55	<.001
Media.Fertiliser_rate	12	10547.6	879.0	1.68	0.109
Residual	40	20962.1	524.1		
Total	59	56566.2			

Appendix 99: ANOVA table for the effect of media and blend fertiliser rate on shoot dry matter at 112 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	145832.	48611.	5.61	0.003
Fertiliser_rate	4	76064.	19016.	2.19	0.087
Media.Fertiliser_rate	12	110774.	9231.	1.06	0.414
Residual	40	346792.	8670.		
Total	59	679463.			

Appendix 100: ANOVA table for the effect of media and blend fertiliser rate on trash dry matter at 112 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	16965.4	5655.1	15.19	<.001
Fertiliser_rate	4	1923.9	481.0	1.29	0.290
Media.Fertiliser_rate	12	5488.7	457.4	1.23	0.299
Residual	40	14895.8	372.4		
Total	59	39273.8			

Appendix 101: ANOVA table for the effect of media and blend fertiliser rate on total plant dry matter at 112 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	470703.	156901.	7.02	<.001
Fertiliser_rate	4	46824.	11706.	0.52	0.719
Media.Fertiliser_rate	12	160723.	13394.	0.60	0.829
Residual	40	893613.	22340.		
Total	59	1571862.			

Appendix 102: ANOVA table for the effect of media and blend fertiliser rate on green leaf area at 112 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	8.153E+11	2.718E+11	2.14	0.110
Fertiliser_rate	4	2.507E+12	6.267E+11	4.95	0.002
Media.Fertiliser_rate	12	1.377E+12	1.147E+11	0.91	0.550
Residual	40	5.069E+12	1.267E+11		
Total	59	9.768E+12			

Appendix 103: ANOVA table for the effect of media and blend fertiliser rate on number of green leaves at 112 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	12633.1	4211.0	4.99	0.005
Fertiliser_rate	4	27869.4	6967.4	8.26	<.001
Media.Fertiliser_rate	12	13890.3	1157.5	1.37	0.219
Residual	40	33746.0	843.6		
Total	59	88138.9			

Appendix 104: ANOVA table for the effect of media and blend fertiliser rate on number of internodes at 112 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	8.717	2.906	2.10	0.115
Fertiliser_rate	4	47.433	11.858	8.57	<.001
Media.Fertiliser_rate	12	25.367	2.114	1.53	0.154
Residual	40	55.333	1.383		
Total	59	136.850			

Appendix 105: ANOVA table for the effect of media and blend fertiliser rate on average internodes length at 112 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	14.0948	4.6983	29.30	<.001
Fertiliser_rate	4	6.3489	1.5872	9.90	<.001
Media.Fertiliser_rate	12	11.6498	0.9708	6.06	<.001
Residual	40	6.4131	0.1603		
Total	59	38.5066			

Appendix106: ANOVA table for the effect of media and blend fertiliser rate on stem girth at 112 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.49133	0.16378	13.10	<.001
Fertiliser_rate	4	0.09233	0.02308	1.85	0.139
Media.Fertiliser_rate	12	0.14367	0.01197	0.96	0.503
Residual	40	0.50000	0.01250		
Total	59	1.22733			

Appendix 107: ANOVA table for the effect of media and blend fertiliser rate on leaf calcium concentration percent at 112 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.189277	0.063092	10.78	<.001
Fertiliser_rate	4	0.204275	0.051069	8.72	<.001
Media.Fertiliser_rate	12	0.164293	0.013691	2.34	0.022
Residual	40	0.234213	0.005855		
Total	59	0.792059			

Appendix 108: ANOVA table for the effect of media and blend fertiliser rate on leaf potassium concentration percent at 112 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	1.62481	0.54160	18.42	<.001
Fertiliser_rate	4	2.33173	0.58293	19.83	<.001
Media.Fertiliser_rate	12	0.85554	0.07129	2.42	0.018
Residual	40	1.17604	0.02940		
Total	59	5.98811			

Appendix 109: ANOVA table for the effect of media and blend fertiliser rate on leaf magnesium concentration percent at 112 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	0.111610	0.037203	20.84	<.001
Fertiliser_rate	4	0.004562	0.001140	0.64	0.638
Media.Fertiliser_rate	12	0.041509	0.003459	1.94	0.059
Residual	40	0.071421	0.001786		
Total	59	0.229101			

Appendix 110: ANOVA table for the effect of media and blend fertiliser rate on leaf nitrogen concentration percent at 112 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	1.02129	0.34043	16.92	<.001
Fertiliser_rate	4	4.71741	1.17935	58.62	<.001
Media.Fertiliser_rate	12	0.76359	0.06363	3.16	0.003
Residual	40	0.80480	0.02012		
Total	59	7.30709			

Appendix 111: ANOVA table for the effect of media and blend fertiliser rate on leaf phosphorus concentration percent at 112 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Media	3	1.323625	0.441208	53.99	<.001
Fertiliser_rate	4	2.163974	0.540993	66.20	<.001
Media.Fertiliser_rate	12	0.292757	0.024396	2.99	0.005
Residual	40	0.326881	0.008172		
Total	59	4.107237			

Appendices for Chapter 6 on assessing container size for suitability of growing sugarcane plants

Appendix 112: ANOVA table for the effect of media and container size on stem height at 38 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		11.630	5.815	0.67	0.523
Container_size	2		9.463	4.731	0.55	0.588
Media.Container_size	4		27.481	6.870	0.80	0.544
Residual	17	(1)	146.833	8.637		
Total	25	(1)	189.663			

Appendix 113: ANOVA table for the effect of media and container size on stem height at 53 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		2.147	1.074	0.12	0.886
Container_size	2		61.354	30.677	3.48	0.054
Media.Container_size	4		39.937	9.984	1.13	0.374
Residual	17	(1)	149.813	8.813		
Total	25	(1)	252.159			

Appendix 114: ANOVA table for the effect of media and container size on stem height at 67 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		58.01	29.01	2.89	0.083
Container_size	2		61.63	30.82	3.07	0.073
Media.Container_size	4		92.74	23.18	2.31	0.100
Residual	17	(1)	170.86	10.05		
Total	25	(1)	343.85			

Appendix 115: ANOVA table for the effect of media and container size on stem height at 81 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		231.39	115.70	7.21	0.005
Container_size	2		325.50	162.75	10.14	0.001
Media.Container_size	4		34.01	8.50	0.53	0.715
Residual	17	(1)	272.79	16.05		
Total	25	(1)	858.74			

Appendix 116: ANOVA table for the effect of media and container size on stem height at 95 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		680.52	340.26	15.96	<.001
Container_size	2		1205.24	602.62	28.27	<.001
Media.Container_size	4		75.70	18.93	0.89	0.492
Residual	17	(1)	362.33	21.31		
Total	25	(1)	2320.16			

Appendix 117: ANOVA table for the effect of media and container size on stem height at 108 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		1870.13	935.06	14.35	<.001
Container_size	2		7255.96	3627.98	55.68	<.001
Media.Container_size	4		440.73	110.18	1.69	0.198
Residual	17	(1)	1107.59	65.15		
Total	25	(1)	10670.87			

Appendix 118: ANOVA table for the effect of media and container size on number of tillers at 38 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		6.0000	3.0000	6.95	0.006
Container_size	2		0.2222	0.1111	0.26	0.776
Media.Container_size	4		4.4444	1.1111	2.58	0.075
Residual	17	(1)	7.3333	0.4314		
Total	25	(1)	17.8846			

Appendix 119: ANOVA table for the effect of media and container size on number of tillers at 67 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		188.963	94.481	13.31	<.001
Container_size	2		3.630	1.815	0.26	0.777
Media.Container_size	4		55.259	13.815	1.95	0.149
Residual	17	(1)	120.667	7.098		
Total	25	(1)	365.885			

Appendix 120: ANOVA table for the effect of media and container size on number of tillers at 81 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		203.19	101.59	8.33	0.003
Container_size	2		106.96	53.48	4.39	0.029
Media.Container_size	4		29.48	7.37	0.60	0.665
Residual	17	(1)	207.33	12.20		
Total	25	(1)	530.65			

Appendix 121: ANOVA table for the effect of media and container size on number of tillers at 95 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		413.56	206.78	5.32	0.016
Container_size	2		412.67	206.33	5.31	0.016
Media.Container_size	4		125.78	31.44	0.81	0.536
Residual	17	(1)	660.67	38.86		
Total	25	(1)	1511.12			

Appendix 122: ANOVA table for the effect of media and container size on number of tillers at 108 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		587.17	293.58	9.50	0.002
Container_size	2		1037.17	518.58	16.79	<.001
Media.Container_size	4		271.00	67.75	2.19	0.113
Residual	17	(1)	525.17	30.89		
Total	25	(1)	2253.88			

Appendix 123: ANOVA table for the effect of media and container size on SPAD index at 53 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		52.177	26.089	3.97	0.039
Container_size	2		10.461	5.230	0.80	0.467
Media.Container_size	4		28.546	7.136	1.09	0.395
Residual	17	(1)	111.778	6.575		
Total	25	(1)	197.678			

Appendix 124: ANOVA table for the effect of media and container size on SPAD index at 67 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		7.501	3.751	0.93	0.413
Container_size	2		2.128	1.064	0.26	0.771
Media.Container_size	4		67.650	16.913	4.21	0.015
Residual	17	(1)	68.352	4.021		
Total	25	(1)	131.186			

Appendix 125: ANOVA table for the effect of media and container size on SPAD index at 81 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		7.778	3.889	0.89	0.431
Container_size	2		16.917	8.458	1.92	0.176
Media.Container_size	4		55.876	13.969	3.18	0.040
Residual	17	(1)	74.698	4.394		
Total	25	(1)	152.215			

Appendix 126: ANOVA table for the effect of media and container size on SPAD index at 95 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		19.05	9.52	0.76	0.485
Container_size	2		169.82	84.91	6.74	0.007
Media.Container_size	4		50.16	12.54	1.00	0.437
Residual	17	(1)	214.03	12.59		
Total	25	(1)	446.43			

Appendix 127: ANOVA table for the effect of media and container size on SPAD index at 108 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		16.421	8.211	4.21	0.033
Container_size	2		25.540	12.770	6.56	0.008
Media.Container_size	4		10.256	2.564	1.32	0.304
Residual	17	(1)	33.118	1.948		
Total	25	(1)	84.335			

Appendix 128: ANOVA table for the effect of media and container size on medium temperature at 43 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		27.4513	13.7256	26.09	<.001
Container_size	2		14.9124	7.4562	14.17	<.001
Media.Container_size	4		10.4115	2.6029	4.95	0.008
Residual	17	(1)	8.9450	0.5262		
Total	25	(1)	60.3246			

Appendix 129: ANOVA table for the effect of media and container size on medium temperature at 92 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		30.3617	15.1808	39.15	<.001
Container_size	2		39.2539	19.6269	50.62	<.001
Media.Container_size	4		14.6478	3.6619	9.44	<.001
Residual	17	(1)	6.5917	0.3877		
Total	25	(1)	88.5185			

Appendix 130: ANOVA table for the effect of media and container size on log dry matter of stems, sheath and tops at 112 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		0.04392	0.02196	1.06	0.368
Container_size	2		3.26486	1.63243	78.96	<.001
Media.Container_size	4		0.25713	0.06428	3.11	0.043
Residual	17	(1)	0.35146	0.02067		
Total	25	(1)	3.89561			

Appendix 131: ANOVA table for the effect of media and container size on log root dry matter at 112 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		0.01432	0.00716	0.18	0.838
Container_size	2		0.16329	0.08164	2.03	0.162
Media.Container_size	4		0.54995	0.13749	3.42	0.032
Residual	17	(1)	0.68372	0.04022		
Total	25	(1)	1.40696			

Appendix 132: ANOVA table for the effect of media and container size on log green leaf area at 112 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		0.02248	0.01124	0.35	0.710
Container_size	2		1.84057	0.92029	28.64	<.001
Media.Container_size	4		0.15997	0.03999	1.24	0.330
Residual	17	(1)	0.54617	0.03213		
Total	25	(1)	2.52227			

Appendix 133: ANOVA table for the effect of media and container size on log number of green leaves at 112 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		0.033998	0.016999	2.70	0.096
Container_size	2		0.542697	0.271349	43.07	<.001
Media.Container_size	4		0.044776	0.011194	1.78	0.180
Residual	17	(1)	0.107113	0.006301		
Total	25	(1)	0.707047			

Appendix 134: ANOVA table for the effect of media and container size on number of internodes at 112 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		11.630	5.815	5.11	0.018
Container_size	2		23.185	11.593	10.19	0.001
Media.Container_size	4		2.370	0.593	0.52	0.722
Residual	17	(1)	19.333	1.137		
Total	25	(1)	56.346			

Appendix 135: ANOVA table for the effect of media and container size on stem diameter at 112 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		0.69241	0.34620	4.60	0.025
Container_size	2		0.57352	0.28676	3.81	0.043
Media.Container_size	4		0.65037	0.16259	2.16	0.117
Residual	17	(1)	1.27833	0.07520		
Total	25	(1)	3.18500			

Appendix 136: ANOVA table for the effect of media and container size on first internodes length at 112 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Container_size	2		17.1919	8.5959	14.92	<.001
Media	2		3.9563	1.9781	3.43	0.056
Container_size.Media	4		2.7837	0.6959	1.21	0.344
Residual	17	(1)	9.7933	0.5761		
Total	25	(1)	33.7215			

Appendix 137: ANOVA table for the effect of media and container size on second internodes length at 112 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Container_size	2		39.890	19.945	13.84	<.001
Media	2		8.192	4.096	2.84	0.086
Container_size.Media	4		8.961	2.240	1.55	0.231
Residual	17	(1)	24.493	1.441		
Total	25	(1)	81.519			

Appendix 138: ANOVA table for the effect of media and container size on third internodes length at 112 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Container_size	2		46.7239	23.3619	30.63	<.001
Media	2		10.8006	5.4003	7.08	0.006
Container_size.Media	4		5.8322	1.4581	1.91	0.155
Residual	17	(1)	12.9650	0.7626		
Total	25	(1)	76.3185			

Appendix 139: ANOVA table for the effect of media and container size on fourth internodes length at 112 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Container_size	2		49.6896	24.8448	41.44	<.001
Media	2		10.4030	5.2015	8.67	0.003
Container_size.Media	4		4.1326	1.0331	1.72	0.191
Residual	17	(1)	10.1933	0.5996		
Total	25	(1)	74.3800			

Appendix 140: ANOVA table for the effect of media and container size on fifth internodes length at 112 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Container_size	2		69.3385	34.6693	38.06	<.001
Media	2		8.0496	4.0248	4.42	0.029
Container_size.Media	4		2.1348	0.5337	0.59	0.677
Residual	17	(1)	15.4867	0.9110		
Total	25	(1)	94.8465			

Appendix 141: ANOVA table for the effect of media and container size on sixth internodes length at 112 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Container_size	2		101.9430	50.9715	69.96	<.001
Media	2		14.4763	7.2381	9.93	0.001
Container_size.Media	4		5.9970	1.4993	2.06	0.132
Residual	17	(1)	12.3867	0.7286		
Total	25	(1)	133.3985			

Appendix 142: ANOVA table for the effect of media and container size on seventh internodes length at 112 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Container_size	2		122.936	61.468	33.13	<.001
Media	2		23.078	11.539	6.22	0.010
Container_size.Media	4		5.459	1.365	0.74	0.581
Residual	16	(2)	29.685	1.855		
Total	24	(2)	168.830			

Appendix 143: ANOVA table for the effect of media and container size on eighth internodes length at 112 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Container_size	2		163.306	81.653	25.30	<.001
Media	2		26.720	13.360	4.14	0.037
Container_size.Media	4		6.699	1.675	0.52	0.723
Residual	15	(3)	48.418	3.228		
Total	23	(3)	216.065			

Appendix 144: ANOVA table for the effect of media and container size on average internodes length at 112 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Container_size	2		68.6772	34.3386	52.54	<.001
Media	2		9.3070	4.6535	7.12	0.006
Container_size.Media	4		2.8574	0.7143	1.09	0.392
Residual	17	(1)	11.1116	0.6536		
Total	25	(1)	91.4409			

Appendix 145: ANOVA table for the effect of media and container size on calcium concentration at 112 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		0.0015369	0.0007684	0.78	0.472
Container_size	2		0.0002880	0.0001440	0.15	0.864
Media.Container_size	4		0.0040764	0.0010191	1.04	0.416
Residual	17	(1)	0.0166667	0.0009804		
Total	25	(1)	0.0218660			

Appendix 146: ANOVA table for the effect of media and container size on magnesium concentration at 112 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		0.0011722	0.0005861	0.89	0.428
Container_size	2		0.0012056	0.0006028	0.92	0.418
Media.Container_size	4		0.0015222	0.0003806	0.58	0.681
Residual	17	(1)	0.0111500	0.0006559		
Total	25	(1)	0.0149087			

Appendix 147: ANOVA table for the effect of media and container size on potassium concentration at 112 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		0.00009	0.00005	0.00	0.997
Container_size	2		0.00796	0.00398	0.27	0.763
Media.Container_size	4		0.01715	0.00429	0.30	0.876
Residual	17	(1)	0.24615	0.01448		
Total	25	(1)	0.27112			

Appendix 148: ANOVA table for the effect of media and container size on nitrogen concentration at 112 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		0.05661	0.02831	0.50	0.617
Container_size	2		0.06168	0.03084	0.54	0.592
Media.Container_size	4		0.31626	0.07906	1.39	0.280
Residual	17	(1)	0.96812	0.05695		
Total	25	(1)	1.37694			

Appendix 149: ANOVA table for the effect of media and container size on phosphorus concentration at 112 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Media	2		0.00935	0.00468	0.31	0.739
Container_size	2		0.00780	0.00390	0.26	0.776
Media.Container_size	4		0.02752	0.00688	0.45	0.769
Residual	17	(1)	0.25782	0.01517		
Total	25	(1)	0.30242			

Appendices for Chapter 7 on evaluation of tolerance to water-deficit stress ofreleased sugarcane varieties in Zimbabwe

Appendix 150: ANOVA table for the effect of media and water application rate on stem height at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	13	8850.56	680.81	22.11	<.001
Water_regime	1	5732.11	5732.11	186.14	<.001
Variety.Water_regime	13	1343.80	103.37	3.36	<.001
Residual	56	1724.51	30.79		
Total	83	17650.98			

Appendix 151: ANOVA table for the effect of media and water application rate on number of tillers at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Water_regime	1	300.96	300.96	13.64	<.001
Variety	13	3627.54	279.04	12.64	<.001
Water_regime.Variety	13	354.20	27.25	1.23	0.281
Residual	56	1236.00	22.07		
Total	83	5518.70			

Appendix 152: ANOVA table for the effect of media and water application rate on SPAD index at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	13	512.52	39.42	3.56	<.001
Water_regime	1	141.70	141.70	12.79	<.001
Variety.Water_regime	13	152.71	11.75	1.06	0.411
Residual	56	620.66	11.08		
Total	83	1427.59			

Appendix 153: ANOVA table for the effect of media and water application rate on vapour pressure deficit at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Water_regime	1	1.22404	1.22404	12.93	<.001
Variety	13	2.05020	0.15771	1.67	0.095
Water_regime.Variety	13	2.49716	0.19209	2.03	0.035
Residual	56	5.30213	0.09468		
Total	83	11.07353			

Appendix 154: ANOVA table for the effect of media and water application rate on relative water content at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	13	516.76	39.75	1.01	0.457
Water_regime	1	324.04	324.04	8.21	0.006
Variety.Water_regime	13	448.96	34.54	0.88	0.582
Residual	56	2209.01	39.45		
Total	83	3498.77			

Appendix 155: ANOVA table for the effect of media and water application rate on photosynthetic rate at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Water_regime	1	550.30	550.30	5.94	0.018
Variety	13	963.18	74.09	0.80	0.657
Water_regime.Variety	13	1043.72	80.29	0.87	0.591
Residual	56	5185.54	92.60		
Total	83	7742.73			

Appendix 156: ANOVA table for the effect of media and water application rate on leaf temperature at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Water_regime	1	1.214	1.214	0.50	0.484
Variety	13	24.562	1.889	0.77	0.684
Water_regime.Variety	13	27.824	2.140	0.88	0.581
Residual	56	136.767	2.442		
Total	83	190.367			

Appendix157: ANOVA table for the effect of media and water application rate on stomatal conductance at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Water_regime	1	57253.	57253.	10.71	0.002
Variety	13	173266.	13328.	2.49	0.009
Water_regime.Variety	13	197933.	15226.	2.85	0.003
Residual	56	299486.	5348.		
Total	83	727938.			

Appendix 158: ANOVA table for the effect of media and water application rate on transpiration rate at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Water_regime	1	23.872	23.872	19.18	<.001
Variety	13	29.396	2.261	1.82	0.063
Water_regime.Variety	13	30.692	2.361	1.90	0.050
Residual	56	69.687	1.244		
Total	83	153.646			

Appendix 159: ANOVA table for the effect of media and water application rate on number of internodes at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	13	155.333	11.949	7.12	<.001
Water_regime	1	448.048	448.048	266.92	<.001
Variety.Water_regime	13	28.286	2.176	1.30	0.243
Residual	56	94.000	1.679		
Total	83	725.667			

Appendix 160: ANOVA table for the effect of media and water application rate on first internodes length at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	13	27.766	2.136	2.07	0.031
Water_regime	1	26.973	26.973	26.16	<.001
Variety.Water_regime	13	10.247	0.788	0.76	0.693
Residual	56	57.747	1.031		
Total	83	122.732			

Appendix 161: ANOVA table for the effect of media and water application rate on fourth internodes length at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	13	57.3024	4.4079	5.60	<.001
Water_regime	1	122.8876	122.8876	156.21	<.001
Variety.Water_regime	13	19.3490	1.4884	1.89	0.051
Residual	56	44.0533	0.7867		
Total	83	243.5924			

Appendix 162: ANOVA table for the effect of media and water application rate on fifth internodes length at 150 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Variety	13		62.853	4.835	4.82	<.001
Water_regime	1		135.407	135.407	135.01	<.001
Variety.Water_regime	13		19.228	1.479	1.47	0.158
Residual	54	(2)	54.158	1.003		
Total	81	(2)	266.581			

Appendix 163: ANOVA table for the effect of media and water application rate on sixth internodes length at 150 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Variety	13		59.855	4.604	4.22	<.001
Water_regime	1		157.803	157.803	144.66	<.001
Variety.Water_regime	13		24.387	1.876	1.72	0.084
Residual	52	(4)	56.725	1.091		
Total	79	(4)	284.210			

Appendix 164: ANOVA table for the effect of media and water application rate on eighth internodes length at 150 DAP.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Variety	13		130.279	10.021	7.01	<.001
Water_regime	1		239.589	239.589	167.62	<.001
Variety.Water_regime	11	(2)	24.702	2.246	1.57	0.141
Residual	44	(12)	62.892	1.429		
Total	69	(14)	352.906			

Appendix 165: ANOVA table for the effect of media and water application rate on average internodes length at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	13	56.6728	4.3594	5.01	<.001
Water_regime	1	96.8755	96.8755	111.34	<.001
Variety.Water_regime	13	20.9823	1.6140	1.85	0.057
Residual	56	48.7260	0.8701		
Total	83	223.2566			

Appendix Equation 166: ANOVA table for the effect of media and water application rate on number of green leaves at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	13	66449.	5111.	4.77	<.001
Water_regime	1	48576.	48576.	45.30	<.001
Variety.Water_regime	13	14908.	1147.	1.07	0.403
Residual	56	60053.	1072.		
Total	83	189987.			

Appendix 167: ANOVA table for the effect of media and water application rate on green leaf area at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	13	3.516E+13	2.705E+12	1.47	0.158
Water_regime	1	1.786E+14	1.786E+14	97.11	<.001
Variety.Water_regime	13	3.494E+13	2.688E+12	1.46	0.162
Residual	56	1.030E+14	1.839E+12		
Total	83	3.517E+14			

Appendix 168: ANOVA table for the effect of media and water application rate on root dry matter at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	13	1659879.	127683.	3.31	<.001
Water_regime	1	1305584.	1305584.	33.85	<.001
Variety.Water_regime	13	860964.	66228.	1.72	0.082
Residual	56	2159868.	38569.		
Total	83	5986295.			

Appendix 169: ANOVA table for the effect of media and water application rate on shoot: root dry matter ratio at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	13	74.767	5.751	1.93	0.046
Water_regime	1	112.445	112.445	37.65	<.001
Variety.Water_regime	13	29.763	2.289	0.77	0.690
Residual	56	167.229	2.986		
Total	83	384.203			

Appendix 170: ANOVA table for the effect of media and water application rate on total plant dry matter at 150 DAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	13	1881122.	144702.	2.36	0.014
Water_regime	1	69897964.	69897964.	1139.62	<.001
Variety.Water_regime	13	1272287.	97868.	1.60	0.114
Residual	56	3434737.	61335.		
Total	83	76486110.			