BOTSWANA UNIVERSITY OF AGRICULTURE AND NATURAL RESOURCES

EFFECTS OF IRRIGATION REGIME ON THE GROWTH OF THREE WARM SEASON TURFGRASSES IN SOUTHERN, BOTSWANA

A dissertation submitted to the Botswana University of Agriculture and Natural Resources in partial fulfillment of the requirements for the award of Master of Science Degree in Crop Science (Horticulture)

By

Mooketsi Lesego

ID NO: 200400340

January 2022

Main Supervisor: Dr I.A Legwaila

Co-Supervisor: Dr G.K Gaboutloeloe

DEPARTMENT OF CROP AND SOIL SCIENCES

FACULTY OF AGRICULTURE

CERTIFICATION

…………………………….	…….…………	………………………..
Main supervisor's name	**Signature**	**Date**
…………………………….	…….…………	………………………..
Co-supervisor's name	**Signature**	**Date**
…………………………….	…….…………	………………………..
Head of department's name	**Signature**	**Date**

APPROVAL

…………………………….	…….…………	…………………………..
Main supervisor's name	**Signature**	**Date**
…………………………….	…….…………	…………………………..
Co-supervisor's name	**Signature**	**Date**
…………………………….	…….…………	…………………………..
Head of department's name	**Signature**	**Date**
…………………………….	…….…………	…………………………..
Dean of Faculty's name	**Signature**	**Date**

STATEMENT OF ORIGINALITY

The work contained in this dissertation was compiled by the author at Botswana University of Agriculture and Natural Resources between August 2017 and January 2022. It is original except where references were made and it will not be submitted for award of any other degree or diploma of any other University.

Author's Signature

ACKNOWLEDGEMENTS

I would like to take this opportunity to thank the following institutions and individuals for their contribution to the successful completion of this study.

The commissioner of Botswana Prisons Services (BPS) for allowing me the opportunity to further my studies and seeing it fit to sponsor me by providing all the funding necessary for the successful execution of this study. The Botswana University of Agriculture and Natural Resources (BUAN) for providing laboratory and all equipment and resources that were required for the completion of this study.

Dr I.A Legwaila, my main supervisor whose expertise was invaluable in formulating the research questions and methodology. Your insightful feedback pushed me to sharpen my thinking and brought my work to a higher level. Dr G.K Gaboutloeloe my co-supervisor for his support and role throughout the study as my supervisor. He has generously given his time and expertise to better my work. Mr Keletso Ntokome and the BUAN soil lab technicians for their priceless assistance and support.

Above all am grateful to the almighty GOD for blessing me with strength and courage to complete this thesis. His grace and love was sufficient.

DEDICATION

This work is dedicated to my wife and parents for their constant encouragement and enthusiasm for further studies. Thanks for the unconditional love and support. I will always love and appreciate all they have done for me. Thanks to all those who contributed in many ways to the success of this study and made it an unforgettable experience for me. Thank you very much.

ABSTRACT

Botswana is known for its unreliable rainfall, extended dry spells and heat. The combination of these factors puts great demand on water conservation strategies in turfgrass management. These strategies dictate that turfgrasses should be managed increasingly under less frequent or deficit irrigation, yet limited research has been carried out to evaluate growth of warm season turfgrasses as influenced by irrigation regimes in Botswana.

A field study was conducted at the Botswana University of Agriculture and Natural Resources (BUAN) from May 2018 to September 2018 to evaluate the effect of irrigation regimes on the growth of three warm season turfgrasses in southern Botswana. The experiment was a factorial arranged as a randomized complete block design (RCBD) with two factors: irrigation regimes (four levels) and turfgrass species (three turfgrass species) replicated three times. Four daily irrigation levels were applied as follows; 50%, 75%, 100 % (control) and 110% replacement irrigation of the previous day's net evaporation measured using a class 'A' evaporation pan (E_{pan}).

The results showed an increase in root length, root biomass and clip biomass when the three grasses were irrigated at 50% and 75% replacement of daily E_{pan}. Irrigating at 100% (control) and 110% of E_{pan} replacement resulted in shorter root length, lower root biomass and clip biomass. All evaluated turfgrasses performed well, when irrigated at 75% of E_{pan} replacement in terms of growth and quality. Regression analysis revealed that ETo contributed 86.3 %, 63.26 % and 88.26 % to variability in root biomass, root length and clip biomass respectively. Higher clip biomass was associated with higher root length and root biomass.

Based on their performance *Cynodon dactylon* is the best turfgrass to grow in Botswana followed by *Pennisetum clandestine* and *Buchloe dactyloides,* recommended according to their ability to maintain acceptable growth and quality under deficit irrigation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

LIST OF SYMBOLS AND ABBREVIATIONS

µ	Population Mean
ANOVA	Analysis Of Variance
BUAN	Botswana University Of Agriculture And Natural Resources
CEC	Carbon Exchange Capacity
EC	Electrical Conductivity
Epan	Pan Evaporation
ET	Evapotranspiration
ETo	Reference Crop Evapotranspiration
FAO	Food And Agricultural Organization
GLM	General Linear Models
Ha	Alternate Hypothesis
Ho	Null Hypothesis
Kpan	Pan Coefficient
LSD	Least Significant Difference
NTEP	National Turfgrass Evaluation Programme
OM	Organic Matter
P	Phosphorus
SAS	Statistical Analysis Software
SSKIA	Sir Seretse Khama International Airport
WUC	Botswana Water Utilities Cooperation

CHAPTER 1

INTRODUCTION

1.1 General introduction

Turfgrasses are ground cover crops with long, narrow leaves that can form a uniform turf which can tolerate traffic and low mowing heights. They are often grouped into cool season (C_3) grasses and warm season (C_4) grasses based on their photosynthetic pathways (Christians, 2011). They have an alluring green colour and a uniform appearance that increases the value of properties (Emmons and Rossi, 1995). Their multiple uses include erosion control, aesthetics and recreation, and absorption of atmospheric pollutants, and often are an element in the landscaping of commercial, residential, and public spaces. They have a proven capacity to cool the environment and enhance of mental health (Stier *et al*., 2013). In Botswana different turfgrasses, such as *Dactyloctenium australe*, *Cynodon dactylon*, *Pennisetum clandestinum* and *Buchloe dactyloides*, are used in different places inclusive of stadia, golf courses and parks, and public areas for aesthetic purposes.

Turfgrasses, like other agronomic, horticultural and landscape vegetation need water for growth and development. This water may be from rainfall, irrigation or a combination of the two (Pessarakli, 2008). However, turfgrass water requirements depend on species and differ among cultivars of the same species (Salaiz *et al*., 1991; McCarty, 2001). Warm season turfgrasses can use from 2 mm to 5 mm of water per day, depending on location, species, weather conditions and type of maintenance (Wiecko, 2006). Feldhake *et al*., (1983) reported that warm-season grasses used about 20% less water than the cool-season grasses under identical management and microenvironment conditions.

The highest usage of water occurs in arid regions, where precipitation is low but evapotranspiration (ET) is high, and the least occurs in the humid tropics, where rainfall is high and ET is low (Wiecko, 2006). Precipitation in the tropics ranges from just about 0 mm - 2000mm per year and from 0 mm -700mm per year for arid regions (FAO, 1998; Perrasakli, 2008). In Botswana, annual rainfall varies from maximum of 650mm in Kasane to a minimum of less than 250mm in Kgalagadi (Department of meteorological services, 2003).

Turfgrass species variations in water-use efficiency are associated with differences in shoot and root characteristics, leaf orientation, shoot density, growth habit, rooting depth, and density (Beard, 1973; Huang and Fry, 1999). The most important factor that determines the plant’s water requirements is ET which is affected by factors such as humidity, temperature, wind speed and canopy resistance (Wiecko, 2006). Knowledge of water use requirements for various turfgrass species is important for identifying turfgrasses that persist with reduced water inputs and also for developing efficient irrigation management practices (DaCosta and Huang, 2006).

1.2 Justification of the study

When rainfall is insufficient and water resources become limited, supplemental irrigation is required to sustain landscape turf which is often the first to be placed on water use restrictions under such conditions. In Botswana, Water Utilities Cooperation (WUC) imposed water restrictions on the utilization of portable water for irrigating gardens and lawns (Selepeng, 2004; Mguni, 2017). Under these restrictions turfgrass managers, growers and homeowners have been compelled to maintain functional and high quality turfgrasses with less water and using alternative water sources such as treated sewage effluent and borehole water. Botswana has low and unreliable rainfall with high ET in the range of 1800 mm - 3000mm per annum (Emongor *et al*., 2008), making water the most constraining resource in turfgrass management. This situation acerbated by climate change that causes extreme weather conditions such as extended dry spells and heat. The combination of these factors puts high demand on water conservation strategies in turfgrass management. Therefore, it is important to know the water requirements of different turfgrasses grown in Botswana. In Botswana, no research has been conducted and published on turfgrass management.

1.3 Objectives

The study was conducted to determine the effects of irrigation regimes on growth of three warm season turfgrasses (*Cynodon dactylon*, *Pennisetum clandestinum* and *Buchloe dactyloides)* in Southern, Botswana.

1.3.1 Specific objectives

1.3.1.1 To evaluate the growth response of *Cynodon dactylon*, *Pennisetum clandestinum* and *Buchloe dactyloides to* different irrigation regimes.

1.3.1.2 To determine how different irrigation regimes, affects turfgrass quality of *Cynodon dactylon*, *Pennisetum clandestinum* and *Buchloe dactyloides*.

1.4 Hypotheses

1.4.1 **H1o**: Irrigation regimes have no effect on growth of *Cynodon dactylon, Pennisetum clandestinum* and *Buchloe dactyloides.*

1.4.2 **H1a**: Irrigation regimes have an effect on growth of *Cynodon dactylon*, *Pennisetum clandestinum* and *Buchloe dactyloides.*

1.4.3 **H2o**: Irrigation regimes have no effect on turfgrass quality of *Cynodon dactylon*, *Pennisetum clandestinum* and *Buchloe dactyloides.*

1.4.4 **H2a**: Irrigation regimes have an effect on turfgrass quality of *Cynodon dactylon*, *Pennisetum clandestinum* and *Buchloe dactyloides.*

CHAPTER 2

LITERATURE REVIEW

2.1 Water use and evapotranspiration

Turfgrass water use is the total amount of water required for growth in addition to the amount of water lost through ET per unit time. Evapotranspiration is the sum of soil water evaporation and plant transpiration (Beard, 1973). Since the amount of water used by turfgrasses for growth is little, water use is typically referred to as ET (Gibeault *et al.*, 1989).

Reference crop evapotranspiration (ET_o) is the evapotranspiration rate from a reference surface, not short of water (FAO, 1998). The reference surface is a hypothetical grass reference crop with specific characteristics (a grass of uniform height (8-15cm)), which is actively growing, disease free, completely shading the ground and not short of water (Allen *et al.,* 1998). Estimations of ET_o are widely used in irrigation engineering to define crop water requirements. A good estimation of evapotranspiration is vital for proper water management. Many empirical and semi-empirical methods for estimation of ET_o exist and are used by individual scientists and researchers around the world (Kumar *et al*., 2012). The type of data (climatic data) available determines the method to be used (Doorens and Pruitt, 1998). Penman-monteith (PM) equation has been recommended as the standardized ET_o equation, but it has a high requirement of climatic data (Peng *et al*., 2017). In the absence of some climatic data, FAO-24 Blaney-Criddle method is the second best (Chiew *et al*., 1995). (Table 1).

Despite the FAO Penman-Monteith being the best recommended method for calculating ET_o, the Pan Evaporation method is still widely used in some parts of East and Southern Africa. This is mainly because the method is very practical and simple, which appeals to many farmers and practitioners (Savva and Frenken, 2002). In this study, Pan Evaporation method will be used to estimate daily ET_o due to its practicality and poor availability of climatic data required by other methods.

Table 1: Reference estimation methods (source: Kumar *et al*., 2012)

METHOD OF ET_O ESTIMATION	**EQUATIONS USED**	**REQUIRED METEOROLOGICAL DATA**
FAO-24 corrected Penman (c ¼ 1), (Fc P-Mon	$ET_O = C[\frac{\Delta}{\Delta+y}(R_n - G) + \frac{y}{\Delta+y} 2.7W_f + (e_a - e_d)]$	Net radiation, vapor pressure deficit and wind velocity
Priestley-Taylor (P-T)	$ET_O = \alpha \frac{\Delta}{\Delta+y} (R^n - G)$	Net radiation, soil heat flux and vapor pressure deficit
FAO-24 Blaney-Criddle, (F B-C)	$ET_O = a + b [p(0.46T + 8.13)]$	Annual day time hours, temperature and wind velocity
Hargreaves-Samani (H-S)	$ET_O = 0.0135(KT) (R_a) (TD^{1/2}) (TC+17.8)$ $KT = 0.00185 (TD)^2 - 0.0433TD + 0.4023$	Net radiation, min/max temperature
FAO Pan Evaporation (F E-Pan)	$ET_O = K_p \times E_{pan}$	Pan evaporation
Penman Monteith* (P-Mon)	$ET_O = \frac{0.408\Delta(R_n-G) + y(900/(T+273))u_2(e_s-e_a)}{\Delta + y \quad (1 + 0.34u_2)}$	Vapor pressure deficit, radiation flux, wind velocity, temperature and soil heat flux
Kimberly-Penman Model (K-M)	$\lambda ET_r = \frac{\Delta}{\Delta+y} (R_n - G) + \frac{\Delta}{\Delta+y} 6.43W_f (e_z^0 - e_z)$	Vapor pressure deficit, radiation flux, wind velocity, temperature and soil heat flux

Jensen-Haise Alfalfa Reference Model	$\lambda ET_r = C_r (T - T_x) R_s$	Solar radiation and mean air temperature
SCS Blaney-Criddle Model	$U = KF = \Sigma kf$	Mean air temperature, average relative humidity, and mean percentage of daytime hours
Generalized Form of ASCE Standardized Equation	$ET_O = \frac{0.408\Delta(Rn-G) + y(C_n/T+273))u_2(e_s-e_a)}{\Delta + y \quad (1 + Cdu_2)}$	Vapor pressure deficit, radiation flux, wind velocity, temperature and soil heat flux

2.2 *Cynodon dactylon* (Bermudagrass)

Cynodon dactylon is a warm season turf that grows in a wide range of climates, soils and environmental conditions (Pessarakli, 2008). There are two varieties of bermudagrasses used as turfgrass: common bermudagrass and improved hybrids [cross between common bermudagrass (*Cynodon dactylon*) and African bermudagrass (*Cynodon ransvaalensis*)] (Emmons, 2000). It originated in Africa but now it occurs worldwide in both tropical and subtropical regions including Asia, North, Central and South America, the Caribbean and island in the Pacific Ocean (Sandoval and Rodrigues, 2014). It is known in different regions around the world by at least 20 different common names, the most popular one's being bermudagrass and baharagrass, devil's grass and wiregrass (Wiecko, 2008).

It is a perennial grass, with rhizomes and stolons (Cabrera, 1968; Covas and Salvai, 1970). It produces a vigorous deep rooted light to dark green dense turf, horizontal stems and is competitive against weeds (McCarty, 2001). It is drought tolerant, has a good tolerance to wear and can tolerate a wide soil pH (Wiecko, 2006). When the soil temperatures drop to 10^{o}C for 10 to 14 days, Bermuda grass loses its chlorophyll and turns yellow to light brown and remains dormant until the soil temperature rises ≥ 10^{o}C (Wiecko, 2006). Mathowa *et al*., (2014), assessed the influence of irrigation regime on growth parameters including, relative water content in leaves, clip biomass, root biomass and clip root ratio and water use efficiency (WUE) of the native common Bermudagrass at Khon Kaen university Thailand. He found that of the four daily irrigation levels of 50%, 75%, 100% (control) and 125%, Epan, 75% resulted in higher records for the parameters measured. The study reported that reduction of water supply increased root growth and that excessive irrigation lead to reduced shoot growth. Barton *et al*., (2006) also concluded that irrigating turfgrasses at 140% E_{pan} replacement decreased *Cynodon dactylon* root growth by 30%.

In another study, Fu *et al*., (2004) examined the minimum water requirements of four turfgrasses (*Cynodon dactylon, Festuca arundinacea, Poapratensis L* and *Zoysia jabonica*) at Rock Ford Turfgrass Research Center, Manhattan. The study reported that the minimum annual irrigation amounts required to maintain quality ranged from 244mm for bermudagrass to 552mm for bluegrass.

2.3 *Pennisetum clandestinum* (Kikuyugrass)

Pennisetum clandestinum is a coarse-textured species that originates in the highlands of East Africa, such as Ethiopia, Kenya, Tanzania, Uganda, Rwanda, Burundi and the Democratic Republic of Congo (USDA-ARS, 2008). It is now used around the world in regions such as Australia and islands of Hawaii. Kikuyu is a low-growing perennial grass which spreads by thick, leafy rhizomes and stolons (McCarty, 2001). Under optimal conditions, it has an extremely competitive and aggressive growth habit, often invading and overtaking areas with more desirable species. According to Helfgott (1994) kikuyu grass completely devastated lucerne fields in 2-3 years following infestation in South America. It is drought tolerant but has poor cold and shade tolerance (McCarty, 2001). The plant can withstand severe and repeated defoliation; hence, it is very resistant to overgrazing or mowing (Holm *et al*., 1977). It tolerates a wide range of soil pH, and acidic soils to pH 4, but has less tolerance to alkalinity (Semple *et al*., 2004). It has also shown good tolerance to salinity up to 100 or 150 mM NaCl in South Africa (Radhakrishnan *et al*., 2006).

Mantell (1966) evaluated the effects of irrigation and nitrogen fertilization on growth and water use of kikuyu grass in Rehovot, Israel. In his study five irrigation frequencies (7, 14, 21, 25 and 30 days) were used as treatments from June to October 1965. The study found that the evapotranspiration (ET) rate for the infrequently irrigated grass remained below 3mm/day for the entire period of the experiment. In the wetter treatments water consumption was greater, reaching a peak of 6.1mm/day in July for plots irrigated weekly.

When comparing water use and drought tolerance in turfgrasses (Kikuyugrass, Zoysiagrass, Bermudagrass and Buffalograss) Short (2001) also reported that traits such as deep, extensive root systems and lower ET rates improved the performance of turfgrasses when irrigation volumes were reduced. The study showed that there was little variation among the turfgrasses evaluated.

2.4 *Buchloe dactyloides* (Buffalograss)

Buffalo grass is a low-growing, perennial, stoloniferous grass with curly-leaves which forms dense, clonal mats (COSEWIC, 2011). It originates from the American tropics and is naturalized in almost every tropical and sub-tropical region (FAO, 2010). It is a warm season turfgrass that grows 10 to 15 cm in height (Brakie, 2013). It is commonly found in hot humid areas and in open or moderately shaded areas. It has the ability to go dormant with the advent of severe drought and to initiate new growth after prolonged periods of moisture stress (McCarty, 2001). The excellent drought resistance of buffalo grass is one of its most outstanding characteristics, it is adapted to a wide range of soil conditions, but is exceptionally well suited to fine-textured alkaline soils (Turgeon, 1996). Buffalo grass has C_4 physiology, which gives it higher water use efficiency (WUE) than C_3 grasses (Ford, 1999).

Huang (1998) evaluated water relations and root activities of *Buchloe dactloides* and Zoysia Japonica in response to localised soil drying at Kansas State University Manhattan, KS, USA. The grasses were subjected to three soil moisture regimes (well-watered, partially dried and fully dried. He reported increased root biomass on partially dried Buffalograss, less root biomass for well-watered Buffalograss and severe root biomass decline in the fully dried treatment. In another study, McAfee and Lebs (2001) evaluated native and non-native turfgrasses in taxas and reported a higher survivability (85% to 90%) of Buffalograss compared to (5% to 35%) of Bermudagrass under deficit irrigation after 3 years.

Qian and Engelke (1999) evaluated the minimum irrigation requirements and relative drought resistance of Buffalograss, Bermudagrass, Zoysiagrass and St Augustinegrass at Texas, USA. Irrigation was applied every 3 days at a rate of 120% of the previous3 day class ‘A’ pan evaporation. They concluded that Buffalograss required the least irrigation (26%) to maintain acceptable turf quality when compared to Bermudagrass (35%), Zoysiagrass (68%) and St Augustine (44%). When comparing the performance of Kentucky bluegrass, Tall fescue and Buffalograss under line source irrigation, Ervin (1995) also reported superior adaptability of Buffalograss while irrigation treatments were applied every day at 80%, 60%, 45% and 20% of reference ET.

Most literature indicates that *Cynodon dactylon*, *Pennisetum clandestinum* and *Buchloe dactyloides* can tolerate high temperature and are efficient in water use. This adaptability means that they have a large future role in Botswana turf industry. This study will provide data relevant to turfgrass managers and homeowners on their field performance.

2.5 Influence of irrigation on growth and quality of turfgrasses

For turfgrass irrigation, frequency and water quantity and quality are the most important factors. A daily ET measurement enables precise determination of how much water has been lost within a day. The ET rates can be used to decide how much to irrigate (Pessarakli, 2008). Various studies have demonstrated that, over-irrigating and under-irrigating turf can be detrimental to both its functional and visual quality (Qian and Engelke, 1999; Baldwin *et al*., 2006; Mathowa *et al*., 2014). Different sizes of experimental units [(2m by 1m), (1.5m by 1.5m), (15cm by 36cm), (1.20m by 1.90m), and (4m by 1m)] have been used by several researchers to evaluate turfgrass response to different irrigation regimes and drought (Jordan *et al*., 2003; Geren *et al*., 2009; Mathowa *et al*., 2014; Duan, 2018; Pornaro *et al*., 2021)

Baldwin *et al*., (2006) studied the response of six Bermudagrass cultivars to different irrigation intervals which included 5, 10, 15 days and a control (irrigated daily). They reported a decline in turfgrass quality, an increase in root weight as drought stress was imposed longer than 5 days. Feldhake *et al*., (1984) also reported greater relative decreases in turf quality with larger irrigation deficits. According to Aydinsakir *et al*., (2016) Bermudagrass can be irrigated at a level of 50% of Epan to get an acceptable visual quality with improved water conservation. While, Hejl *et al*., (2016) reported that irrigation of *Cynodon dactylon* at 30% of ET_o was generally adequate for maintaining acceptable turf quality. Barton and Colmer (2006) observed that efficient irrigation scheduling that does not cause water to move beyond the active rooting zone decreased the amount of nitrogen (N) leached from established turfgrasses and in some instances enhanced turfgrass growth and quality. However, Colmer (2006) concluded that over irrigating caused leaching of nutrients. Biran *et al*., (1981) found that delaying irrigation until the onset of temporary wilting caused a significant decrease in water consumption and growth (up to 30%) in most turfgrasses (Zoysiagrass, Bermudagrass and Buffalograss, and St Augustinegrass).

2.6 Turf quality and quality assessment techniques

Turfgrass quality is a function of its visual and functional qualities. The most visible determinates of quality include, density, texture, uniformity, and colour. Functional components of quality include rigidity, elasticity, resilience, yield, verdure and putting speed (Turgeon, 1996; Turgeon, 1980). These measures are affected by natural environment, irrigation and fertilization. Average turfgrass qualities can be achieved with less irrigation. Irrigating Bermudagrass at a level of 50% of Epan has been reported to be enough to obtain average standard visual qualities (Turgeon, 1996). Evaluation of these qualities is challenging because they are qualitative variables. They are estimated subjectively by visual evaluation techniques (Wherley, 2011). Turfgrass evaluators judge the turfgrass quality based on visual observations. Turfgrass quality assessment ratings differ from individual to individual. They are made by trained evaluators on a 1 to 9 scale, where 1 demonstrates dormant, brown, rough, dead grass that is not uniform and 9 indicates the highest quality (uniform, dark green and dense turfgrass) (Morries and Sherman, 2016). Wherley (2011) used a 1-9 numeric scale to evaluate turfgrass visual quality, where 1 represented brown dead turf, 6 represented minimally accepted and 9 represented optimal colour, density and uniformity. Turfgrass quality determinants such as density, texture, uniformity, and colour are also evaluated using multispectral radiometry and digital image analysis (Karcher and Richardson 2003; Leinaur *et al.*, 2014). Even though these techniques are widely used, Leinaur *et al.*, (2014) reported that these quality evaluations were still questionable or not valid enough to replace visual assessment. Some functional qualities such as yield, verdure and rooting can be quantified. Different researchers have used clippings and root length/ biomass to assess turfgrass quality.

The aesthetic appearance of turf venues is a high priority for turf managers, growers and homeowners and is often demanded by users as well, even in those situations where there is an intense use or unfavorable weather conditions. By selecting turfgrass species with superior drought resistance, turfgrass managers and homeowners can delay or postpone drought stress injury and the associated decline in turfgrass quality.

CHAPTER 3

MATERIALS AND METHODS

3.1 Experimental site

The study was conducted at the Botswana University of Agriculture and Natural Resources (BUAN) from May 2018 to September 2018. The University is located at Sebele, approximately 10 km from the Centre of Gaborone, the capital city of Botswana. The BUAN campus lies on 23°34'S; 25°57'E latitude and longitude. It is 994 m above sea level. The study area climate is semi-arid with an average rainfall of 538mm (30 year mean) with most rainfall being received between the months of October and March/April. Soils are predominantly sandy loams (76% sand, 10% silt and 14% clay) with low water holding capacity, low cation exchange capacity (1.2 meq/100g) and pH of 6.3 (Toteng *et al*., 2014). The pan evaporation rate for the study area is 1905mm/year with a daily range between 8mm in summer and 2 mm in winter (Gieske, 1992).

3.2 Experimental design

The experiment was a factorial arranged as a randomized complete block design with two factors; Irrigation regimes as main-plot (factor A) and Turfgrass species as sub-plot (factor B). There were four irrigation regimes. The irrigation regimes were the replacement irrigation of the previous day’s net evaporation measured using a class ‘A’ evaporation pan ($E_{pan)}$ at 50%, 75%, 100% (control) and 110%. Water regimes were randomly assigned to experimental units measuring 1.5 m by 1 m (Jordan *et al*., 2003; Geren *et al*., 2009; Duan, 2018; Pornaro *et al*., 2021) to which the turfgrass species were assigned. There were three turfgrass species; *Cynodon* *dactylon*, *Pennisetum clandestinum and Buchloe dactyloides*. There were twelve experimental units replicated three times (In total there were 36 plots).

3.3 Land preparations and turfgrass establishment

Before planting, soil samples were collected for determination of pH, exchangeable bases, organic carbon, texture, and available phosphorus using standard laboratory procedures (AOAC, 2005). Debris and all unwanted objects and plants materials (weeds) were removed, and the soil was tilled to establish a rough grade. The area was watered for two weeks to germinate and uproot weeds. Final grade was established to make the soil surface smooth and even for planting. The soil was slightly firmed to close air pockets and to prevent depressions caused by settling soil during irrigation. The soil surface was then light raked to loosen it for planting. *Cynodon dactylon* and *Pennisetum clandestinum* were then established at a recommended seeding rate of 20g/m^2 (Toteng *et al*., 2014). A total of 20g of seeds was measured using a precision electronic weighing balance after which they were then spread on the prepared land, and then lightly raked in to cover them. After planting, the experimental units were gently watered. *Buchloe dactyloides* was propagated vegetatively using stolons that were collected from the University grounds. The stolons were cut and spread 4cm apart in the prepared land and were covered lightly with the soil, which was then firmed to ensure good stolon to soil contact. Stolons were used because seeds for this grass species were not available in the market.

3.4 Cultural practices

3.4.1 Irrigation

After planting, the turfgrasses were irrigated twice a day in the morning and late afternoon using a 10-liter watering can. The watering can was fitted with a rose to avoid erosion of the seed bed. After 36 weeks when the turfgrasses were fully established, daily irrigation was stopped, and the experimental plots received their assigned Epan replacement irrigation regime which was calculated on daily basis for the duration (5 months) of the experiments. Compensation for rainfall was done by reducing the amount of watering during the months of May, July and September.

3.4.2 Mowing

Mowing height for all the three grasses was maintained at 30mm as recommended (Handreck and Black 1994; Johnston, 1999). Mowing was done once a week for each turfgrass, and no more than one-third of the leaf area was removed at any one mowing.

3.4.3 Weed/Pest monitoring and control

Weed control was done by hand or hand hoeing at any appearance of weeds during the experimental period. Termites outbreak was treated with application of Terminix at a rate of 2500l/ha (dosage rate 60ml: 100l), to prevent further damage to the turfgrasses. The turfgrasses were inspected on a regular basis for both weeds and insect infestation.

3.5 Evaporation pan installation and data collection

A class ‘A’ evaporation pan (figure 1) was installed 5m from the experimental site. It was placed away from bushes, trees, and other obstacles which could obstruct natural air flow to represent open water in an open area. The pan was mounted on a wooden frame platform 15cm above the ground and was levelled as recommended (Savva and Frenken, 2002). It was fenced in to keep animals from drinking from it or destroying it. The pan was kept clean all the time by removing any foreign materials.

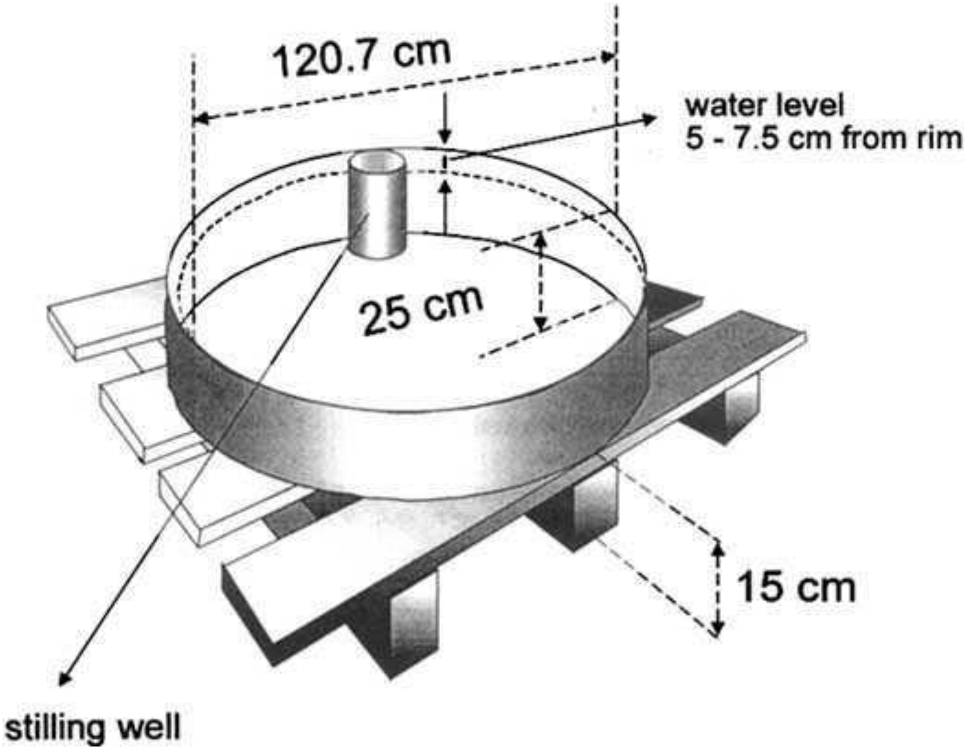


Figure 1. Class ‘A’ pan (FAO, 1998)

The pan was filled with water to 5cm below the rim, and the water level was not allowed to drop to more than 7.5cm below the rim during the experimental period. The water was regularly renewed weekly, to eliminate extreme turbidity. The pan was filled with water to 20cm depth and the water depth was recorded.

The water was allowed to evaporate over a period of 24 hours and the remaining quantity of water (water depth) was measured every morning at 0700hrs and recorded. The amount of evaporation per unit time (the difference between the two known water depths) was calculated and recorded; this represented the pan evaporation for the day (Epan in mm/day). The Epan was then multiplied by an average Kp (pan coefficient) value of 0.70 as recommended by (FAO, 1984) to obtain the ETo (reference crop evaporation). The ETo values were calculated using the formula below as proposed by (FAO, 1998) and recorded on daily basis for 5 months (May 2018 to September 2018). These represented daily estimated turfgrass water use (water requirements)

Formula: $ET_o = Kp \times Epan$

Where:

ETo = reference crop evapotranspiration

Kp = pan coefficient

Epan = pan evaporation

When the water depth in the pan dropped to 7.5cm below the rim, water was added and the water depth was measured before and after the water was added. When the water level rose above the 5cm mark due to rain, water was taken out of the pan to drop the water level back to the 5cm mark and the water depths before and after removing water was measured.

3.6 Dependent variables determined

3.6.1 Clip biomass

Clip biomass was recorded weekly. Clip sampling was done within a 20 cm × 20 cm square inside each experimental unit (Mathowa *et al*., 2014). The square was measured with a 30cm ruler and marked with pegs. The clippings were cut with a pair of scissors at 1 cm above the crown and were collected with a vacuum cleaner and discharged into brown paper bags. All the unwanted materials collected with the clippings were hand-picked and discarded. The fresh clip samples were then taken to a laboratory to measure the fresh weight using a digital analytical balance (NBL-1602e-Adam/Nimbus). The same samples were then oven dried at 80^{o}C for 24 hours using a hot air oven (Scientific Series 2000). The dry clip biomass was then obtained using a precision electronic weighing balance and recorded.

3.6.2 Root biomass

Root biomass was measured at termination of the experiment. From each plot, a sample was collected to a depth of 50cm using a soil probe. The samples were cleaned with fresh water to remove soil and field debris then placed in a brown paper bags. The fresh samples were taken to the laboratory to measure the fresh root weight using a digital analytical balance (NBL-1602e-Adam/Nimbus). The same samples were then oven dried at 80^{o}C using a hot air oven (Scientific Series 2000) after which the dry root biomass was determined using a precision electronic weighing balance.

3.6.3 Root length

Root length was measured at termination of the experiment. From each experimental unit, a sample was collected at a depth of 50 cm using a probe. Samples were then cleaned with fresh water to remove the field debris. The samples were taken to laboratory, where a 1m ruler and a string were used to measure the length of the roots. A string was put against the root then the ruler to measure the length and the results recorded.

3.6.4 Quality evaluation

Chlorophyll content was quantified to evaluate turfgrass quality of the three turfgrasses. Chlorophyll meter (SPAD-502 Plus-Konica Minolta) was used to collect chlorophyll content of leaves. Three samples were obtained from each plot and averaged on weekly basis. Random leaves were sampled from each plot.

3.7 Data analysis

Data on clip biomass, root biomass, root length and chlorophyll content parameters were subjected to analysis of variance (ANOVA) using general linear models (GLM) procedures of Statistical Analysis System (SAS, 2002-2008). When f-values were significant at $P \leq 0.05$, treatment means were separated using the least squares means separation (Nelson, 1993), which was performed using the PDIFF option of GLM Procedure in Statistical Analysis System (SAS, 2002-2008) to evaluate the significance and magnitude of the fixed effects at $P \leq 0.05$. All data were expressed on dry matter basis and expressed as means ± standard error.

CHAPTER 4

RESULTS

4.1 Some physical and chemical properties of experimental sites soil

The physical property of the soil showed that the experimental site had sandy loam soil. Sandy soils generally have low cation exchange capacity (CEC). Soils high in CEC are more fertile than those lower in CEC's because they retain more exchangeable plant nutrients. Basically the soil had poor soil fertility. This was supported by the low levels of OM, CEC and extractable phosphorus. Some physical and chemical properties of the experimental site soil test results are presented in Table 2.

Table 2. Some physical and chemical properties of experimental site soil

PHYSICAL PROPERTIES				Chemical properties				
Silt (%)	Clay (%)	Textural class	Silt (%)	Electrical conductivity (µS /cm) 1:5 H_2O	Extractable P (ppm)	PH ($CaCI_2$)	CEC (cmol kg-1	OM (%)
11.6	7.3	Sandy loam	11.6	6.19	2.20	6.39	4.60	1.8

4.2 Climatic conditions of the experimental sites

This experiment was conducted between May 2018 to September 2018, which are winter and spring months under Botswana conditions. Rainfall limited drought stress symptoms in May and June. The total rainfall recorded during the experiment period was 13.7mm (Figure 2). Compensation for rainfall by reducing the amount of watering was done when rainfall occurred. There was a dry spell extending from mid-July to late September. Minimum temperature recorded during the experimental period was 2.7^{o}C in June and a maximum of 34.2^{o}C in September (Figure 3). In general, lower temperatures were recorded during winter and higher temperatures were recorded in spring. The average relative humidity was 42.4 % (Figure 4). The average humidity recorded was high in winter and low in spring.

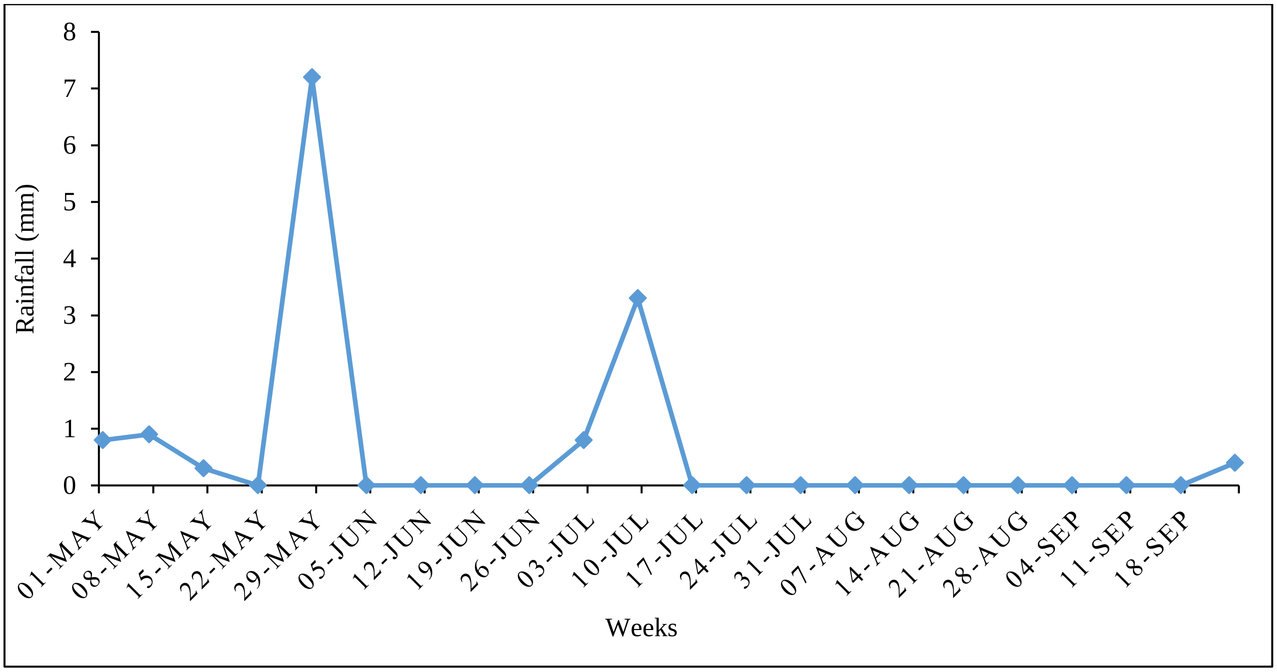


Figure 2. Rainfall distribution recorded at Sir Seretse Khama International Airport (SSKIA) during the study period.

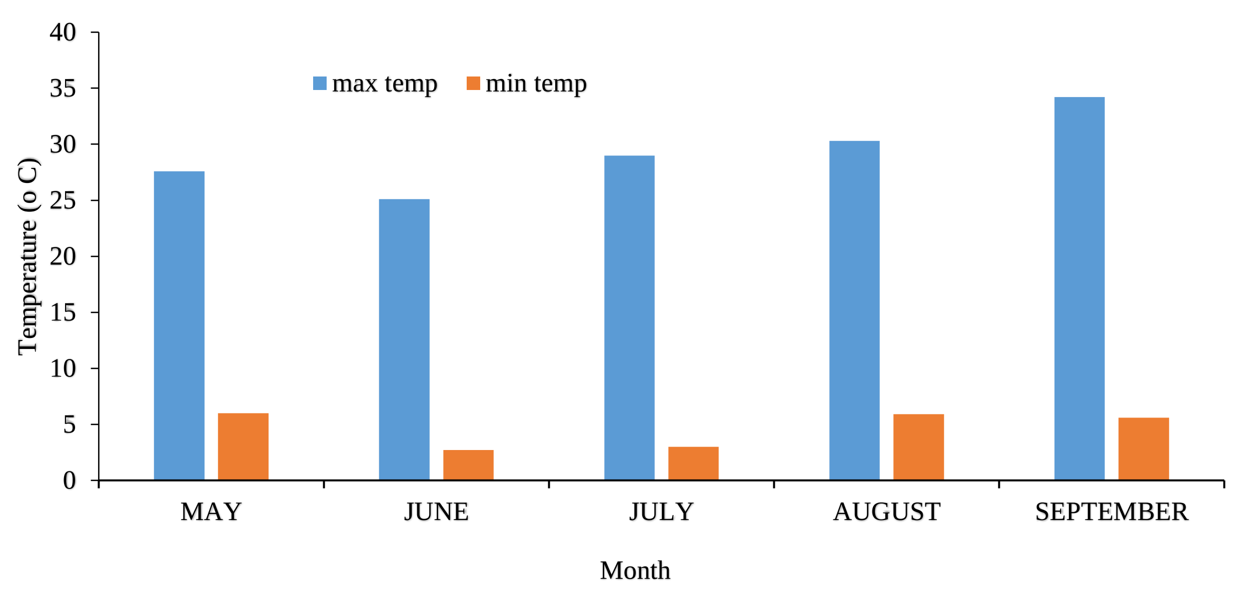


Figure 3. Monthly minimum and maximum temperatures recorded at SSKIA during the study period.

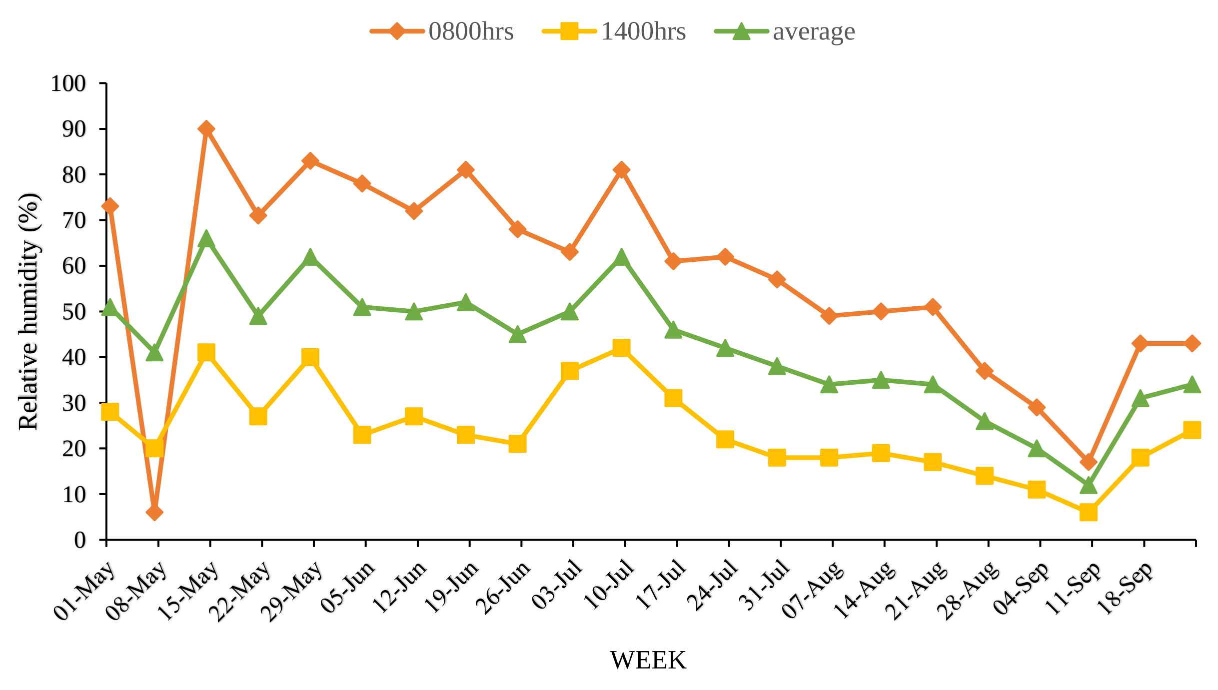


Figure 4. Weekly relative humidity recorded at SSKIA during the study period.

4.3 Evapotranspiration

There were significant differences ($P < 0.0001$) in ETo values recorded from May to September. As shown in Table 3, the highest ETo of 5.67 mm/day was recorded in September while the lowest (0.78 mm/day) was recorded in May. A significant distinction in ETo values across months were observed at ($P \leq 0.05$).

Table 3: Average ETo for all turfgrass species measured in different months

Month	ETo (mm/day)
May	0.78^{d}
June	2.06^{c}
July	2.05^{c}
August	3.16^{b}
September	5.67^{a}
Significance	****
LSD	0.540

**** Significant at $P = 0.0001$; means within a column followed by the same letter are not significantly different at $P = 0.05$.

4.4 Effect of irrigation regimes and turfgrass species on turfgrass growth

Irrigation regimes significantly affected the growth of *Cynodon dactylon, Pennisetum clandestinum*, and *Buchloe dactyloides*. The results indicated an increase in root growth with deficit irrigation and a decreasing root growth with over irrigation. All evaluated turfgrasses that received deficit irrigation (50% replacement of daily E_{pan}) had more root growth in terms of biomass and length (Table 4). While over irrigation (100 % and 110 % replacement of daily E_{pan}) resulted in less root growth (root biomass and root length). There was no significant difference in Chlorophyll content of all evaluated turfgrasses at all levels of irrigation (50 %, 75 %, 100 % and 110% replacement of daily E_{pan}). Replacing daily evapotranspiration with moderate irrigation (75 % replacement of daily E_{pan}) increased the clip biomass of *Cynodon dactylon*, *Pennisetum clandestinum*, and *Buchloe dactyloides*, while deficit irrigation (50% replacement of daily $E_{pan)}$ and over irrigation (100 % and 110% replacement of daily E_{pan}) reduced it (Table 4).

Turfgrass species significantly affected root biomass, root length and clip biomass. *Cynodon dactylon* exhibited the highest root length (13.67 cm), followed by *Pennisetum clandestinum* (root length = 12.21) and *Buchloe dactyloides* (root length = 7.09 cm) respectively (Table 4). Chlorophyll content was significantly the same among different turfgrass species. The highest root biomass was recorded for *Pennisetum clandestinum* (1.87 g), followed by *Cynodon dactylon* (1.73 g), while the lowest was recorded for *Buchloe dactyloides* (0.78 g). *Pennisetum clandestinum* also recorded the highest clip biomass of 2.86 g, followed by *Buchloe dactyloides* (2.48 g) and *Cynodon dactylon* (1.70 g) respectively.

Table 4. Effect of irrigation regimes and turfgrass species (Ir * Ts interaction) on turfgrass root biomass, root length, chlorophyll and clip biomass.

Treatment	Root biomass (g)	Root length (cm)	Chlorophyll SPAD readings	Clip biomass (g)
Irrigation regime (%)				
50	2.36±0.13a	14.90±0.73a	23.71±1.2ns	2.17±0.1b
75	1.65±0.13b	11.38±0.73b	27.52±1.2ns	3.26±0.1a
100	0.94±0.13c	8.67±0.73c	23.47±1.2ns	2.45±0.1b
110	0.90±0.13c	9.01±0.73c	23.62±1.2ns	1.50±0.1c
Turfgrass species				
Buchloe dactyloides	0.78±0.11b	7.09±0.63b	24.68±1.1ns	2.48±0.1b
Cynodon dactylon	1.73±0.11a	13.67±0.63a	25.73±1.1ns	1.70±0.1c
Pennisetum clandestinum	1.87±0.11a	12.21±0.63a	23.33±1.1ns	2.86±0.1a
F statistics				
Irrigation regime (Ir)	30.201***	15.44***	2.50ns	53.06***
Turfgrass species (Ts)	29.852***	29.81***	1.25ns	46.58***
Ir * Ts	2.404*	0.68ns	2.67**	2.89**

Values followed by dissimilar letters in the same column within a treatment are significant at P≤0.05 according to Fischer LSD. *: P≤0.05; **: P≤0.01; ***: P≤0.001. ns=not significant. Values in the columns represent the means and their standard errors. Ir * Ts indicates interaction.

4.5 Interactive effect of irrigation regimes and turfgrass species on root biomass

There was a significant interactive effect between turfgrass species and irrigation regimes. *Pennisetum clandestinum* produced a significantly higher root biomass irrespective of the applied irrigation regime, followed by *Cynodon dactylon*, While *Buchloe dactyloides* had the lowest biomass across all applied irrigation regimes (50 %, 75 %, 100 % and 110% replacement of daily E_{pan}). Interaction also shows that turfgrasses that received lower replacement of daily E_{pan} (50 % and 75 %) had more root biomass than those which were over irrigated (100 % and 110% replacement of daily $E_{pan)}$. (Figure 5)

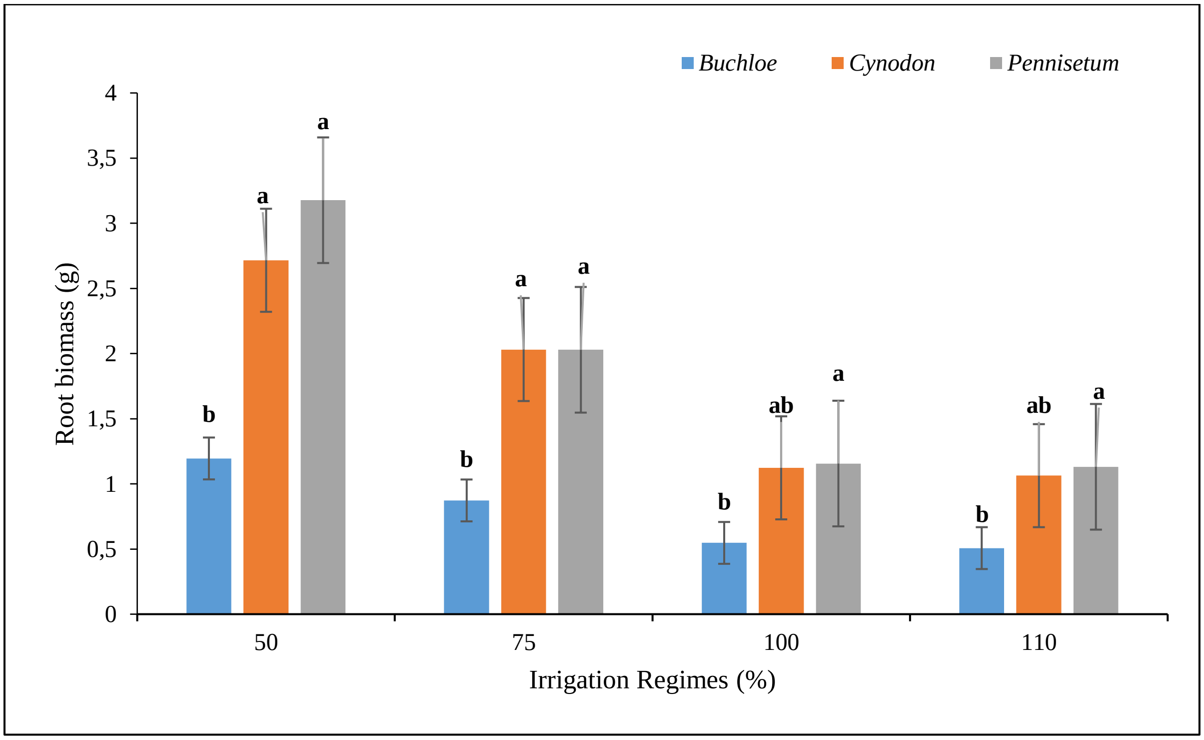


Figure 5. Interactive effect of irrigation regimes and turfgrass species on root biomass. Different letters on the bars of each irrigation regime indicate significant differences at P≥0.05 according to Fischer LSD. Error bars represents standard error.

4.6 Interactive effect of irrigation regimes and turfgrass specie on clip biomass.

As summarized on (figure 6), significant differences were observed between the interactive effect of irrigation regimes and turfgrasses on clip biomass. The highest clip biomass was recorded when turfgrasses were moderately irrigated at 75 % replacement of $E_{pan.}$ The lowest clip biomasses were recorded when they were over irrigated at 110 % replacement of $E_{pan.}$ The analysis of variance also showed that the interaction between irrigation regimes and turfgrass species was significant at $P < 0.001$ (Table 5).

A comparison between turfgrass species shows that *Pennisetum clandestinum* consistently recorded the highest clip biomasses across all irrigation regimes, seconded by *Buchloe dactyloides* and *Cynodon dactylon* with the lowest clip biomass across all irrigation regimes.

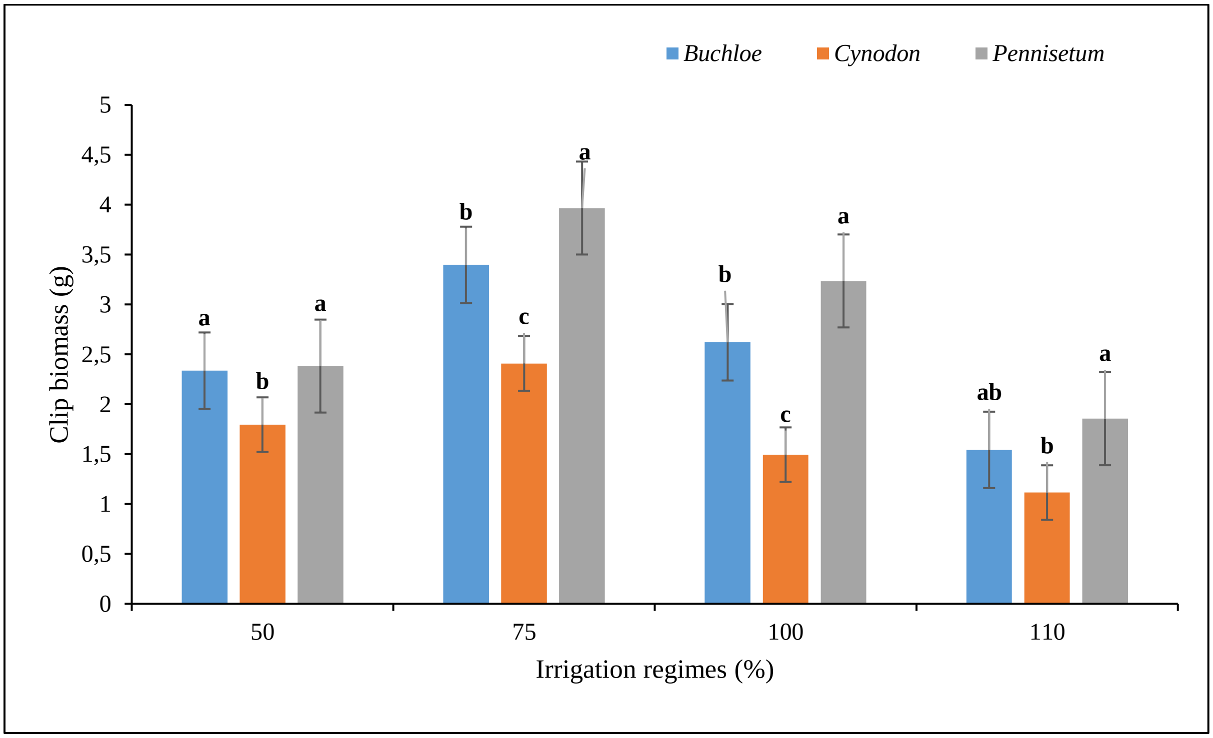


Figure 6. Interactive effect of irrigation regimes and turfgrass species on clip biomass. Different letters on the bars of each irrigation regime indicate significant differences at P≥0.05 according to Fischer LSD. Error bars represents standard error.

4.7 Interactive effect of irrigation regimes and turfgrass species on chlorophyll content

There was a significant interaction in chlorophyll content among turfgrasses that received deficit and normal irrigation (50 % and 75 % of daily replacement of E_{pan}). Among these turfgrasses, *Cynodon dactylon* followed by *Buchloe dactyloides* exhibited the highest level of chlorophyll content while *Pennisetum clandestinum* at 50 % and 75 % of daily replacement of E_{pan} exhibited the lowest values (Figure 7). However, there was no significant interaction in chlorophyll content among turfgrasses that received the highest replacement of daily evapotranspiration (100 % and 110 % replacement of E_{pan}).

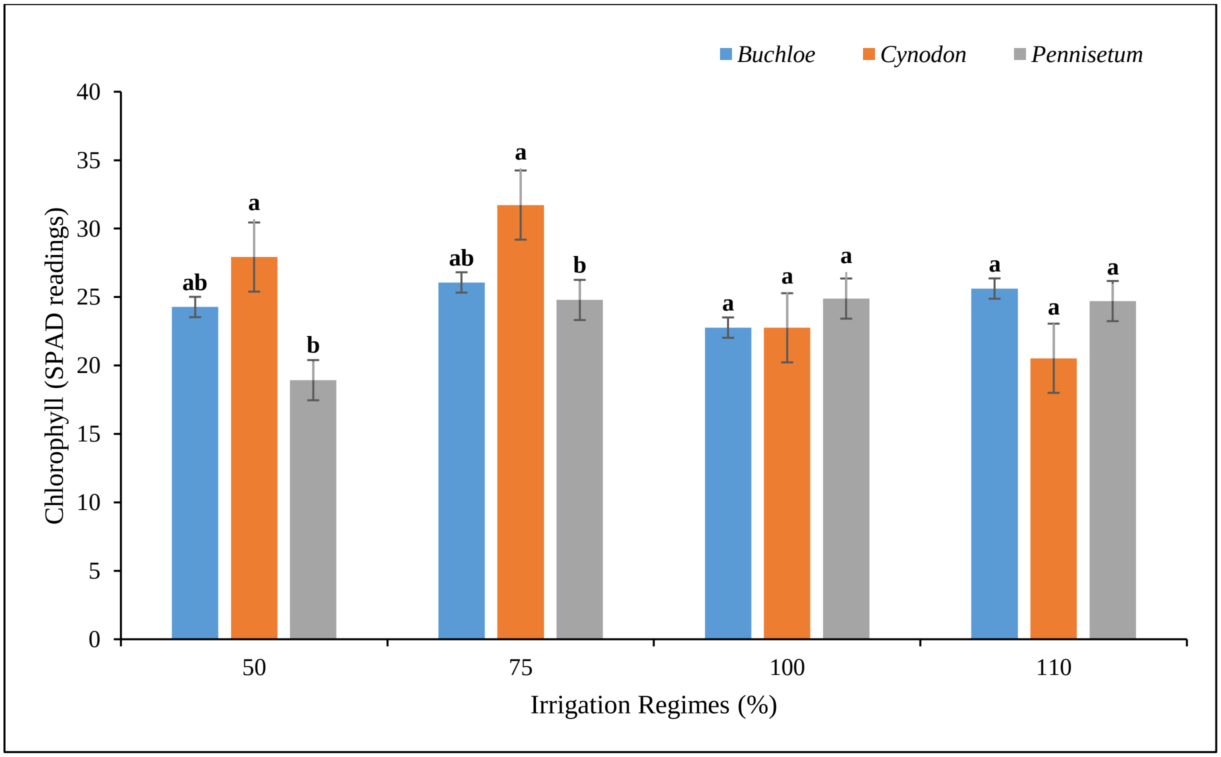
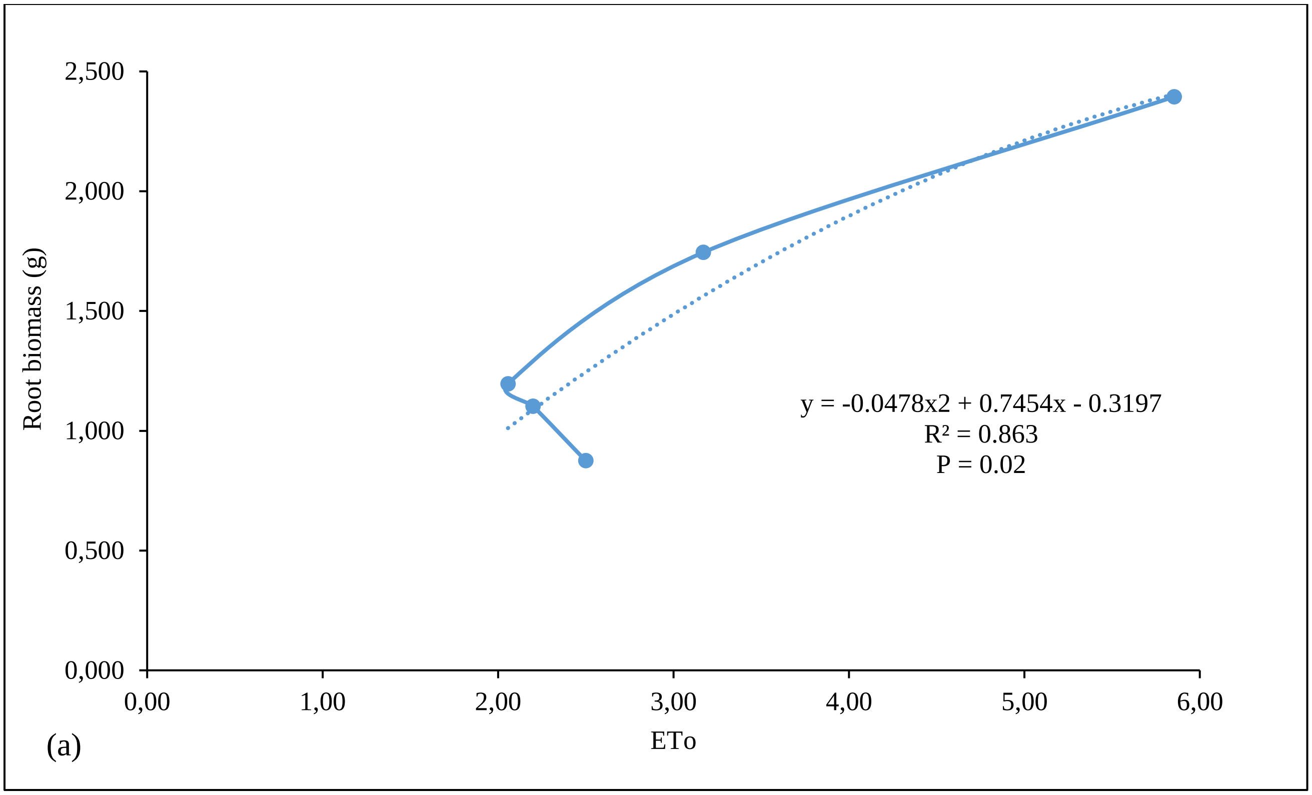


Figure 7. Interactive effect of irrigation regime and turfgrass species on chlorophyll content. Different letters on the bars of each irrigation regime indicate significant differences at $P \geq 0.05$ according to Fischer LSD. Error bars represents standard error.

4.8 Regression analysis

Figure 8 (a, b and c) indicates the relationship between reference evapotranspiration (ETo), root biomass, root length and clip biomass. Regression analysis revealed that ETo contributed 86.3 %, 63.59 % and 88.26 % to variability in root biomass, root length and clip biomass respectively. A significant polynomial relationship between ETo and root biomass with $R^2 = 0.863$ was observed. The relationship (polynomial) between ETo and clip biomass was also significant with $R^2 = 0.8826$, while a non-significant polynomial relationship between ETo and root length with $R^2 = 0.6359$ was observed.



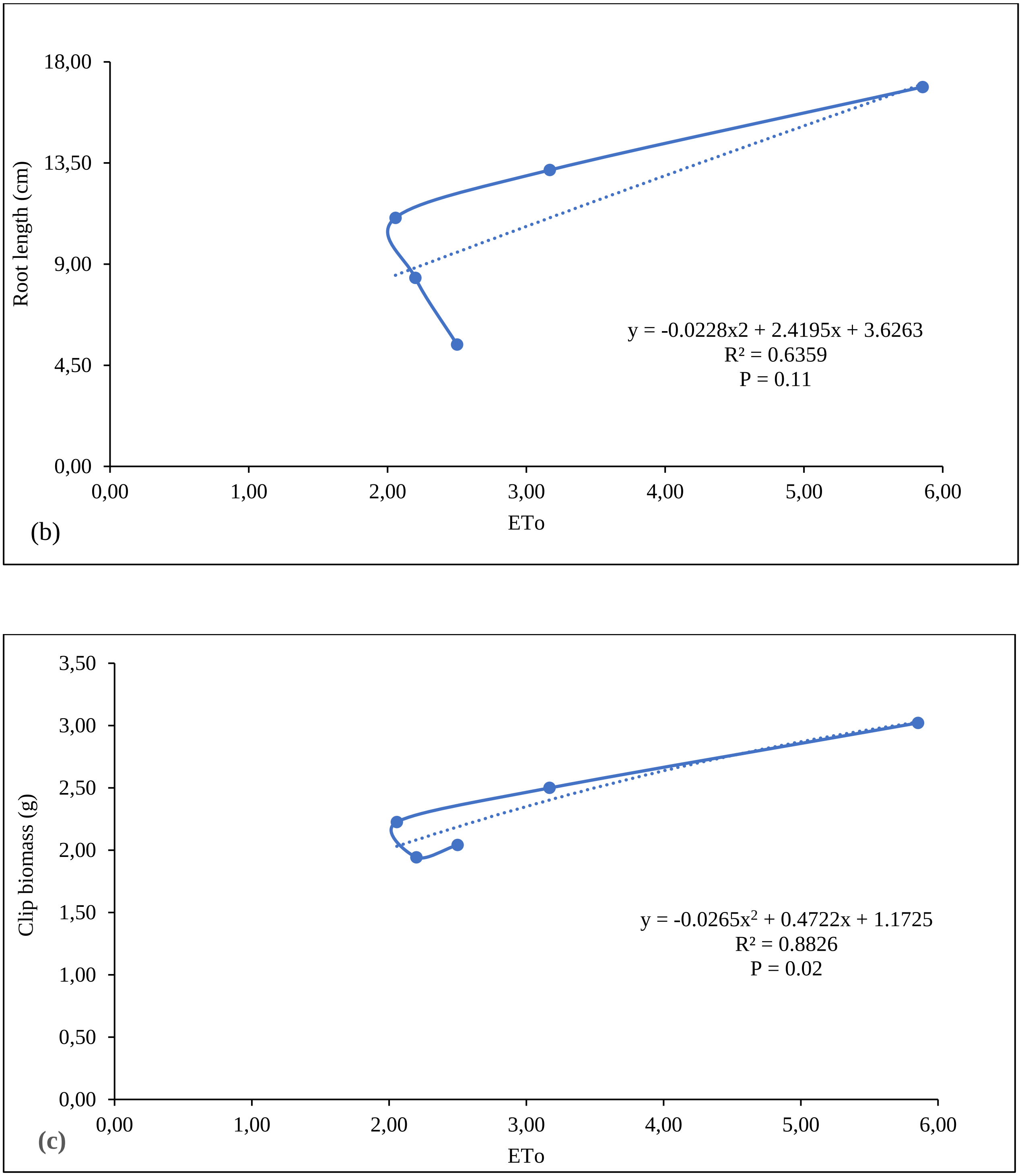
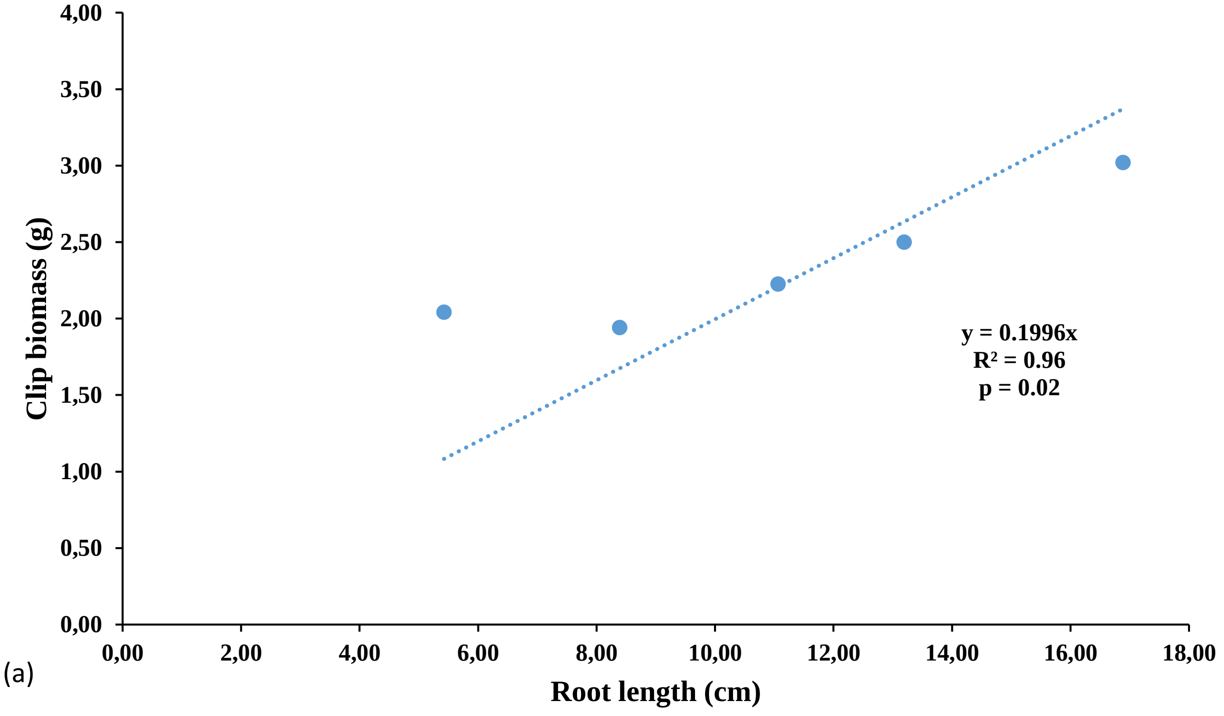


Figure 8. Relationship between root biomass (a), root length (b) and clip biomass (c) against reference crop evapotranspiration (ETo) of turfgrasses.

Figure 9 (a and b) indicates the relationship between below ground (Root length and Root biomass) and above ground variables measured in this study. There is a significantly higher regression between clip biomass and Root length ($R^2 = 0.96$) and between clip biomass and Root biomass ($R^2 = 0.96$). Root length contributed 96% to variability in clip biomass while Root biomass contributed 95.9% to variability in clip biomass.



(b)

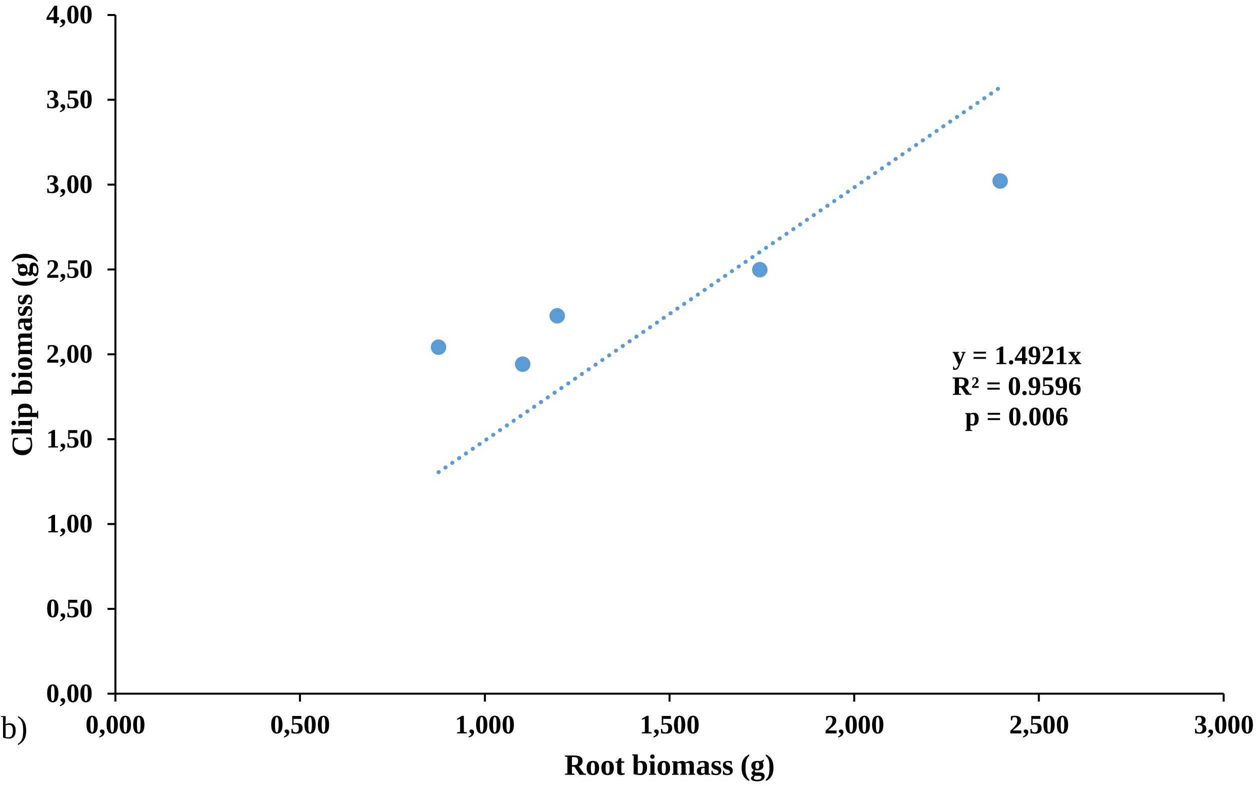


Figure 9. (a and b). Relationship between clip biomass and root lenth (a) and between clip biomass and root biomass (b).

CHAPTER 5

DISCUSSION

5.1 Response of root biomass and root length to irrigation regimes

The results of this study indicates that irrigating *Cynodon dactylon*, *Pennisetum clandestinum*, and *Buchloe dactyloides* had both detrimental and incremental effect on turfgrass root biomass and root length at different irrigation regimes (50%, 75%, 100% (control) and 110%). Irrigating *Cynodon dactylon, Pennisetum clandestinum,* and *Buchloe dactyloides* at 100 % and 110 % replacement of E_{pan} reduced root biomass and root length, while deficit irrigation (50 % and 75% replacement of E_{pan}) increased root biomass and root length. These results are in agreement to those reported in literature that when deficit irrigation is applied, turfgrasses develop longer roots with more biomass and over irrigation leads to shallow roots with less root biomass (Huang *et al.,* 1997; Short, 2001; Barton *et al*., 2006). Similarly, Fu *et al*., (2004); Mathowa *et al*., (2014) and Scott and DaCosta, (2020) reported more roots growth (deep and extensive root system) when different turfgrass species were irrigated at lower levels of irrigation regimes and reduced roots growth when they were irrigated at 100% or more of irrigation regimes. The results of Hejl *et al.,* (2016) corroborated the findings of this research.

Warm season turfgrasses are generally more resistant to drought when compared to cool season turfgrasses (McCarty, 2001; Brakie, 2013). When below ground resource availability decreases they allocate relatively more biomass to their roots to enhance resource capture (Evans and Edwards, 2001; Reich, 2002; Cristiano, 2015). Deficit irrigation increases rooting depth and in turn makes the turfgrass more equipped to face future drought periods (Schild and Dworak, 2013). With deficit irrigation, 50% to 75% replacement of E_{pan}, more roots biomass and root length were reported for *Cynodon dactylon*, followed by *Pennisetum clandestinum* and *Buchloe dactyloides* respectively with the least root biomass and root length. These results indicate that *Cynodon dactylon* was more tolerant to water deficit than *Pennisetum clandestinum* and *Buchloe dactyloides*. Furthermore, these results demonstrate variation in water usage by these three turfgrass species under water deficit stress consistent with previous studies (Fu *et al*., 2004; Huang, 2008; Young, 2019). *Cynodon dactylon* roots elongated more than *Pennisetum clandestinum* and *Buchloe dactyloides*. Deep rooting enables plants to avoid water stress by taking up water from deeper in the soil profile when the surface soil is dry. These roots elongations are directly associated with drought resistance of turfgrass species (Carrow, 1996; Huang, 1999; Mathowa *et al*., 2014).

5.2 Response of clip biomass to irrigation regimes

In this study clip biomass of all evaluated turfgrasses was significantly affected by irrigation regimes. Irrigating *Cynodon dactylon*, *Pennisetum clandestinum*, and *Buchloe dactyloides* turfgrasses at 50%, 75%, 100% (control) and 110% replacement of E_{pan} had both increasing and decreasing effect on shoot growth. When compared to each other, *Pennisetum clandestinum* out performed *Cynodon dactylon* and *Buchloe dactyloides* in terms of clip growth. Similarly, Salman, (2008) and Geren *et al*., (2009) reported higher ground cover rate for *Pennisetum clandestinum*. All evaluated turfgrasses had characteristics of turfgrasses adapted to deficit irrigation and over irrigation. They exhibited increased clip biomass with less irrigation and reduced clip biomass when over irrigated. supporting evidence indicating increased and reduced clip biomass due to deficit and over irrigation were also reported by (short, 2001; Mathowa *et al*., 2014; Culpepper *et al*., 2019; Young, 2019;). Optimum clip biomass production was recorded when all evaluated turfgrasses were irrigated at 75 % replacement of Epan across all evaluated turfgrasses. Similarly, Garrot and Mancino (1994) and Mathowa *et al*., (2014) reported higher clip biomass production at 75 % replacement of E_{pan}. Additionally, deficit irrigation has been found to promote turfgrass tolerance to subsequent severe drought stress associated with increased clip biomass and enhanced osmotic adjustments (Beared, 1973; Jiang and Huang, 2001).

5.3 Turfgrass quality as influenced by irrigation regimes and turfgrass species

Previous studies used visual quality evaluation techniques and multispectral radiometry and digital image analysis to assess turfgrass quality (Wherly, 2011; Leinaur *et al.*, 2014; Morries and Sherman, 2016). The most visible determinates of quality include density, texture, uniformity and color. Turfgrass quality determinants such as color (chlorophyll content) are usually evaluated using multispectral radiometry and digital image analysis, (Karcher and Richardson 2003; Leinaur *et al.*, 2014). The current study used SPAD-502 plus-konica Minolta to quantify turfgrass color (chlorophyll content). Under water deficit stress, chloroplast ultra-structures are the first target to be damaged at the cellular levels since it is the major site of reactive oxygen species production, hence affecting turfgrass quality (Munne-Bocsh and Penuelas, 2003)

Among the three turfgrasses evaluated in this study, *Cynodon dactylon* maintained acceptable quality (had more chlorophyll) across all irrigation regimes (at 50%, 75%, 100% and 110% replacement of E_{pan}), followed by *Buchloe dactyloides* and *Pennisetum clandestinum* respectively. These results are similar to turf quality assessments noted for these species from previous studies (Croce *et al*., 2001; DeLuca *et al*, 2004; Geren *et al*., 2009; Culpepper, 2019; Young, 2019). Previous studies also suggested that *Cynodon dactylon* was likely to maintain acceptable turf quality due to its water conservative and water use characteristics (Zhou *et al*., 2013) or deeper rooting potential (Carrow, 1996; Huang *et al.*, 1997; Fu *et al*., 2004; Culpepper *et al*., 2019). However, the results differed from those by Young, (2019) who reported that *Buchloe dactyloides* was able to maintain acceptable and similar turf quality ratings at all water deficit levels, where else *Cynodon dactylon* had lower turf quality at severe water deficit stress. This suggests that *Buchloe dactyloides* has better drought survival mechanism when compared to

Cynodon dactylon (Ludlow *et al*., 1985; Qian and fry, 1997; Young, 2019). *Buchloe dactyloides* and *Cynodon dactylon* have superior drought resistance, while *Pennisetum clandestinum* is just judged to be good (Harivandi *et al*., 2009). Warm-season turfgrasses have some advantages over cool-season grasses in the summer since they have a unique morphology, high photosynthetic efficiency and reduced water requirements (Volterrani *et al*., 1997; Zhou and Abaraha, 2007). However, they tend to be frost-sensitive, and winter performance can be an issue. Thus, research to identify varieties with superior performance in traits such as colour retention and surface homogeneity during autumn, winter, and early spring will provide useful information for turf growers and managers.

5.4 Effect of environmental factors on dependent variables determined

In this study data was collected in winter and spring months, therefore low temperatures may have affected the results because *Cynodon dactylon*, *Pennisetum clandestinum*, and *Buchloe dactyloides* are warm season turfgrasses and are sensitive to low temperatures (Emmons, 2000 ; Anderson *et al*., 2002).Their growth usually stops below 16°C , and they become dormant when average daily temperatures drop below 10°C ,but when environment conditions are favorable they start growing (Emmons, 2000; Anderson *et al*., 2002). They have the ability to remain actively growing longer into the winter months (Holm *et al*., 1977; McCarty, 2001; Wieko, 2006). Intolerance to low temperature is one major limiting factor for most of the warm season turfgrass species (Thomas *et al*., 2009). As temperature increased during the months of August and September (figure 3), Root biomass, root length, clip biomass and turfgrass quality improved significantly for all turfgrass species. This was expected as they are classified as warm season grasses (Huang, 2006; Wieko, 2006; Hatfield, 2017), hence the reason why they were doing well in these warmer months as expected. Temperature responses of turfgrasses have been summarized by DiPaola and Beared (1992) and characterized chilling and high temperature stresses as being detrimental to turfgrass growth and quality. One of the noticeable differences in the results of this study as compared to existing studies was that, it compared the drought resistance of *Pennisetum clandestinum, Buchloe dactyloides* and *Cynodon dactylon* under Botswana conditions.

5.5 Turfgrass water use (evapotranspiration) as influenced by turfgrass species

Reference evapotranspiration rates recorded during the period of May 2018 to September 2018 indicated an increase in water use as the months became warmer. Winter months of May, June and July showed the lowest water use rates (0.78mm/day, 2.06mm/day and 2.05mm/day respectively). Early spring months (August and September) showed the highest water use rates (3.16mm/day and 5.67mm/day respectively). Lack of rainfall and increased temperatures in the months of August and September lead to increased evapotranspiration rates. Similar findings were reported by Colmer and Barton, (2017). They reported an increase of evapotranspiration with increasing aridity. When temperatures reached an average of 30°C during the study period, turfgrasses used more water. This increase in water usage across two seasons (winter and spring) may be due to the fact that *Cynodon dactylon*, *Pennisetum clandestinum*, and *Buchloe dactyloides* are warm season turfgrasses and they have an optimum growth temperature range between 27°C and 35°C (DiPaola and Beared, 1992; Hatfield, 2017) at which they perform better, hence more growth during August and September months which recorded the same range of temperatures (figure 3). Temperatures below 10°C were reported during the month of May, June and July. Lower temperatures lead to dormancy (Anderson *et al.*, 2002; Habib, 2017), therefore affecting turfgrass evapotranspiration and growth. Root growth differences among species appear to have a stronger relationship to ET_o rates than shoot growth rates (Wherley *et al.*, 2015). The results of this study showed that *Cynodon dactylon*, *Pennisetum clandestinum*, and *Buchloe dactyloides* had a range of 0.78mm to 5.67mm monthly averages of ET_o during the experimental period. These results agree with several studies which reported ET_o of warm-season turfgrasses to be within the range of 0.51mm/day (minimum) and a maximum 11.68 mm/day (Davit *et al.*, 1992; Fu *et al.*, 2004; Jia *et al.*, 2009; Colmer and Barton, 2017). However, the ET_o range of 0.78mm to 5.67mm was lower than the ET_o range of 6mm/day to 7mm/day reported by Beared and Kim, (1989) when evaluating water use for *Buchloe dactyloides* and *Cynodon dactylon*. This high variability in ET_o among warm-season turfgrasses makes it difficult to establish minimum and maximum ET_o rates for a specific species due to variation in climatic conditions, turfgrass species, mowing height and fertilization (Romero and Dukes, 2016).

5.6 Relationships between some measured response variables

In this study the highest root biomass, root length and clip biomass were associated with higher reference evapotranspiration (ET_o). An increase in ET_o showed an increasing tendency in root biomass, root length and clip biomass. This demonstrated that water use was responsible for turfgrass growth. These results are comparable to those reported by (Mathowa *et al*., 2014; Young, 2019), While contrary findings have also been reported by Jazi *et al*., (2018). This study was conducted in winter and spring months (May 2018 to September 2018) which recorded minimum temperatures, which in turn may have affected ET_o, hence its relationship to other variables measured in this study.

In this study the highest clip biomass was associated with the highest root biomass and root length. This implies that plants which accumulate more root biomass and root length may produce more clip biomass. These results agrees with the findings of Jordan, *et al*., (2003) and Mathowa *et al*., (2014) who also found that clip biomass was associated with root length and root biomass.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

Irrigation regimes had a significant effect on all turfgrass attributes measured in this study. *Cynodon dactylon*, *Pennisetum clandestinum* and *Buchloe dactyloides* were more efficient under water deficit conditions (50 % and 75 % replacement of E_{pan}). Full irrigation (100% replacement of E_{pan}) and over irrigation (110% replacement of E_{pan}) resulted in less clip biomass, root biomass and shorter root length. All turfgrasses had more growth (clip biomass, root biomass and root length) as temperatures became warmer (spring). Cold susceptibility of these turfgrass species was reflected in poor growth during winter for all measured growth variables, *Pennisetum clandestinum* performed better than *Cynodon dactylon* and *Buchloe dactyloides*, when irrigated at 75% replacement of E_{pan}.

It is concluded that the most efficient irrigation regime is 75 % replacement of E_{pan} and *Pennisetum clandestinum* is the best turfgrass to grow at 75 % replacement of E_{pan} followed by *Cynodon dactylon* and *Buchloe dactyloides,* though its quality is more compromised at lower temperatures (during winter) when compared to *Cynodon dactylon* and *Buchloe dactyloides.* Irrigating these turfgrass species (*Pennisetum clandestine, Cynodon dactylon* and *Buchloe dactyloides)* at 75 % replacement of E_{pan} has the potential of being a useful management program for irrigation requirements in turfgrass management, therefore reducing expenses associated with turfgrasses irrigation. There is a need to assess water use of this turfgrasses in both controlled and uncontrolled environments for longer periods (two years or more) to determine longer term effects of irrigation regimes on their growth characteristics.

Reducing water use in turfgrass management presents an opportunity for saving both money and water for turfgrass managers and homeowners hence reducing the production and management costs in turfgrass business. This can be achieved by adopting healthy landscape practices such as irrigating based on turfgrass water needs rather than a regular irrigation schedule.

6.2 Recommendations

From this study, the following recommendations are made:

6.2.1 Based on their performance *Pennisetum clandestinum and Cynodon dactylon* are recommended for Botswana conditions under limited water resources, due to their ability to maintain acceptable growth and quality with deficit irrigation.

6.2.2 For further studies, the effect of propagation methods, humidity, temperature, wind, vigor and canopy resistance on turfgrass growth and establishment in Botswana should be conducted under well controlled and uncontrolled conditions.

6.2.3 Further studies taking advantage of new technologies such as Digital Image Analysis, spectral reflectance, handheld optical sensors for visual quality assessments and lysimeters for accurate ET recording are recommended. These technologies will improve data accuracy and capturing in the absence of trained turfgrass quality evaluators.

REFERENCES

Allen, R.G., Smith, M., Pereira, L.S. and Smith, M. (1998). Crop evaporation and Guidelines for computing crop requirements. FAO Publication. Rome, Italy.

Anderson, J.A., Taliaferro, C.M. and Martin, D.L. (2002). Freeze tolerance of Bermuda grasses. Vegetatively propagated cultivars intended for fairway, putting green use and seed-propagated cultivars. *Crop Sci 42*: 975–977.

AOAC. (2005). Methods of Soil Analysis, 12th edition. Association of Official Analytical Chemists, Washington DC. United States of America.

Atkins, C.E., Green, R.L., Sifers, S.I. and Beard, J.B. (1991). Evapotranspiration rates and growth characteristics of ten St. Augustinegrass genotype. *HortSci* 26(12):1488-1491.

Aydinsakir, K., Buyuktas, D., Bastug, R. and Yilmaz, S. (2016). Evapotranspiration and quality characteristics of some bermudagrass turf cultivars under deficit irrigation. *Japanese Society of Grassland 62*(4): 224-232.

Baldwin, C.M., Liu, H., McCarty, L.B. and Bauerle, W.L. (2006). Response of six bermudagrass cultivars to different irrigation intervals. *Horttechnology* 16(3): 466-470.

Barton, L., Wan, G.G.Y. Colmer, T.D. (2006). Turfgrass (Cynodon dactylon L.) sod production on sandy soils: I. Effects of irrigation and fertiliser regimes on growth and quality. *Plant and Soil* 285: 129-145.

Beard, J. and Green, R. (1994). The Role of Turfgrasses in Environmental Protection and Their Benefits to Human. *Environ. Qual 23*: 452-458.

Beard, J.B. (1973). Turfgrass: Science and Culture. Prentice-Hall Publishers. United State of America.

Beared, J. and Kim, K. (1989). Low water-use turfgrasses. USGA. *Green section record* 27: 12-13.

Biran, I., Bravdo, B., Bushkin-Harav, I. and Rawitz, E. (1981). Water Consumption and Growth Rate of 11 Turfgrasses as Affected by Mowing Height, Irrigation Frequency, and Soil Moisture. *Agron. Journal* 73: 85-90.

Brakie, M. R. (2013). Plant Guide for buffalograss. USDA-Natural Resources Conservation Service, East Texas Plant Materials Center. Nacogdoches. TX 75964.

Cabrera, A.L. (1968). Flora de la Provincia de Buenos Aires. II. Buenos Aires, Argentina: INTA. Pp. 309-404.

Carrow, R.N. (1996). Drought resistance aspects of turfgrasses in the southeast. Root-shoot responses. *Crop Science* 36: 687-694.

Chiew, F.H.S., kamaladasa, N. N., Malano, H.M. and McMahon, T.A (1995). Penman-monteith, FAO-24 reference crop evapotranspiration and class ‘A’ pan data for Australia. *Agriculture water Management* 28: 9-21.

Colmer, T.D., and Barton, L. (2017). A review of warm-season turfgrass evapotranspiration, responses to deficit irrigation, and drought resistance. *Crop science*. 57: 98-110.

COSEWIC. (2011). COSEWIC assessment and status report on the Buffalograss Bouteloua dactyloides in Canada. Committee on the Status of Endangered Wildlife in Canada. Retrieved from: http://www.registrelepsararegistry.gc.ca

Covas, G. and Salvai, A.F. (1972). Las especies de Cynodon (Graminae) de la Rep. *Blica Argentina*. *Kurtziana* 5:191-252.

Cristiano, M.P., Posse, G. and Bella, M.C. (2015). Total and above ground radiation use efficiency in C_3 and C_4 grass species influenced by nitrogen and water availability. *Japanese Society of Grassland Science* 21: 1744-6961.

Christians, N. (2011). Fundamentals of turfgrass management. 4th edition. John Willey and sons, Inc. New Jersey, United States of America.

Croce, P.,De Luca, A., Mocioni, M., Volterrani, M. and Beard, J. B. (2001). Warm season turfgrass species and cultiva characterizations for a mediterranean climate. *Turfgrass Soc* 9: 855-859.

Culpepper, T., Young, J. and Wherley, B. (2019). Comparison of four warm-season turfgrass species to natural rainfall or supplemental irrigation in a semiarid climate. *Agrosyst Geosci Environ* 20: 20011.

DaCosta, M. and Huang, B. (2006). Minimum water requirements for creeping, colonial and velvet bentgrasses under fairway conditions. *Crop Sci* 46: 81-89.

De Luca, A., Croce, P., Mocioni, M., Volterrani, M. and Beard J. B. (2004). Adaptability of warm season turfgrass species and cultivars in a mediterranean climate. *Actahortic* 661: 365-368.

Department of meteorological services. (2003). Botswana’s climate. Retrieved from http://www.info.bw.

Devitt, D.A., Morris, R.L. and Bowman, D.C. (1992). Evapotranspiration, crop coefficients, and leaching fractions of irrigated desert turfgrass system. *Agron* 84(4):717-723.

DiPaola, J.M. and Beard, J.B. (1992). Physiological effects of temperature stress. In Waddington D.V., Carrow, R.N. and Shearman, R.C. (Eds). *Turfgrass, American Society of Agronom* 231–267.

Doorenbos, J. And Pruitt, O. (1988). Guidelines for predicting crop water requirements. FAO Publication. Rome, Italy.

Duan, H. (2018). Investigations into water use rates and drought resistance of tufgrasses under shaded conditions. MSc Thesis. Oklahoma State University. United States of America.

Ehleiringer, J. R., Cerling, T. E. (2002). The Earth sytem: biological and ecological dimensions of global environmental change. In Mooney, H.A. and Canadell, J.G. (Eds). Encyclopedia of global environmental change. 186–190.

Ervin, E. H. (1995). Performance of Kentucky bluegrass, Tall fescus, and Buffalograss under line source irrigation. MSc thesis. Colorado State University. United States of America.

Emmons, R. (2000). Turfgrass science and management. 3rd edition. Thompson Learning, Inc. United Kingdom. Pp. 43-60.

Emongor, V. E., Ramolemana, G. M. and Machacha, S. (2008). Physico-chemical properties and faecal coliform content of Notwane River and its suitability for irrigation. Botswana Journal of Agriculture and Applied Sciences 4(2): 194-202.

Evans, J.R. and Edwards, E.J. (2001). Nutrient uptake and use in plant growth. In: report of the CRC for greenhouse accounting, Canberra. Pp.75-81.

FAO. (1984). Crop water requirements. By: J. Doorenbos and W.O. Pruitt. FAO Irrigation and Drainage Paper 24. Rome, Italy.

FAO. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. By: Richard Allen, Luis Pereira,Dirk Raes and Martin Smith. FAO Irrigation and Drainage Paper 56. Rome, Italy.

FAO. (2010). Grassland Index. A searchable catalogue of grass and forage legumes. Retrieved from: http://www.fao.org.

Feldhake, C.M., Danielson, R.E and Butler, J.D. (1983). Turfgrass evapotranspiration. Factors influencing rate in urban environments. *Agronomy Journal* 75: 824-830.

Feldhake, C.M., Danielson, R.E. and Butler, J.D. (1984). Turfgrass Evapotranspiration. Responses to Deficit Irrigation1. *Agronomy Journal* 76: 85-89.

Ford, P.L. (1999). Response of Buffalograss (Buchloë dactyloides) and blue grama (Bouteloua gracilis) to fire. *Great Plains Research* 9: 261-276.

Fu, J., Fry, J. and Huang, B. (2004). Minimum water requirements of four turfgrasses in the transition zone. *Hortscience 39*(7): 1740-1744.

Garrot, D. J. and Mancino, C. F. (1994). Consumptive water use of three intensively managed Bermuda grasses growing under arid conditions. Crop Sci 24: 215-221

Geren, H., Avcioglu, R. and Curaoglu, M. (2009). Performances of some warm-season turfgrasses under Mediterranean conditions. *African Journal of Biotechnology* 8: 4469–4474.

Green, R.L., Sifers, S., Atkins, C.E. and Beared, J.B. (1991). Evapotranspiration rates of eleven zoysia genotype. *HortSci* 26:264-266.

Gibeault, V.A., Cockerham, A.S., Henry, J.M. and Meyer, J. (1989). California turfgrass: its use, water requirement and irrigation. *Turfgrass Cult* 39:1-9.

Gieske, A.S.M. (1992). Dynamics of groundwater recharge: a case study in semi - arid Eastern Botswana. Phd Thesis. University of Twente, Netherlands.

Gould, F.W and shaw, R.B. (1983). Grass systematic.Texas A and M university press. Dallas, United States of America.

Habib, U., Harrington, K. and Matthew, C. (2017). Comparative Evaluation of Visual Quality Attributes for Warm Season Turfgrasses. Institute of Agriculture and Environment. Massey University, New Zealand.

Handreck, K.A. and Black, N.D. (1994). Growing media:manns lawn certificate in horticulture: *Turf culture* 46: 160-163

Harivandi, M.A, (1996). Hybrid bermudagrass winter overseeding,university of California, cooperative extension. *California turfgrass Cult* 36:1-4.

Harper, C. J. (2018). Mowing turfgrasses. Retrieved from: http://plantscience. Psu.edu.

Hatfield, J. (2017). Turfgrass and climate change. *Agronomy Journal* 109:1708-1718.

Hejl, R.W., Wherley, B.G., White, R.H., Thomas, J.C. and Fontanier, C.H. (2016). Deficit irrigation and simulated traffic on ‘tifway’ bermudagrass summer performance and autumn recovery. *Crop Science* 56:809-817.

Helfgott, S.F. (1994). Pennisetum clandestinum Hochst. In Labrada, R., Caseley, J.C. and Parker, C. (eds). Weed Management for Developing Countries. Rome, Italy.

Huang, B. (1999). Water relations and root activities of *Buchloe Dactyloides* and *Zoysia japonica* in response to localized soil drying. *Plant Soil* 208:179-189.

Huang, B. (1999). Water relations and root activities of Buchloë dactyloides and Zoysia japonica in response to localized soil drying. *Plant and Soil* 208:179-186.

Huang, B. (2006). Turfgrass water use and conservation strategies. In water quality and Quantity issues for turfgrasses in urban landscapes. Ames, Iowa: council for agricultural science and technology. Pp: 193-204.

Huang, B. (2008). Turfgrass water requirements and factors affecting water usage. *Council for Agriculture Science and Technology* 27:193-205.

Huang, B., Duncan, R. and Carrow, R. (1997). Drought-resistance mechanisms of seven warm-season turfgrasses under surface soil drying and Root aspects. *Crop Sci* 37:1863-1869.

Jia, X.H., Dukes, M.D. and Jacob, J.M. (2009). Bahiagrass crop coefficients from eddy correlation measurements in central Florida. *IrrigSci* 28(1): 5-15.

Jiang, Y. and Huang, B. (2001). Drought and heat stress injury to two cool-season turfgrasses in relation to antioxidant metabolism and lipid peroxidation. *Crop sci* 41: 436-442.

Johnston, K. and Forrest, J. (1999). Arresting summer decline of couch greens. Turfcraft INT. 66:39-44 GEN, 1999. Mower choice can boost turf quality. GEN magazine, June 1999, Pp. 22-23.

Jordan, J.E., White, R.H., Vietor, D.M., Hale, T.C., Thomas, J.C. and Engelke, M.C. (2003). Effect of irrigation frequency on turf quality, shoot density, and root length density of five bentgrass cultivars. *Crop Sci* 43: 282-287.

Karcher, D.E. and Richardson, M.D. (2003). Quantifying turfgrass color using digital image analysis. Crop Sci 45: 1536–1539.

Kreuser, C.B. (2015). Simplifying soil test interpretations for turf production. G2265. http://extension. Unl. Edu/publications.

Kumar, R. Jat, M.K. and Shankar, V. (2012). Methods to estimate irrigated reference crop evaporation-a review.water science and technology. Iwa, United States of America.

Leinaur, B., Vanleeuwen, D.M., Severana, M., Schiavon, M. and Sevostianov, A. (2014). Digital image analysis and spectral reflectance to determine turfgrass quality. *Agronomy Journal* 106:1787-1794.

Madison, J. H. (1962). Turfgrass Ecology. Effects of Mowing, Irrigation, and Nitrogen Treatments of Agrostis palustris Huds, 'Seaside' and Agrostis tenuis Sibth, 'Highland' on Population, Yield, Rooting, and Cover1. *Agronomy Journal* 54: 407-412.

Mantell, A. (1966). Effect of Irrigation Frequency and Nitrogen Fertilization on Growth and Water Use of a Kikuyugrass Lawn (Pennisetum clandestinum 1Hochst.). *Agronomy Journal* 58:559-561.

Mathowa, T., Chinachit, W., Yangyuen, P. and Isarangkool Na Ayutthaya, S. (2014). Influence of irrigation regime on some growth characteristics and water use efficiency of native common Bermuda grass (*Cynodon dactylon* L.) maintained as turfgrass. *ActaHort* 1025: 163-172.

McAfee, J.A. and Leps, R.E. (2001). Wiliamson county non-irrigated Turfgrass Study. Professional bulletin. Williamson County extension center, Georgetown, USA.

McCarty, L. (2001). Best golf course management practices. Upper Saddle River, NJ: Prentice Hall. New Jersey, United States of America.

Mguni, M. (2017). Water restrictions stay, Masama West goes on. *Mmegi*. Retrieved from http://www.mmegi.bw.

Morries, N.K. and Sherman, C.R. (2016). A guide to NTEP turfgrass evaluation ratings. Retrieved from: www.ntep.org.

Morris, K. N. and Shearman, R. C. (2014). NTEP turfgrass evaluation guidelines. In *NTEP turfgrass evaluation workshop,* Beltsville, MD (1–5).

Munne-Bosch, S. and Penuelas, J. (2003). Photo and antioxidative protection, and a role for salicylic acid during drought and recovery in field grown phillyrea angu-stifolia plants. *Planta* 217(5): 758-766.

Nelson, P. R. (1993). Additional uses for the analysis of means and extended tables of critical values. *Technometrics* 35:61-71.

Parker C, 1992. Weeds of Bhutan. National Plant Protection Centre. Thimphu Bhutan. Pp.236.

Peng, L., Li, Y. and Feng, H. (2017). The best alternative for estimating reference crop evaporation in different sub- regions of mainland china. *Scientific Report* 7: 5458.

Pessarakli, M. (2008). Handbook of turfgrass management and physiology (1st edition). CRC Press. https://doi.org/10.1201/9781420006483.

Pornaro, C., Dal Maso, M. and Macolino, S. (2021). Drought resistance and recovery of kentucky bluegrass (*Poa Pratensis* L.) cultivars under different nitrogen fertilisation rates. *Agronomy Journal* 11:1128.

Qian, Y., and Engelke, M. (1999). Performance of Five Turfgrasses under Linear Gradient Irrigation. *Hortscience* 34: 893–896.

Radhakrishnan, M., Waisel, Y. and Sternberg, M. (2006). Kikuyu grass: a valuable salt-tolerant fodder grass. *Communications in Soil Science and Plant Analysis* 37:1269-1279.

Reich, B.P. (2002). Root-shoot relations: optimality in acclimation and adaptation or the “Emperor’s new clothes” In: plnt Roots-The Hidden half. Marcel dekker. New York. Pp. 205-220.

Romero, C.C. and Dukes, M.D. (2016). Review of turfgrass evapotranspiration and crop Coefficiency. *American society of agricultural and biological engineers* 59: 207-223.

Salaiz, T.A., Horst, G.L. and Shearman, R.C. (1994). Mowing Height and Vertical Mowing Frequency Effects on Putting Green Quality. Crop science. Journal series no. 10770. University of Nebraska, United States of America.

Salman, A. (2008). Effect of different fertilizer levels on some cool and warm season turfgrass on turf performances, Ege university graduate school of Natural and Applied Science, Turkey. Pp. 170.

Sandova, J.R. and Rodriquez, P.A. (2014). Invasive species compendium cynodon dactylon (Bermudagrass). Retrieved from: www. Cabi.org/ISC.

Savva, A.P. and Frenken, K. (2002). Crop water requirements and irrigation scheduling. Water resources development and management officers. FAO sub-reginal office for east and southern Africa.harare. Irrigation manual module 4.1-10.

Schild, A.J. and Dworak, S. (2013). Drought effects on turf in the landscape. University of Nebraska-lincoln extension. G2191. http:// extension.unl.edu/publications.

Selepeng, W. (2004). Water group supports water restrictions. *Mmegi*. Retrieved from https://www.mmegi.bw.

Semple, W.S., Cole I.A. and Koen T.B. (2004). Native couch grasses for revegetating severely salinised sites on the inland slopes of NSW. *Rangeland Journal* 26: 88-101.

Short, D. (2001). Water use and drought tolerance in turf grasses (Ph.D). The University of Western Australia, Australia.

Statistical analysis software institute (SAS). (2002-2008). SAS/STAT User's Guide; statistics, release 9.4 Edition.SAS Institute Inc.,Cary, NC,USA.

Stier, J., Steinke, K., Ervin, E., Higginson, F. and McMaugh, P. (2013). Turfgrass Benefits and Issues. *American Society of Agronomy, Crop Science Society of America, Soil Science Society of America 3:105*-133.

Thomas, R.S., Rodgers, C.A., VanDyke, R., Williams, D.W. and Phillips, T.D. (2009). The Inheritance of Cold Tolerance and Turf Traits in a Seeded Bermuda grass Population. *Crop Science 49*: 1489–1495.

Toteng, J., Legwaila, I., Mpofu, C. and Mathowa, T. (2014). Performance of Three Warm Season Turfgrasses as Influenced by Different Seeding Rates in Gaborone Region, Botswana. *Int'l Conf. On Advances in Environment, Agriculture & Medical Sciences* 14: 33-36. Retrieved from http://dx.doi.org/10.17758/IAAST.

Turgeon, A. J. (1980). Turfgrass management. 1st edition. Reston Publishing. Virginia, United States of America.

Turgeon, A.J. (1996). Turfgrass management, 4th edition. Prentice-Hall Publishers. Upper Saddle River, New Jersey, United States of America.

Turgeon, A. (1999). Turfgrass management. 5th Edition. Prentice-Hall Publishers. Upper Saddle River, New Jersey, United States of America.

USDA-ARS. (2008). Germplasm Resources Information Network (GRIN). Online Database. Beltsville, Maryland, USA: National Germplasm Resources Laboratory. https://npgsweb.ars-grin.gov/gringlobal/taxon/taxonomysearch.aspx

Volterrani, M., Grossi, N., Pardini, G., Miele, S., Gaetani, M. and Magni, S. (1997). Warm season turfgrass adaptation in Italy. Intl. *Turfgrass Soc Journal* 8:1344-1354.

Wherley, B. (2011). Turfgrass Growth, Quality, and Reflective Heat Load in Response to Deficit Irrigation Practices, Evapotranspiration, Prof. Leszek Labedzki (Ed.), InTech, doi: 10.5772/15064.

Wherley, B., Dukes, M.D., Cathey. S. and Miller, L.G. (2015). Consumptive water use and crop coefficients for warm-season turfgrass species in the southeastern united states. *Agricultural water management* 156:10-18.

Wiecko, G. (2006). Fundamentals of tropical turf management. 1st edition. CAB International, Oxfordshire, United Kindom.

Wiecko, G. (2008). Management of tropical turfgrasses. In: M. Pessarakli (1st edition), handbook of turfgrass management and physiology. Tylor and francis group, CRC press Tempe. Arizona, United States of America. Pp: 115-137

Young, J. (2019). Physiological Responses in C_3 and C_4 turfgrasses under soil water deficit. *HortScience* 54 (12): 2249-2256.

Zhou, S. and Abraham, A. (2007). Response to heat stress in warm season and cool season turfgrass cultivars. *Scientific Research and Essays* 2: 95–100.

Zhou, Y., Lambrides, C.J., Roche, M.B., Duff, A. and Fukai, S. (2013). Temporal and spatial patterns of soil water extraction and drought resistance among genotypes of a perennial C_4 grass. *Functional Plant Biology* 40: 379-392.

Zuk, A. and McGinnis, E. (2017). Interpreting the UDSU soil test analysis for managing turfgrass. www.ag.nsdu.edu. (Accessed 3rd May 2021).

APPENDIX

Table 1: Weekly average meteorological data recorded at SSKIA during the study period

Week	**Date**		**Relative humidity (%)**			**Temperature (^{o}C)**			**Total rain fall(mm)**
	From	**To**	**0800hrs**	**1400hrs**	**Ave**	**Max**	**Min**	**Ave**	
1	May 1	May 6	73	28	51	27.6	8.0	17.8	0.8
2	May 7	May 13	6	20	41	27.3	6.0	33.3	0.9
3	May 14	May 20	90	41	66	22.1	7.4	14.8	0.3
4	May 21	May 27	71	27	49	27.3	9.2	18.3	-
5	May 28	June 3	83	40	62	24.6	7.6	16.1	7.2
6	June 4	June 10	78	23	51	23.1	2.7	12.9	-
7	June 11	June 17	72	27	50	22.6	3.6	13.1	-
8	June 18	June 24	81	23	52	25.1	3.8	14.5	-
9	June 25	July 1	68	21	45	24.0	3.0	13.5	-
10	July 2	July 8	63	37	50	18.0	5.2	23.2	0.8
11	July 9	July 15	81	42	62	22.2	6.5	14.4	3.3
12	July 16	July 22	61	31	46	18.7	3.0	10.9	-
13	July 23	July 29	62	22	42	24	3.3	13.7	-
14	July 30	Aug 5	57	18	38	29.0	8.9	19.0	-
15	Aug 6	Aug 12	49	18	34	25.9	5.9	15.9	-
16	Aug 13	Aug 19	50	19	35	29.5	10.3	19.9	-
17	Aug 20	Aug 26	51	17	34	30.3	10.1	20.2	-
18	Aug 27	Sep 2	37	14	26	27.1	8.0	17.6	-
19	Sep 3	Sep 9	29	11	20	27.9	9.4	18.7	-
20	Sep 10	Sep 16	17	6	12	31.6	5.6	18.6	-
21	Sep 17	Sep 23	43	18	31	34.2	14.6	24.4	-
22	Sep 24	Sep 30	43	24	34	33.4	17.3	25.4	0.4

Table 2. Correlation matrix of some growth parameters of turfgrass

	root biomass	root length	chlorophyll	clip biomass	eto
Root biomass	1.00				
Root length	0.95**	1.00			
Chlorophyll	-0.22ns	-0.46ns	1.00		
Clip biomass	0.97**	0.93*	-0.10ns	1.00	
ETo	0.92*	0.80ns	0.10ns	0.94*	1