EVALUATION AND SELECTION OF 20 SORGHUM [*SORGHUM BICOLOR* (L.) MOENCH] GENOTYPES FOR DROUGHT TOLERANCE

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Evaluation and selection of 20 sorghum [*Sorghum bicolor* (L.) Moench] genotypes for drought tolerance

by

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ABSTRACT

A field study was conducted at ARC - Grain Crops Institute, Potchefstroom Experimental Farm and at Taung Crop Production Center during 2006/07 summer growing season. Twenty sorghum genotypes were planted in two separate blocks, under full irrigation and rain fed conditions with plot size of 4 rows x 5 m x 0.9 m giving a density of 55 555 plants ha^{-1}. The experiment was laid out in a randomised complete block design replicated three times. The irrigated block received scheduled irrigation from planting until maturity, while the rain fed block received irrigation prior to germination only. Agronomic traits measured were plant height, stem diameter, biomass, flowering date, panicle exertion, panicle length, leaf area, grain yield, and thousand seed mass at Potchefstroom and Taung experiments. Drought susceptibility index (DSI) was quantified using the formula: $DSI = [1 - (Ydi/ Ypi)]/ [1 - (YD/YP)]$ and %yield reduction (%YR) was calculated using the formula: $\%YR = (Ypi – Ydi)/ Ypi \times 100$. Significant variations among genotypes with regard to grain yield (GYLD), plant height (PH), panicle length (PL), biomass (BM), stem diameter (SD), panicle exertion (PEx), and 1000 seed mass (TSM) were observed at Potchefstroom under rain fed conditions, while under irrigated conditions significant variations were only observed for GYLD, PH, PL, BM, days to 50% flowering (DF), SD, leaf area (LA), PEx and TSM. At Potchefstroom genotypes varied significantly with regard to PH, PL, BM, DF, SD, LA, PEx and TSM under rain fed conditions, while under irrigated conditions genotypes varied with all traits measured with exception of harvest index (HI) and relative water content (RWC). At Potchefstroom, soil water deficits significantly affected GYLD, PH, HI, PEx and RWC, while at Potchefstroom soil water deficits significantly affected GYLD, PH, SD, LA, PEx, TSM and RWC. Genotypes varied with their level of resistance/ susceptibility to soil water deficits at both Potchefstroom and Taung. Some remarkable correlations among traits measured were observed under rain fed and irrigated conditions and across the treatments at both Potchefstroom and Taung. At Potchefstroom, significant correlation was only observed between drought susceptibility index (DSI) and PH under rain fed conditions, while at Potchefstroom negative and significant correlation was only observed between DSI and GYLD under rain fed conditions. At Potchefstroom, GYLD under rain fed significantly related to GYLD under irrigated conditions and across the treatments. However, GYLD under irrigated conditions significantly related to GYLD across the treatments. At Potchefstroom, GYLD under rain fed conditions significantly correlated with GYLD across soil water regimes, while GYLD under irrigated conditions significantly correlated with GYLD across the treatments. Genotypes that exhibited the combination of high yield potential and resistant traits were recommended. Genotypes that exhibited high resistant traits with low yield potential were recommended for breeders to incorporate those traits into susceptible genotypes with high yield potential.

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DECLARATION

I hereby declare that the results contained in this dissertation
are from my own original work except as
acknowledged herein

SIGNED…………………Date………………………

Thifhindulwi J Malala

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CONTENTS

CHAPTER **PAGE**

LIST OF TABLES PAGE

LIST OF FIGURES PAGE

APPENDIX TABLES PAGE

GENERAL INTRODUCTION

Grain sorghum [*Sorghum bicolor* (L.) Moench] originated in eastern Africa probably in Ethiopia, a region that is characterized by erratic and unpredictable rainfall patterns. It spread by migrating natives to many African countries (Martin, 1970; Tuinstra *et al.*, 1997). Grain sorghum once grew in the wild before it was domesticated as food and feed for human and animals and cultivated in Africa for more than 2000 years long before European colonization. It subsequently spread to Asia and various parts of the western hemisphere by captive slaves (Martin, 1970; Rosenow *et al*., 1983; Smith & Frederikson, 2000). Presently, sorghum is one of the major food cereal crops, which ranks fifth after rice, wheat, maize and barley in terms of importance and production. It constitutes the main food grain for over 750 million people who live in the semi-arid tropics of Africa, Asia and Latin America (Asante, 1995; Borrell, 2000; Smith & Frederikson, 2000; Zulfirqar & Asim, 2002).

Sorghum is occasionally or to some extent grown in countries of all the six continents of the world (Gul & Saruhan, 2005; Smith & Frederikson, 2000). Although it is a subtropical or tropical crop that cannot tolerate frost (Larsson, 1996) it is adapted to a wide range of agro-ecological conditions that range from the high rainfall highlands to arid areas (National Research Council, 1996). The total world production of grain sorghum in 1998 was 61.7 million metric tonnes from a production area of 43.4 million hectares and across Africa 20 million metric tonnes were produced from 22.9 million hectares (Smith & Frederikson, 2000). Among African states that produce more than a million tonnes per annum are Nigeria, Sudan, Ethiopia and Burkina Faso and followed by Niger (600 000 tonnes), South Africa (480 000 tonnes), Tanzania (420 000 tonnes) and Uganda (290 000 tonnes) with substantial production (Chantereau & Nicou, 1994). Carter *et al*. (1989) stated that sorghum is planted for different uses i.e. animal feed, human consumption or building structures depending on needs of the particular people. Food and drinks that are prepared from sorghum form part of the main menu for the people that use sorghum as a food source and to generate income (Asante, 1995). Sorghum is used for human consumption in many of the developing countries in a variety of ways (Carter *et al*., 1989; Asante, 1995; Tuinstra *et al*., 1997). In communities where sorghum is grown as a subsistence crop, the main food products prepared include thin and thick porridges, fermented and unfermented breads, lactic and alcoholic beers and beverages, malted products for brewing and malted porridge mixes (Asante, 1995; Smith & Frederikson, 2000). Furthermore, sorghum can also be used for fencing, building, weaving, broom making and firewood. The plants can also be used as windbreaks, cover crops and as stakes for yams and other climber crops (National Research Council, 1996).

With special reference to South Africa, grain sorghum is cultivated in drier areas with shallow and heavy clay soils and is produced on less than 1% of the total arable land (Pretorious & Heenop, 1980; Department of Agriculture, 2006). Sorghum is produced commercially in the Free State (61%), Mpumalanga (24.3%), Limpopo (8.1%) and North West (4.6%) provinces (Department of Agriculture, 2009). The production of grain sorghum decreased drastically in 2005/06 as compared to the 2004/05 season. During the 2005/06 season an estimated 37150 ha were planted to sorghum and in 2004/05 season 86500 ha were planted, which represents a decrease of 57.1% in the total area planted. This reduction can be attributed to lower producer prices over the past two seasons, largely because of the domestic oversupply situation and the strength of the currency. In addition, it can also be attributed to moisture deficits (Department of Agriculture, 2006). Sorghum contributes a small percentage of the total domestic grain compared to the most important grain crops produced in South Africa, i.e. maize and wheat (Department of Agriculture, 2004).

There are numerous factors contributing to yield loss in sorghum. Drought stress is one of the major agronomic problems that limit the attainment of maximum yield more than any other environmental parameter with special reference to the arid and semi-arid regions (Krieg, 1975; Tuinstra *et al*., 1997; Abdula *et al*., 2004). Wenzel (1999) added that drought stress is more problematic to small-scale farmers (resource-poor farmers) as their farming activities depend solely on rainfall without option of irrigation. El-Kholy *et al*. (2005) reported that drought stress, generally changes plant growth and development pattern by suppressing cell division, organ growth, net photosynthesis, protein synthesis and alters hormonal balances in major plant tissues, hence causes severe effects on yield. Furthermore, McWilliams (2002) stated that grains from drought-stressed crops are commonly lower in quality.

According to Ozipinar (2004) the world population is gradually increasing and has been estimated to become 8.2 billion in 2025 and the biggest challenge will be to produce sufficient food for the growing population. Tuinstra *et al.* (1997) suggested that this challenge can be minimized by developing and selecting varieties that are more resistant and capable of growing and maintaining satisfactory yield more efficiently under drought stress conditions. The mechanisms of plants to maintain growth and yield under drought stress conditions are complicated and not yet fully understood. This study was conducted to determine the response of 20 sorghum genotypes to two different soil water conditions with the aim of evaluating and selecting genotypes that perform well under these conditions. The objective of the study was to select high potential genotypes that give high grain yield under irrigation and those that perform well under rain fed conditions for resource-poor farmers. Furthermore, to select drought resistant genotypes for breeding programmes.

CHAPTER ONE

1 LITERATURE REVIEW

1.1 INTRODUCTION

Sorghum is an important crop worldwide for its unique ability to produce satisfactory yield under a wide range of harsh environmental conditions (Moghaddam *et al*., 2007). The origin and culture of sorghum, like most other crops, is not clear (Martin, 1970). Sorghum is probably one of the earliest crops to be domesticated in human history, as it was an important crop in the old world long before the Christian era (Leonard & Martin, 1963). Dogget (1965a) as cited by House (1985) indicated that archaeological evidence suggested that the practice of cereal production was introduced from Ethiopia to Egypt about 3000 B.C and the possibility of sorghum domestication might have begun about that time. Sorghum was grown during Neolithic times. Purseglove (1972) stated that sorghum is known with different names around the world, i.e. great millet and guinea corn in West Africa, kafir corn in South Africa, dura in Sudan, mtama in Eastern Africa, jowar, jola and cholam in India, milo and sorgo in USA and kaoliang in China. Sorghum is popularly known for its ability to yield well under rain fed conditions, where other summer crops such as maize and soybeans have consistently failed to grow and yield satisfactorily (Wright *et al*., 1983). Massacci *et al*. (1996) indicated that sorghum is a drought resistant C4 plant, which is cultivated during dry season in warm areas of the world and it forms an important component of traditional or smallholder farming systems in the semi-arid areas of the tropics (Moghaddam *et al.*, 2007).

1.2 BOTANICAL DESCRIPTION

Grain sorghum belongs to the genus *Sorghum*, subfamily of *Panicoideae* and *Andropogeneae* tribe of the grass family (Leonard & Martin, 1963). Sorghum is generally described as annual, vigorous, coarse, erect canelike grass of height ranging from 0.5 to 6 m tall with much variability in growth characteristics, depending on variety and growing conditions (Purseglove, 1972). According to Metcalfe & Elkins (1980) and Carter *et al.* (1989) its architecture, growth model and general appearance is more or less like that of maize and other cereal crops. The number of leaves at maturity correlates with length of vegetative period but usually ranges from seven to eighteen or more leaves (Leonard & Martin, 1963). Sorghum produces grooved stalks or stems that consist of alternate nodes and internodes from where leaves are borne and sometimes nodes produce buds that give rise to new shoots or tillers. Depending on the varieties, dozen of tillers could be produced either early or late in the season, while some plants tiller after harvest and can be cut to allow them to sprout and grow without replanting again like sugarcane (Wilson, 1955; Metcalfe & Elkins, 1980).

Sorghum plants produce a fibrous root system with many lateral roots, which absorb and utilizes soil water efficiently, enabling the crop to adapt in dry climates better than maize (Wilson & Myers, 1954). According to House (1985) sorghum roots penetrate extensively a greater volume of soil than other grain crops to absorb water. In soil that permit root growth, the plant produces deep taproots with a large number of multi-branched lateral roots, which usually occupy the upper layers of the soil and can laterally spread up to 1.5 meters (National Research Council, 1996). The inflorescence, referred to as a panicle, or ordinarily called a head, varies from 7.6 to 50.8 cm in length and from 3.81 to 20.32 cm in width, it may be well exerted or the lower part may remain within the boot (Leonard & Martin, 1963; Purseglove, 1972). According to Wolfe & Kipps (1959) and Carter *et al*. (1989) plants may either produce compact or loose open (spreading) panicles (Figure 1.1) that bear spikelets in pairs that later pollinate and produce grains that vary in colour, depending on the cultivars. Sorghum usually bears erect panicles but may be gooseneck shaped. However, the gooseneck shaped heads are undesirable for mechanical harvesting because of considerable loss of dropped heads (Wilson & Myers, 1954; Metcalfe & Elkins, 1980; Duke, 1983).

Figure 1.1 Different types of sorghum panicles (heads) at maturity stage ready to be harvested and threshed

Sorghum is a perfect flowered crop and predominantly considered as self-pollinating crop although cross-pollination does occur (Leppan & Bosman, 1923). Conley (2003) added that cross-pollination occurrence in sorghum is on average less than six percent. The degree of cross-pollination depends on both wind and panicle type. Open panicle types have a greater possibility of being cross-pollinated than compact head types (National Research Council, 1996). Sorghum flowers begin to open two days or less after the panicle has been exerted from the sheath but sometimes before it is fully exerted. The flowers start opening from those at the apex proceeding downward to the base of the panicle (Leonard & Martin, 1963). Sorghum flowers shed pollen during the very early hours of the day. Stigmas are receptive for about two days before the flowers shed the pollen and remain receptive six to sixteen days after shedding of pollen if the flower is not fertilized (Wilson & Myers, 1954; Leonard & Martin, 1963). Wilson & Myers (1954) added that pollen viability deteriorate rapidly after shedding. Sorghum produces grain, which are smaller than that of maize and partially covered by husks or glumes but have similar starchy endosperm (National Research Council, 1996). According to Leonard & Martin (1963) the colours of grains vary from white, chalky white, pink, yellow, red, buff or brownish yellow, brown or reddish brown and some white-seeded varieties have red, purple or brown spots that consist of water soluble pigments washed from the glumes (Figure 1.2). Sorghum grain size varies remarkably. Small seeds may weigh 10g per thousand, but large seeds weight may range between 25 and 40g per thousand. The kernel shapes are usually obovoid, less ovoid or ellipsoid. Dark coloured seeds usually contain significant amounts of tannins in the pericarp, which give the seed a bitter taste (Wilson & Myers, 1954; Leonard & Martin, 1963; National Research Council, 1996).

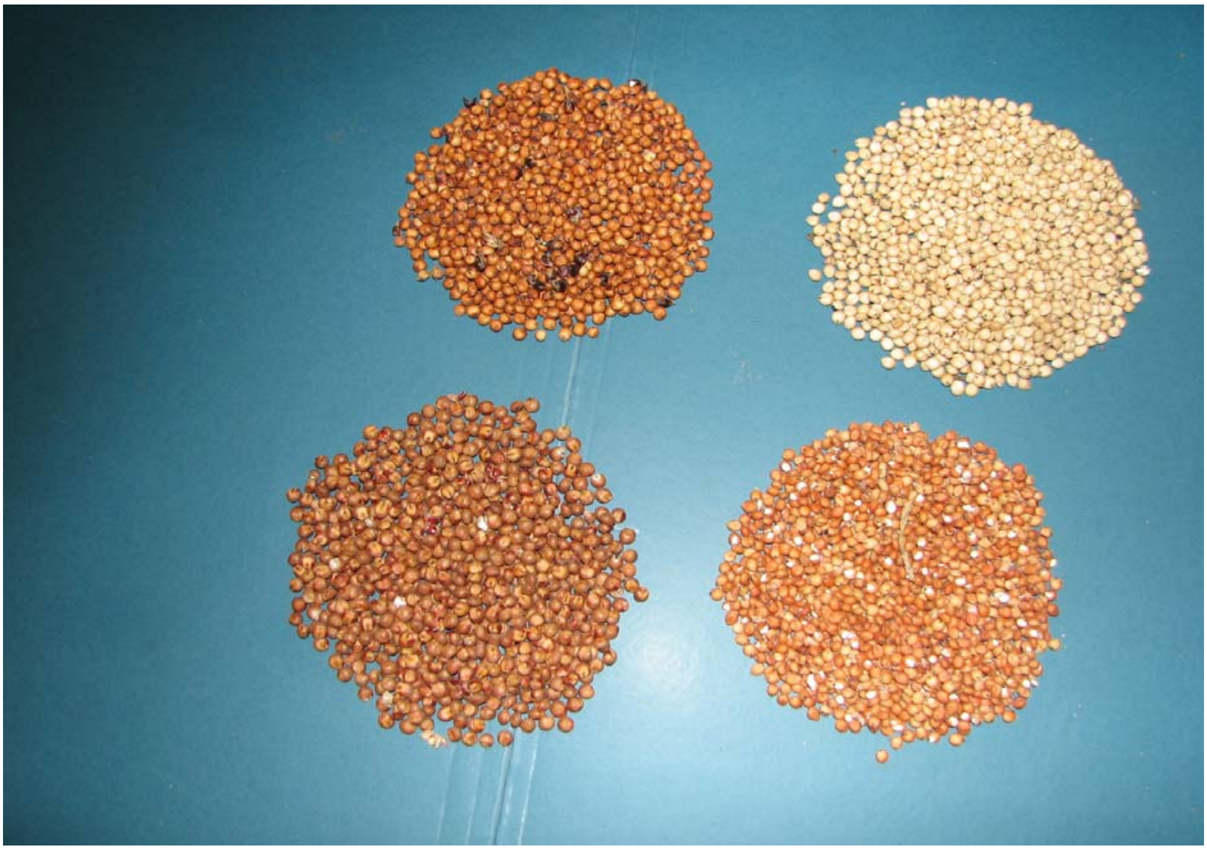

Figure 1.2 Threshed and cleaned different types of sorghum seeds in different colours, shapes and sizes

1.3 CLIMATIC ADAPTATION

Sorghum is a subtropical and tropical crop that cannot tolerate frost and it is adapted to a wide range of agro-ecological conditions that range from high rainfall highlands, where temporary waterlogging can occur to arid areas. Although rainfall and other weather conditions determine planting time and length of the growing season, which varies from season to season (Department of Agriculture, 2006) sorghum has the potential to grow under adverse climatic conditions with minimum inputs and care (Rohman *et al.,* 2004). Sorghum is well adapted to grow in hot, arid or semi-arid areas and it is grown mainly in African, Asian, North American and Australian regions that are too dry and too hot for successful maize production (Leonard & Martin, 1963). It is a major grain feed crop in subhumid and semi-arid areas. It can withstand heat better than other crops like maize but extremely high temperature can reduce grain yield (Kramer & Ross, 1970). Carter *et al.* (1989) also confirmed that grain sorghum requires less water (rainfall) than maize in hot and dry areas, where it is likely to be grown as a substitute to maize and produce better grain yield. It requires 90 to 140 days to reach maturity (House, 1985; Larsson, 1996; National Research Council, 1996). Sorghum is a warm weather plant and its growth and maturity can be retarded when temperatures drop below 15 ^{o}C. It can withstand maximum temperature of up to 37 ^{o}C; however, it grows best at an optimum temperature of about 27 ^{o}C (Wilson & Myers, 1954). Although many sorghum varieties are insensitive to photoperiod, it is basically a short-day plant. Traditional or smallholder varieties transform from vegetative to reproductive growth stage when day length shortens to twelve hours and this character is genetically controlled (Purseglove, 1972; National Research Council, 1996). Grain sorghum is grown successfully on all types of soils with pH ranging from 5.5 to 8.5, but fertile and well-drained soils are important to optimise grain yield (Leonard & Martin, 1963; Nafziger, 2002). In South Africa it is mainly cultivated on low-potential, shallow soils with high clay content, which is not suitable for maize cultivation (Department of Agriculture, 2006). According to Biswas *et al*. (2001) and Rohman *et al*. (2004) sorghum can tolerate drought and moderate salt stress conditions effectively.

1.4 CULTIVATION OF GRAIN SORGHUM

Sorghum is usually planted from seed, but it can also be propagated through stem cuttings if desired depending on the availability of primordial roots at the nodes (Purseglove, 1972; National Research Council, 1996). It is highly responsive to a well-prepared seedbed that is warm, of good till and moist so that seeds will germinate quickly (Wilson & Myers, 1954). According to Leppan & Bosman (1923) sorghum like other cereals such as oats, wheat, millet and barley has small seeds and planting should be shallower than that of maize at about 2.5 to 5 cm. Usually, deep seed planting may result in failure to obtain satisfactory plant density due to poor soil surface conditions. Since sorghum seedlings are less vigorous than that of maize, the soil surface should be fine tilled and prepared. Deep ploughing is not always desirable as it may result in excessive topsoil and subsoil desiccation, which will limit plant growth; however, in certain soils deep ploughing has been proved to be necessary (Leppan & Bosman, 1923). Martin (1970) stressed that the seedbed should be free of weeds and other factors that might hinder seedling emergence and establishment. Furthermore, Martin (1970) stated that farmers usually increase their planting rate to counteract expected poor plant density that may be due to planting using poor quality seeds, improper seedbed preparation, inadequate soil water content, insects and disease problems.

Generally, the seeding rate for grain sorghum on average varies from two to twelve kg ha^{-1} depending on soil water content expectancy of the particular soil and density required, with heavier seeding rate being for forage production. In areas that annual rainfalls vary from 600 to 750 mm, the seeding rates can vary from seven to eight kg ha^{-1} (Martin, 1970). According to Wilson & Myers (1954) sorghum should be planted in rows just like maize. Furthermore, Leonard &Martin (1963) stated that the proper spacing between and within the rows depends upon the soil water content supply and the tillering behaviour of the varieties. Wilson (1955) also mentioned that plants should be spaced much closer in areas with adequate rainfalls (precipitations) and irrigation supply than in dry regions. Generally, grain sorghum can grow and produce highest yield when planted in spacing of about 15 to 20 cm within the rows and spacing between the rows of about 60 to 106 cm apart in semi-arid non-irrigated conditions; however, for irrigated and humid conditions, plant population can be doubled by planting in narrower rows (Wilson & Myers, 1954; Leonard & Martin, 1963). According to Metcalfe & Elkins (1980) the optimum plant population is mostly ranges between 148 000 to 296 000 plants per hector. The choice of inter-row spacing depends on the availability of equipment used for planting, weed control and harvesting (Wilson & Myers, 1954).

1.5 DISEASES

Yield reduction in grain sorghum as a result of disease infections may average up to ten percent annually (Metcalfe & Elkins, 1980). According to Wilson & Myers (1954) sorghum is subjected to four general groups of diseases including those that reduce stand by rotting the seeds and killing the seedlings, those that attack leaves and heads and those that cause roots and stalk rot and prevent normal development and maturity of the plants. Although smuts, stalk and root rot and foliar diseases are principal diseases that cause grain sorghum losses, grain mould is one of the most important diseases, which prematurely infects the spikelets on developing kernels during anthesis by parasitic field fungi such as *Curvularia lunata* (Wak.) Boeding and *Fusarium moniliforme (*Metcalfe & Elkins, 1980; Frederiksen *et al*., 1982). Grain mould is a major concern because it reduces the quality of grains (ICRISAT, 1982). Reddy *et al*. (2005) confirmed that grain mould is a highly destructive disease, which is caused by a complex of pathogenic and saprophytic fungi and is widely spread in the semi-arid tropics of Africa and India. The estimated global losses due to grain mould are US $30 million annually (ICRISAT, 1992). Mouldy grains have pink or blackened layer scattered over the head and are usually chalky and easily pulverized (Frederiksen *et al*., 1982). Grain moulds form a visible black mycelium layer around the seed, which develops to form a mycelium mat 10 to 16 days before seed matures. The damage can be estimated by visual observation and by a set of standards (Frederiksen *et al*., 1982; ICRISAT, 1982). Some fungi are more detrimental than others, but grain mould is important because it causes quality loss of grains regardless of cultural practices implemented. Cultivation of disease resistant varieties is the most valuable and practical solution to control disease problems. However, cultural measures should also be integrated so as to minimize the incidence and spread of diseases (ICRISAT, 1982).

1.6 HARVESTING AND STORAGE OF GRAIN SORGHUM

Grain sorghum should be harvested when grains are physiologically matured and when translocation of photosynthetic assimilates into grains and dry weight increase has stopped (Kramer & Ross, 1970). Leonard & Martin (1963) pointed out that grains mature when they are fully coloured and contained moisture content that range between 18 to 20 percent. According to Leppan & Bosman (1923) and Wilson (1955) mature panicles can be harvested manually by cutting them from the standing stalk with clippers and threshed by machine or manually. However, in developed countries panicles are harvested by combine harvesters (machine). Machine harvesting was made possible by developing dwarf varieties and hybrids suitable to be harvested by a combine harvester (Leonard & Martin, 1963). The most desirable moisture content for harvesting sorghum range between 20 and 25%, only if it is not intended for storage; however, if grains are intended to be stored, they should be left to dry in the field or artificially dried up to 13% or less to avoid overheating and rotting (Kramer & Ross, 1970).

1.7 DROUGHT RESISTANCE

Generally, drought is a meteorological event that results in the absence of rainfall for a period of time that is long enough to cause water deficits in the soil, accompanied with a decrease in water potential in plant tissues. From an agricultural point of view, drought is the availability of inadequate water including precipitation and soil water storage capacity, which inhibits the expression of full genetic potential of the plant (Mitra, 2001). Plant water deficits develop when evaporative demand of the atmosphere upon leaves exceeds the capacity of the roots to extract water from the soil. Furthermore, Blum (2005) stated that the strain of drought is developed when crop demand for water is not met by the supply and plant water status is reduced. Yield loss due to drought in the tropics alone exceeds 20 million tonnes of grains per year or 17% of well-watered production, reaching up to 60% in severely affected regions such as southern Africa in 1991 and 1992 (Edmeades *et al*., 1989; Ribaut *et al*., 2002). Sharma & Lavanya (2002) as cited by Ali *et al*. (2009) stated that worldwide, yield losses each year due to drought stress are estimated to be around

500 million US dollar. Furthermore, these large losses were also due to poor drought resistance of the available cultivars. According to Turner (1986), Wenzel *et al.* (1999) and Mitra (2001) drought resistance is the ability of the plants to produce satisfactory yield under limited soil water or drought stress conditions. In addition, Blum (2005) stated that when a genotype yields better than another under a severe strain of drought, it is relatively more drought resistant. Sullivan & Ross (1979) and Mitra (2001) stated that drought resistance is a complex characteristic and it is difficult to assess cultivars that are resistant to drought stress since their expressions depend on the action and interaction of different morphological, physiological and biochemical characteristics of the plants. Blum (1996) defined drought as a multidimensional stress that affects plants at various levels of their organisation. Moreover drought resistance in terms of the plant physiology involves interactions with the magnitude and the timing of the drought stress (Blum, 2005). According to Ribaut *et al*. (2002) genotypes vary in their ability to withstand or tolerate drought stress. Plants respond differently to drought stress throughout their ontogeny depending on the type of crop, the magnitude or intensity of prevalent drought stress and growth stage of the crop plant when soil water deficit occurs (Lewis *et al*., 1974; Blum *et al*., 1989; Manjarrez-Sandoval *et al*., 1989; Blum, 2005).

1.7.1 Mechanisms of drought resistance

Stout & Simpson (1978), Krieg & Hutmacher (1982), Tuinsntra *et al.* (1997) and Mitra (2001) reported that there are three different mechanisms by which crops maintain their growth, development and yield under drought stress conditions and can use one or more mechanisms at a time to tolerate drought stress. Turner (1986) stated that although there is a wide range of mechanisms of adaptation to drought stress among plants (cultivars), many of these mechanisms seem to be more important for crop survival than increasing yield production. However, the degree at which these mechanisms could be expressed place limits on the extent to which the harmful consequences of drought stress can be avoided or tolerated (Jordan *et al*., 1983). According to Jordan & Monk (1980) and Turner (1986) drought resistance mechanisms include drought escape, drought tolerance at high tissue water potentials and drought tolerance at low tissue water potentials as the major components of resistance.

1.7.1.1 Drought escape

Jordan & Monk (1980), Rosenow & Clark (1981), Krieg & Hutmacher (1982) and Mitra (2001) defined drought escape as a mechanism by which plants grow and complete their life cycle before severe drought stress occurs. Turner (1979) confirmed that plants are able to produce flowers with a minimum vegetative growth, which enables them to produce grains with a limited water supply. Drought escape involves rapid phenological development, developmental plasticity and remobilisation of pre-anthesis assimilates to the grains while good soil water content conditions prevail (Krieg & Hutmacher, 1982; Turner, 1986; Mitra, 2001). Developmental plasticity is the ability of plants to halt growth during drought stress periods hence it is an important aspect for drought resistance. The evidence confirmed that when water supply is adequate, only a small proportion of the grains' dry weight comes from the stored assimilates in stems, leaves and roots, but when drought stress occurs during grain filling stage, a large portion of the assimilates are transferred to the grains (Turner, 1979). According to Rosenow & Clark (1981) and Rosenow *et al*. (1983) the common cultural practices that can be employed to escape drought stress periods are the use of early maturing genotypes and adjustment of planting dates. Schmidt (1983) stated that early maturing genotypes reduce the total plant water requirements and may increase grain to shoot ratio. Turner (1979) reported that the increase in yield that could be due to early maturity was greater when soil water deficit was more severe, but when given an adequate water supply, yield positively correlated with maturity date in annuals or determinate crops such as maize, sorghum and sunflower; therefore, selection based on early maturity as the way to avoid severe drought stress might result in lower yield during years of adequate water supply.

1.7.1.2 Tolerance at high tissue water potential

Although considerable success has been achieved by developing cultivars that can escape drought stress, most cultivars still suffer or experience yield loss during soil water deficits or soil water shortage periods. Therefore, some measures of drought tolerance mechanisms are required for cultivars to survive drought stress conditions (Krieg & Hutmacher, 1982). Drought tolerance at high tissue water potential is the mechanism by which plants are able to maintain high water level within the tissues despite increasing soil and atmospheric water deficits (Blum, 1974; Blum *et al*., 1978; Stout & Simpson, 1978; Krieg & Hutmacher, 1982). According to Turner (1986) and Pugnaire *et al*. (1999) this mechanism can also be referred to as dehydration postponement or drought avoidance. According to Krieg & Hutmacher (1982) green plants have two options for maintaining high tissue water status during soil water deficit periods, i.e. reduction of transpirational water loss and increasing water absorption.

1.7.1.2.1 Reduced water loss

To reduce the effects of soil water deficit, plants have to control transpirational water loss from the aboveground parts. This can be accomplished by changes in the surface area of transpiring parts such as leaves, physical changes in transpiring surface and by regulating the opening and closing of stomata (Simpson, 1981) through reduction of stomatal and lenticular conductance (Tuinstra *et al*., 1997; Mitra, 2001). Pugnaire *et al*. (1999) stressed that increased stomatal sensitivity is a functional way that allows plants to maintain high tissue water status during soil water deficits as a consequence of soil water depletion, increased vapour pressure deficit or both occurring together simultaneously. However, succulent plants were given as an example representing extreme plants that control water loss through stomatal closure. Since stomata are sensitive to reduced total water potential, they tend to open during the night when water loss is minimal (Turner, 1979). The common way of minimizing water loss is the reduction of transpiring surface area by the plants. This can be in a form of reduced leaf area or changed leaf shape by rolling the leaves as a response to water deficits hence small leaves can have favourable energy budget producing lower transpirational rates (Simpson, 1981). Schmidt (1983), Tuinstra *et al*. (1997) and Mitra (2001) stated that it could also be achieved by minimizing radiation absorption through increased epicuticular wax load, leaf orientation and leaf rolling. Accelerating leaf senescence and shedding of leaves, reduction of leaf growth or expansion and death of the tillers help in drought tolerance with high tissue water potential. Leaves and stems pubescence is one of the morphological plant features that help them to adapt to arid environments. Furthermore, it can reduce the radiant heat load in leaves by increasing the reflectance of the leaf surface and reducing the absorption of photosynthetic active radiation (Simpson, 1981; Schmidt, 1983).

1.7.1.2.2 Increase and maintain water uptake or absorption

By maintaining and absorbing water more efficiently from the soil through increased roots depth, efficient root system and increased hydraulic conductance can help plants to maintain high tissue water content (Jordan & Monk 1980; Turner, 1986; Tuinstra *et al*., 1997). According to Krieg & Hutmacher (1982) it is a mechanism by which plants increase the total water supply by extending their roots into previously unexplored soil containing water. Turner & Begg (1981) stated that the development of a deeper roots system is a useful adaptive feature, only if soil water content is available at reachable depths. This mechanism can be functional only if there is available water stored in the soil up to the existing root zone and the availability of sensory system within the plants (hormones) that triggers root growth without damaging effect on the developing shoot (Krieg & Hutmacher, 1982). According to Simpson (1981) the size of the plant root system depends on both genetic and environmental conditions. Turner & Begg (1981) confirmed the genotypic differences in rooting depths that have been demonstrated in wheat. Since genetic variability in root system morphology exists, selecting for better rooting system is a valuable option and must be used effectively (Krieg & Hutmacher, 1982). Hinckley *et al*. (1981) reported that species that have capacity to grow through zones of low soil water potential into the regions of high soil water potential give them competitive advantage on the very dry ecological sites. Varieties that have deeper rooting systems yield better under drought stress (Turner & Begg, 1981).

1.7.1.3 Drought tolerance at low water potential

According to Krieg & Hutmacher (1982) if crop plants could not maintain high tissue water content they must be able to tolerate drought at low water potential. Drought tolerance at low water potential is the ability of plants to endure or withstand water deficits and maintain physiological processes even though low tissue water potential develops (Jordan & Monk, 1980; Rosenow & Clark, 1981). According to Tuinstra *et al*. (1997) this mechanism functions within the tissues, since it protects and stabilizes cellular and metabolic processes during tissue dehydration. Jordan & Monk (1980) stated that drought tolerance at low water potential could be accomplished by accumulation of solutes (osmotic adjustment), an increase in cellular elasticity and decreasing cell size. According to Babu *et al*. (1999) and Hopkins & Hüner (2004) osmotic adjustment refers to net increase of solute concentration due to metabolic processes as triggered by drought stress. Hinckley *et al.* (1981) and Babu *et al*. (1999) mentioned that osmotic adjustment is able to increase water-absorbing power of the foliage, delay wilting and stomatal closure and protect protoplasm from desiccation and maintaining turgor pressure. Jordan & Monk (1980), Krieg & Hutmacher (1982) and Pugnaire *et al*. (1999) stated that the solutes that are mostly accumulated and synthesised as a response to water deficits include organic acids, amino acids and sugars and this process directly involves the need for plants to maintain turgor-dependent processes at a significantly lower water availability. According to Babu *et al*. (1999) osmotic adjustment generally means maintaining turgor pressure for both shoots and roots as long as plants are experiencing water deficits. Babu *et al*. (1999) and Pugnaire *et al.* (1999) stated that osmotic adjustment allows cell enlargement and all turgor-dependent processes including plant growth to continue progressively at high water deficits, since it keeps the stomata open so that carbon dioxide could be assimilated. Genetic variations in osmotic adjustment exist among cultivars throughout the ontogeny (Jordan & Monk, 1980; Krieg & Hutmacher, 1982; Blum *et al*., 1989). Blum *et al*. (1999) concluded that there are consistent genetic differences existing among wheat cultivars in terms of osmotic adjustment and cultivars with high osmotic adjustment activities tend to yield better than cultivars with low osmotic adjustment activities when exposed to drought stress conditions.

Drought tolerance mechanisms mostly depend on the developmental stage of the plants at the time of drought stress occurrence (Stout & Simpson, 1978; Tuinstra *et al*., 1997). According to Tuinstra *et al*. (1997) drought stress tolerance has been identified and susceptibility symptoms have been categorized into three different growth stages, which include early seedling and vegetative stage, pre-flowering and post-flowering stages. Rosenow & Clark (1981) stated that sorghum cultivars that have good drought tolerance during pre-flowering developmental stage are usually found to be susceptible to drought stress during post-flowering growth stage. Some genotypes have been found to possess moderate levels of drought tolerance at both pre-flowering and post-flowering stages (Rosenow & Clark, 1981). Pre-flowering response period starts during head differentiation until flowering (Tuinstra *et al*., 1997). According to Rosenow & Clark (1981) symptoms of pre-flowering drought stress include leaf rolling, excessive leaf erectness, leaf bleaching, delayed flowering, floret abortion, leaf tip and margin burn, reduced seed set and reduced panicle size, poor head exertion and reduced plant height. Furthermore, Rosenow & Clark (1981) stated that a post-flowering drought stress symptom is plant senescence, which is usually accompanied by charcoal stalk rot, lodging and reduction in seed size. Post-flowering resistance is indicated by the stay green trait during grain filling stage which makes plants resistant to premature senescence (Crasta *et al.,* 1999).

1.8 WATER DEFICITS AND PHYSIOLOGICAL PROCESSES

1.8.1 Plant growth

Plant growth is defined as a permanent change in volume of plant tissues accompanied by a change in form and this process could be significantly retarded by soil water deficits (Thomas *et al*., 1960; Donatelli *et al*., 1992; Ghobadi *et al*., 2006). Reddy *et al*. (2004) reported that drought stress is one of the adverse factors that inhibit plant growth and yield production. Loomis (1934) as cited by Shaw & Laing (1966) stated that plant growth is directly dependent on a free supply of water to the growing point. In stress tolerant plants, rapid growth may be prevented during drought stress because the driving force for growth and turgor pressure is low or absent (Stout & Simpson, 1978). Soil water deficits affect every aspect of plant growth, which include anatomical and morphological growth, physiological and biochemical processes. Plant growth solely depends on cell division, enlargement and differentiation and all can be delayed by water deficits (Kramer, 1983). According to Hsiao (1973) water stress directly and physically reduces plant growth through reduction of cell turgor. Van Volkenburgh & Boyer (1985) stated that growth rate of cereal leaves is very sensitive to plant water status, since small reduction in water potential of the root medium could limit the growth rate of maize and barley immediately. Hopkins & Hüner (2004) confirmed that shoot growth, particularly growth of the leaves, generally is more sensitive to soil water deficits than root growth. Furthermore, Hopkins & Hüner (2004) found that leaf growth was completely inhibited at -1.00 MPa but root growth still continued until water potential of the root tissues reached -0.45 Mpa. Donatelli *et al*. (1992) added that the effects of soil water stress are more prominent, depending on the time and intensity of water limitation. Furthermore, Kramer (1983) mentioned that vegetative growth and leaf expansion are generally inhibited by relatively moderate water deficits.

1.8.2 Photosynthesis

Photosynthesis occupies a prominent position in the metabolism of higher plants and its rate is regarded as the primary factor regulating plant biomass production and crop productivity (Hopkins & Hüner, 2004). According to Pieters & El-Souki (2005) photosynthesis is one of the main metabolic processes that determine crop production and is directly affected by drought stress. Lu & Zhang (1998) mentioned that it has been proven to be very sensitive to soil water deficits. In addition, Kramer (1983) stated that photosynthesis could be retarded through reduction in plant leaf area, closure of stomata and decreasing the carbon fixation efficiency process. Reddy *et al*. (2004) stated that drought stress progressively reduces carbon dioxide assimilation rate due to a decrease in stomatal conductance, which directly affect the rate of photosynthesis and it stimulates reduction of photosynthesis activities through reduced photosynthetic carbon reduction cycle enzymes, which include the key enzyme riboluse-1,5-bisphosphate carboxylase/oxygenase. Sullivan & Ross (1979) stated that stomatal closure is completely responsible for decreasing photosynthesis rate as soil water deficit increases because of impeded carbon dioxide supply. Similarly, Hopkins & Hüner (2004) confirmed that stomatal closure in sunflower proved to have minor effect on photosynthesis because the direct effects on the photosynthetic activity of chloroplast decrease the demand for carbon dioxide and the level of carbon dioxide inside the leaf remains relatively high. Turner & Begg (1981) stated that water stress generally reduces yield during vegetative stage due to poor light interception arising from the small size of the leaves in conjunction with leaf orientation. Tanner *et al*. (1966) as cited by Berdahl *et al*. (1972) confirmed this by comparing wheat, oats and barley cultivars and found that cultivars that were highest in grain yield had small, upright leaves and the high yield were attributed to reduced competition for light among leaves. Turner & Begg (1981) stated that during grain filling stage yield was reduced due to decreased photosynthesis per unit area and reduced leaf area arising from leaf senescence. Colom & Vazzana (2003) reported that water stress caused large reductions in leaf chlorophyll and carotenoid content, which directly affected photosynthesis due to poor light absorption and conversion into energy. Shaw & Laing (1966) found that there was a direct correlation between the rate of photosynthesis per unit leaf area and water content of the leaf. When water content of the leaf decreased the rate of photosynthesis also decreased. Brilliant (1924) as cited by Shaw & Laing (1966) observed the maximum rate of photosynthesis when water content of the leaves was reduced by 5 to 15% below the maximum leaf saturation and photosynthesis stopped when leaves lost 50% of their maximum water content.

1.8.3 Grain yield

Drought severely reduces grain yield in many cereal growing regions, which results in fluctuations in the world food supply (Gallagher *et al*., 1976). Grain yield is the product of many growth processes occurring throughout the developmental stages of the plants. In the *Gramineae* family, these processes include the number and growth rate of inflorescences and the number and growth rates of the seed set (Morgan, 1984). Saeed *et al*. (1986) added that grain yield in sorghum is a complex phenomenon because of the multiplicative nature of yield components and the temporal influence of climate on their expression; hence drought stress affects the physiological and developmental characteristics, which determine the final yield. According to Kramer (1983) just like plant size and leaf area, water stress also causes crop yield reduction. Naserian *et al*. (2007) emphasized that yield reduction is mediated through reduced leaf growth and lower photosynthetic productivity. Saeed *et al*. (1986) stated that yield components are developed through a series of sequential events that involve various metabolic and developmental activities. Stress at any stage of development might have a significant effect on yield reduction, but might be compensated through production of productive basal or nodal tillers (Schmidt, 1983). Lewis *et al*. (1974), Manjarrez-Sandoval *et al*. (1989) and Saeed *et al*. (1986) stated that the effects of drought stress on grain yield and its components is not only dependent on the intensity of the drought stress, but also on the crop stage of development in which the soil water deficits occur. Ghobadi *et al*. (2006) stressed that the time of soil water deficit occurrence is more important than stress intensity. Although crop damage may occur at any point in the crop developmental stage the most critical stage is from the early booting to anthesis stage (Schmidt, 1983). Awala & Wilson (2005) added that drought stress could occur any time during the crop cycle but drought stress during flowering through grain filling stage resulted in low and unstable yield in pearl millet. Morgan (1984) found that in wheat and other crop plants grain yield is sensitive to soil water stress that occur shortly prior to anthesis and yield reduction is generally attributed to pollen sterility or abortion of spikelets because the turgor of the expanded leaf falls to zero.

Lewis *et al*. (1974) found that grain yield reduction is between 10 and 17% when drought stress occurs shortly before booting stage through anthesis until soft dough stage. These results were supported by findings of Inuyama (1978) who reported a yield reduction of 61% when drought stress occurred at booting stage. However, Manjarrez-Sandoval *et al*. (1989) disagreed with these two findings by stating that in sorghum the most critical stage of susceptibility to drought stress is unknown. Mirhadi & Kobayashi (1980) stated that grain yield loss due to drought stress before anthesis is related to a decrease in grain number and small grain size. Rice & Eastin (1986) confirmed that low grain yield is usually associated with reduced seed number, which is commonly caused by soil water deficits or high temperature stress.

CHAPTER TWO

2 MATERIAL AND METHODS

2.1 DESCRIPTION OF EXPERIMENTAL SITES

Field experiments were conducted in a semi-arid climate at two research localities i.e. Agricultural Research Council – Grain Crops Institute (ARC – GCI) Experimental Farm based at Potchefstroom which is situated at latitude 26^{o} 73' 61''S, longitude 27^{o} 07' 57''E and 1347 meters above sea level and the Department of Agriculture, Crop Production Center at Taung is situated at latitude 27^{o} 54' 99''S, longitude 24^{o} 76' 60''E and 1111 meters above sea level. Both Potchefstroom Experimental Farm and Taung Crop Production Center are in the North West Province of the Republic of South Africa and are located within the summer rainfall region. Rain is expected between October and March months. The highest amount of rain in this region fall during December to February and the lowest amount of rain falls during winter months from May to July.

Long-term monthly climatic information for both Potchefstroom Experimental Farm and Taung Crop Production Center is presented from 1990 to 2007 (Table 2.1). The data were obtained from the Agricultural Research Council – Institute of Soil, Climate and Water (ARC – ISCW) weather stations at Potchefstroom Experimental Farm and Jankempdorp (Vaalharts). Jankempdorp weather station is approximately 20 km away from Taung Crop Production Center, where the experiment was conducted. Although Jankempdorp is far away from the experimental site, it was the closest weather station that could be used for estimating the irrigation requirements for Taung experiments. The long-term climatic information includes the monthly average minimum and maximum relative humidity (RHn and RHx%), average rainfall, average minimum and maximum temperature (t_{min} and t_{max}), and average reference evapotranspiration (ET_o). The total annual rainfalls for Potchefstroom and Taung are approximately 620 and 522 mm, respectively. Taung region is hot, drier and less humid as compared to the Potchefstroom region during summer months.

Potchefstroom and Taung regions usually experience lower winter temperatures, which are subsequently followed by frost. Sometime these regions experience early frost, which may cause damage to late maturing crops.

Table 2.1 Summary of climatic variables at Potchefstroom Experimental Farm (Pot) and Jankempdorp (Tau) weather stations from 1990 to 2007, Potchefstroom reference evapotranspiration was only recorded from 2004 to 2007

Month	Mean monthly rainfall mm		Mean monthly t_{min} ^oC		Mean monthly t_{max} ^oC		Mean monthly RHn %		Mean monthly RHx %		Monthly ET_o mm/day	
	Pot	Tau	Pot	Tau	Pot	Tau	Pot	Tau	Pot	Tau	Pot	Tau
Jan	105	98	17	16	29	32	35	30	86	84	06	06
Feb	98	69	16	17	29	31	35	31	86	81	05	05
Mar	85	67	14	15	27	30	35	33	88	88	05	04
Apr	53	50	10	10	25	26	34	39	91	89	03	03
May	12	56	04	05	22	23	27	33	86	83	03	02
Jun	07	10	01	01	20	20	26	29	85	82	03	02
Jul	01	02	01	01	21	20	24	25	80	81	03	02
Aug	11	16	04	03	23	23	26	23	78	75	04	03
Sept	09	11	08	07	27	27	22	20	70	68	05	04
Oct	61	30	13	11	28	29	26	23	77	76	06	05
Nov	67	50	14	14	29	33	28	24	80	79	07	06
Dec	115	64	16	16	30	32	30	26	85	81	07	06
Total	621	522										

t_{min} – minimum temperature, t_{max} – maximum temperature, RHn% – minimum relative humidity, RHx% – maximum relative humidity, ET_o – reference evapotranspiration

2.2 EXPERIMENTAL DESIGN AND PLANT MATERIALS

Twenty sorghum genotypes were obtained from the Agricultural Research Council – Grain Crops Institute (ARC – GCI) at Potchefstroom, Republic of South Africa. Genotypes involved in these experiments were K919-7, K927-3, K928-40, M100, M105, M153, M26, M48r, M48w, M51, M53, M66, M71, M72, M74, M78, M80, M84, M89, and M99. The experiments at both Potchefstroom and Taung were laid out in a randomised complete block design (RCBD) and replicated three times. The experiment at Potchefstroom was irrigated by a fixed overhead (sprinkler) irrigation system, whereas at Taung irrigation was by means of a movable sprinkler irrigation system. Drought stress at Potchefstroom and Taung was induced by totally withholding irrigation under rain fed treatments so that the drought stress treatments corresponded with naturally stressed plots or resembled naturally dryland farming conditions. Irrigated treatments at both Potchefstroom and Taung received water from rainfall and irrigation to supplement insufficient rainfall, but rain fed treatments strictly received water only from precipitations throughout the growing season. The treatments (dryland and irrigated) at both Potchefstroom and Taung were planted approximately 25 meters apart. Maize was planted in a strip between these blocks to avoid drifting of irrigation water to drought stress (dryland) treatments. Daily amount of rainfall for both experimental sites were recorded at the weather station closest to the sites, where the experimental trials were planted. Only daily amount of irrigation water at both experimental sites was measured within each experimental site using standard rain gauges, which were positioned on the edges of each treatment at a height of 1.5 meters above the ground. At both Potchefstroom and Taung irrigation requirements was estimated using the reference evapotranspiration (ET_o) and crop factor method as described by Green (1985). At Potchefstroom and Taung 40 and 60 mm of water was respectively applied a day before planting to create a conducive environment for seed germination across the treatments. Rain fed treatments only received irrigation prior to germination during week one (Figures 3.1 & 3.2). Thereafter, only irrigated treatments were irrigated once a week until maturity.

The experimental fields at both Potchefstroom and Taung were deep ploughed and disked during early spring season. Standard farm implements and cultural practices were used for preparing a fine seedbed at both Potchefstroom and Taung before planting. Commercial fertilizer LAN (28) and Maxifos (20) were applied at a rate of 175 kg ha^{-1} and 150 kg ha^{-1}, respectively. However, at Potchefstroom only LAN (28) was applied at a rate of 178 kg ha^{-1}. Registered pre-emergence herbicide Sorgomil ® Gold 600SC was applied at both Potchefstroom and Taung as required after planting to minimize emergence of most of the annual broadleaf and some annual grass weeds. Additionally, hand weeding was used when needed at both Potchefstroom and Taung. Registered pesticide Bulldock ® 0,05GR was applied to control stalk (stem) borer at Potchefstroom, but at Taung no insecticides were applied because there were no insect problems throughout the growing season. The plots were planted by hand in four rows of five meters long with inter-row spacing of 0.9 meters and intra-row spacing of 0.2 meters at both localities. The experimental plots were initially over seeded, and then, ten days after emergence, plants were hand-thinned to the desired population density of approximately 55 555 plants ha^{-1}. This was done to avoid competition amongst the plants for nutrients, water and other resources.

2.3 SOIL WATER DETERMINATION

Gravimetric method was used as described by Klute (1986) to determine soil water content of the profile to a depth of 100 cm at Potchefstroom prior to planting and when the crop reached maturity stage, but at Taung experimental site these procedures were not done. Soils were sampled using a soil auger from both dryland and irrigated treatments from at least five different spots, which were randomly selected in each treatment. The sample depths ranged from 0 – 15, 16 – 30, 31 – 60 and 61 – 100 cm. The soil samples were immediately sealed into pre-weighed and identified bottles to avoid soil water loss and then taken to the laboratory to determine their wet mass. After determining their wet mass, samples were put into an oven for drying at 110 ^{o}C for 48 hours to until constant weight was observed and recorded. The gravimetric water content (GWC) was calculated using the following formula as described by Hillel (1982):

$$\text{GWC} = \frac{\text{Wet mass sample} - \text{dry mass sample}}{\text{Dry mass sample}} \times 100$$

Volumetric soil-water content was also measured with a neutron water meter Model 503DR CPN Hydroprobe (Campbell Pacific Nuclear, California, USA). Ten access tubes of one meter length (1 m) were randomly placed within the rain fed treatment and inserted in the center of the plot up to 100 cm deep. The access tubes were installed by electric hammer into the soil. Firstly, before access tubes were hammered into the soil, a soil auger was used to drill to the depth of its cone. This was done for access tubes to be easily hammered without any chance of bending away from the targeted point. The depths of the access tubes could have been deeper than one meter in order to represent the roots zone, however, their depths were limited up to 90 cm because of shallow soil conditions. A neutron water meter was calibrated for the soil bulk density. Volumetric soil-water content was measured once a week from planting until harvesting from layers 30 cm down to 90 cm. The values obtained from neutron probe measurements were used to estimate soil water content and soil water deficits within the profile.

2.4 DETERMINATION OF WATER STATUS OF THE PLANTS

Plant water status was determined during grain filling stage by measuring relative water content using the floatation method as described by Spomer (1972) and Smart & Bingham (1974) for both Potchefstroom and Taung experiments. The leaf discs for determining relative water content were sampled between twelve and two o'clock during hot sunny days. Three leaf disc samples were randomly collected from green fully expanded flag leaves of the same age and at the same position in each plot during grain filling stage. Leaf disc samples sizes varied from 20 x 35 mm to 20 x 60 mm depending on the size of the flag leaf. Care was taken to minimize tissue damage during sampling and leaf veins together with malformed tissues were excluded to maximize uniformity of the samples. The samples were placed into sealed plastic bags and immediately taken to the laboratory where they were weighed to determine the fresh mass (FM) (Jordan & Ritchie, 1971; Smart & Bingham, 1974). Disc samples were floated on distilled water in petri dishes as described by Barrs (1968), Spomer (1972) and Moinuddin & Khanna-Chopra (2004) and kept at room temperature of about 15 ^{o}C for six hours to obtain full turgidity. After six hours, the samples were taken out of the water, quickly and lightly dried of any surface water with an absorbent paper towelling and immediately weighed to obtain full turgid mass (TM). The turgid mass was then recorded and leaf discs were subsequently dried in an oven at about 72 ^{o}C for 48 hours to obtain a constant mass as described by Gill *et al.* (2001). After 48 hours, the samples were reweighed to determine the dry mass (DM). Relative water content was calculated using the following formula:

$$\text{RCW} = \frac{\textit{Leaf fresh mass} - \textit{leaf dry mass}}{\textit{Leaf turgid mass} - \textit{leaf dry mass}} \times 100$$

2.5 AGRONOMIC DATA COLLECTED

Agronomic traits measured were plant height, stem diameter, biomass, flowering date, panicle exertion, panicle length, leaf area, seed mass per plot, and thousand seed mass at Potchefstroom and Taung experiments. From these data number of seeds per plot were calculated so that the effect of drought stress on seed number could be quantified. Flowering date was recorded as days to 50% flowering after planting. Flowering is defined as a stage when 50% of the panicle pollen has been shed (anthesis). Since the experiments at both Potchefstroom and Taung were planted in four rows for each plot, all data were recorded from the two center rows except leaf area because destructive method of sampling was used. For plant height (cm), stem diameter (cm), panicle exertion (cm) and panicle length (cm) data, five plants were randomly measured at harvest from the two center rows. Data for each parameter was averaged into one value per plot and used as a representative of the particular plot. Leaf area was measured at maturity using LI-3100 Area Meter (LI-COR, Inc, Lincoln, Nebraska, USA). Leaf area data was recorded from five plants that were sampled from 0.9 m^2 area of the middle rows. The data obtained were also averaged to represent leaf area of the particular plot. To minimize bird damage, the heads of 20 to 25 plants in each plot from two middle rows were covered using brown paper bags. Because of poor stand and bird damage problems to some plots, ten panicles of main stems from a 1.8 m^2 area of the two middle rows were hand-harvested at maturity when plants starting to dry out, using pruning shears. The panicles were oven-dried at 72 ^oC for 48 hours to ensure that all were uniformly dry or until constant mass, and then weighed. Plants were cut at the soil surface then put into an oven for drying at 85 ^oC for 48 hours as described by Blum *et al*. (1989). The plants were weighed to determine their mass. The mass obtained was used to determine the total aboveground biomass of the plots. The total aboveground biomass of the plot is the panicle mass in addition to the stover mass. After drying, the ears per plot were threshed and thoroughly cleaned to remove the retained glumes. The grains were weighed to determine grain yield per plot. One thousand seeds were counted using a seed counter and weighed in order to determine the 1000 seed mass per plot. Drought resistance indices were used to characterise relative drought stress tolerance or susceptibility in all genotypes for grain yield. The drought susceptibility index was calculated independently for each genotype at both localities using the formula:

DSI = $[1 - (\frac{Ydi}{Ypi})] \div [1 - (\frac{YD}{YP})]$ by Naserian *et al*. (2007).

Where DSI = Drought susceptible index

YP = overall mean yield under irrigated conditions

YD = overall mean yield under stress conditions
Ydi = yield of each genotype under stress conditions
Ypi = yield of each genotype under irrigated conditions

Percentage yield reduction was calculated using the formula:

%YR = (Ypi – Ydi) ÷ Ypi x 100

Where %YR = percentage yield reduction

Harvest index (HI) was calculated using the formula:

HI = $\frac{\text{Grain yield}}{\text{Biological yield}}$ as described by Joshi *et al*. (2005).

2.6 STATISTICAL ANALYSIS

Gravimetric water content and volumetric water content data were not subjected to statistical analysis. Relative water content and agronomic data were subjected to analysis of variances (ANOVA). The correlations between plant height, leaf area, stem diameter, panicle length, panicle exertion, biomass, harvest index and 1000 seed mass with grain yield were determined using GenStat software programme (Genstat, 2006). Percentage yield reduction data were transformed for comparing yield reduction margin among genotypes statistically using SAS software programme (SAS, 2002). But these results could not be presented because of high variation among the replications within the treatments. However, unanalysed results were presented in order to show percentage yield reduction margin trend among the genotypes.

CHAPTER THREE

3. RESULTS

3.1 PRECIPITATIONS AND IRRIGATION

The total precipitation and irrigation data recorded during the summer growing season at Potchefstroom Experimental Farm and Taung Crop Production Center are presented in Figures 3.1 & 3.2, respectively. The total precipitations received throughout the growing season were 374 and 132 mm for Potchefstroom and Taung, respectively. The precipitation at both localities was erratic, unpredictable and unevenly distributed throughout the crop developmental stages, which resulted in variable drought intensities between the localities. The highest rainfall events at Potchefstroom were 63 and 64 mm and were received at the beginning of the growing season (weeks four and five) during the vegetative stage and declined thereafter, but at Taung the highest rainfall events were 29 and 27 mm and were received late in the growing season during weeks 16 and 18 after planting, respectively. Potchefstroom was mostly wet at the beginning of the season, which made it difficult to differentiate between the irrigated, and rain fed treatments until later in the season, while Taung was dry throughout the growing season but generally the season was not too dry for crop production. However, at both Potchefstroom and Taung the total precipitation received during 2006/07 summer season was lower than the average rainfall for the last ten years, but was sufficient for crop establishment (Table 2.1 & Figures 3.1 & 3.2). At Potchefstroom, the highest precipitation of 166 mm was received during December 2006, while at Taung 41 mm was received during March 2007. The total amount of irrigation water applied throughout the growing season at Potchefstroom was 350 mm, while at Taung 499 mm was applied. At Potchefstroom, the highest amounts of irrigation applied were 56, 41 and 40 mm during weeks 9, 10 and 11 after planting, respectively. However, at Taung Crop Production Center, the highest amounts of irrigation applied were 49, 47 and 46 mm during weeks 9, 10 and 11 after planting, respectively.

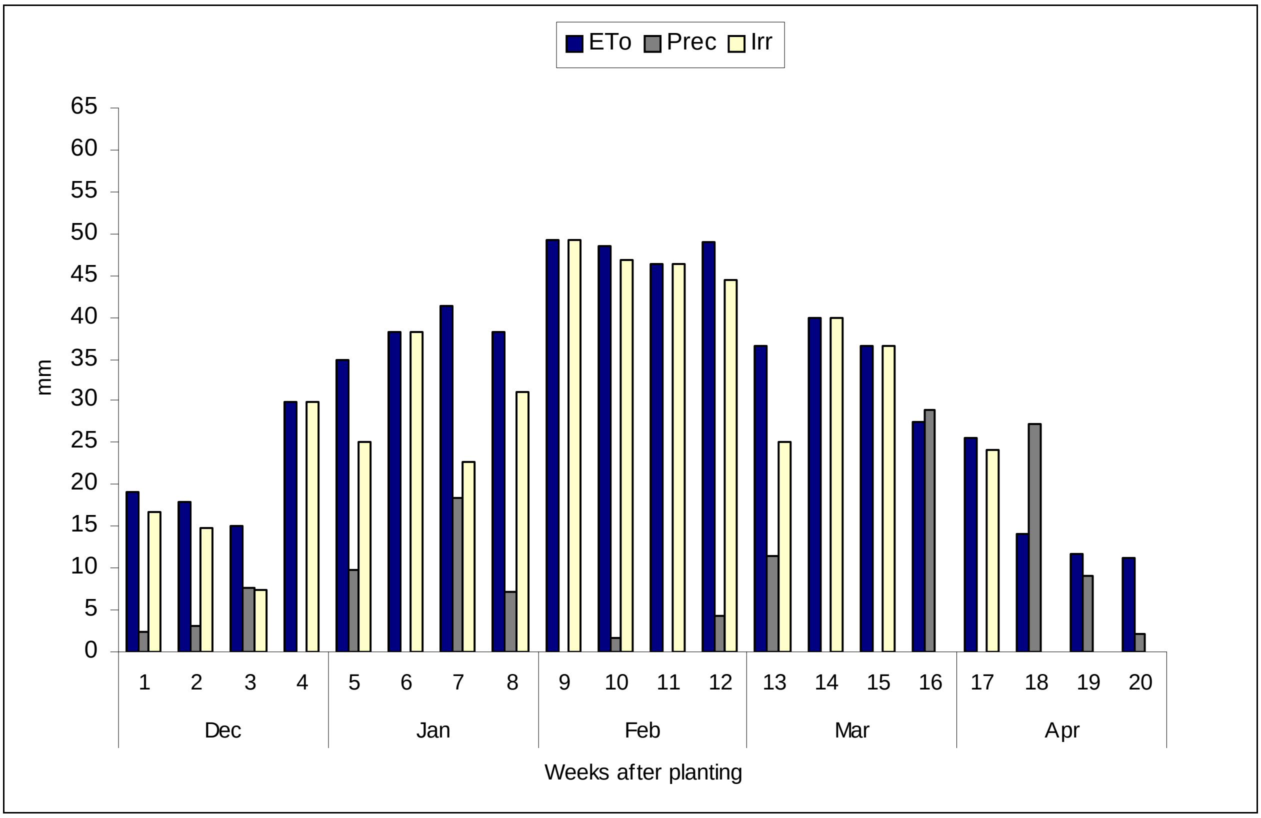

Figure 3.1 Reference evapotranspiration (ET_o), precipitation (Prec), and irrigation (Irr) data recorded at Taung Crop Production Center during 2006/07 summer growing season

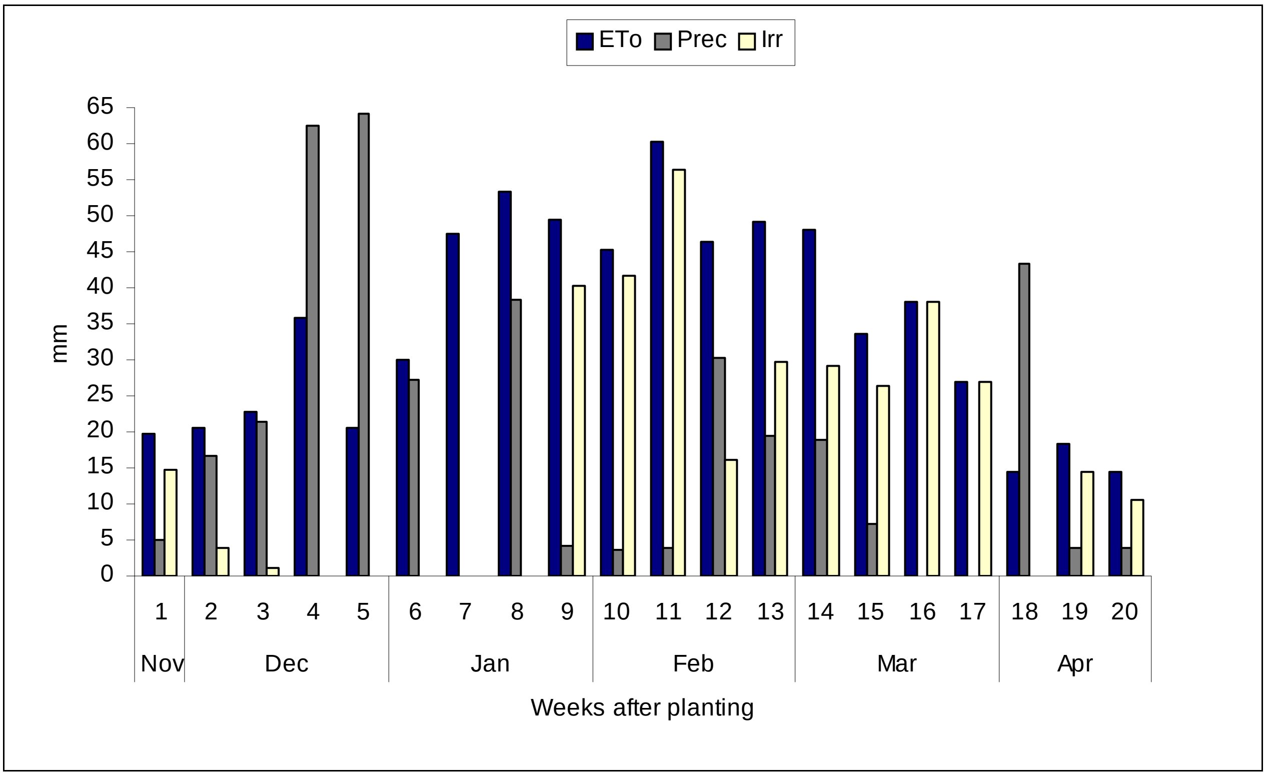

Figure 3.2 Reference evapotranspiration (ET_o), precipitation (Prec), and irrigation (Irr) data recorded at Potchefstroom Experimental Farm during 2006/07 summer growing season

3.2 SOIL WATER CONTENTS

The soil water content of the profile was not measured for each genotype or per plot. Figure 3.3 shows the mean soil water content of the profile (0 to 100 cm) measured at planting and harvesting per water treatment (dryland/ rain fed and irrigated conditions). The gravimetric soil water content determination results showed that the soil profile contained mean soil water of 225 mm to a depth of 100 cm at planting under both rain fed and irrigated conditions. At planting, available soil water was also observed below the depths of 100 cm. The wetness below 100 cm depths could be attributed to precipitations and irrigations received preceding the current summer season. At harvest, the soil profile (0 to 100 cm) under rain fed conditions contained mean soil water of 210 mm, while under irrigation conditions it contained mean soil water of 336 mm. Irrigation played a major role in increasing available soil water content of the profile under irrigated conditions. Rain fed and irrigated conditions differed by up to 126 mm due to irrigation applied throughout the growing season.

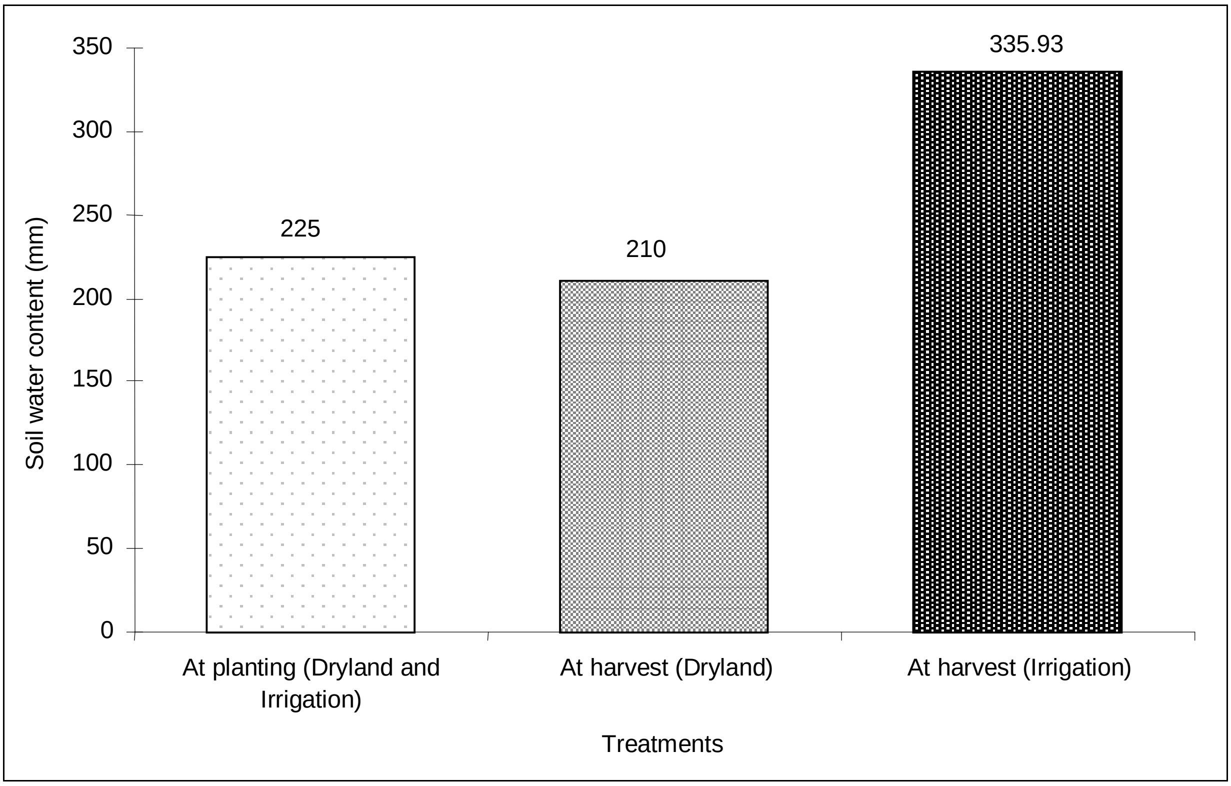

Figure 3.3 Mean soil water content of the soil profile measured at planting and at harvest under rain fed (Dryland) and irrigation conditions at Potchefstroon Experimental Farm during 2006/07 summer growing season

Under rain fed conditions, the mean soil water content among soil depths varied from 20 to 65 mm (Figure 3.4). This response suggested that lowest water content was in the topsoil layer because there the majority of plant roots are concentrated and evaporation processes occurred, while the highest mean soil water was present at the bottom of the soil profile, where less plant roots are concentrated. Under irrigated conditions, the mean soil water content among soil depths varied from 55 to 82 mm (Figure 3.4). However, the soil depth ranking with regard to soil water content did not show the trend of top to bottom scenario. The topsoil layer (20 cm) showed the lowest soil water content but 100 cm depth had lower soil water content than 60 and 80 cm depths. This was because the samples under irrigated conditions were taken 72 hours after irrigation when soil water had already infiltrated to the bottom of the soil profile, but before it reached 100 cm depth. Under irrigated conditions, most soil water content was concentrated at the 80 and 60 cm depths.

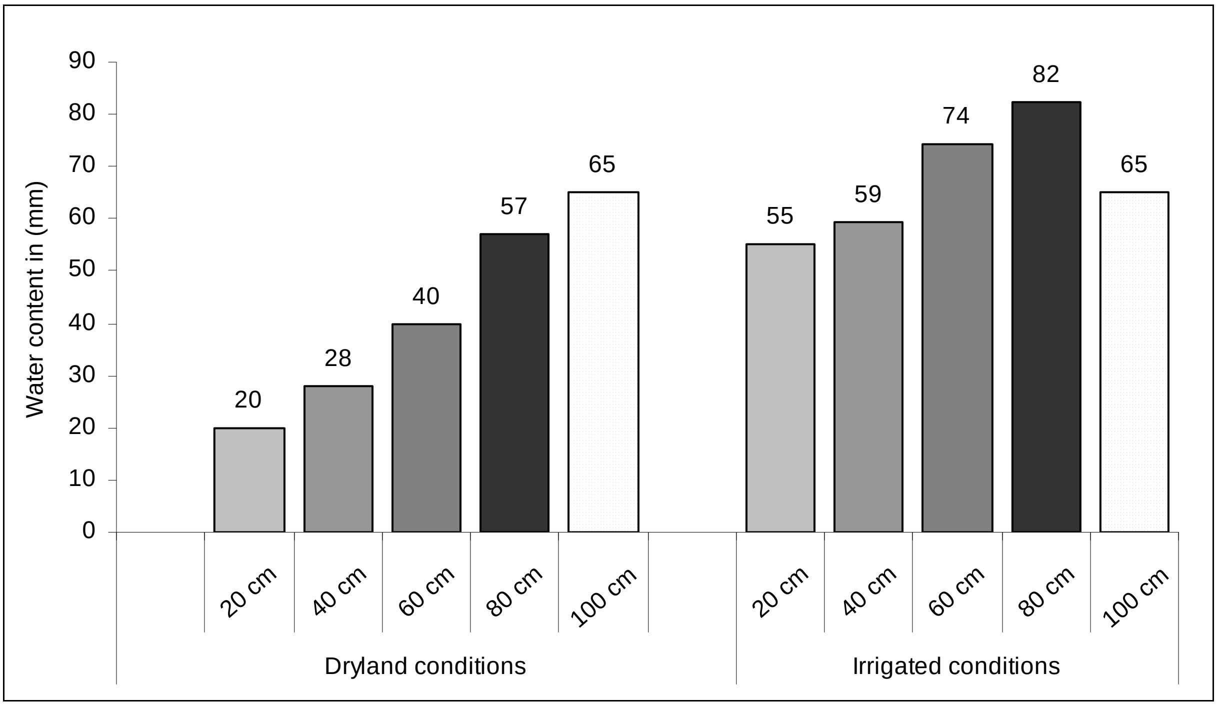

Figure 3.4 Soil water content of different depths 20, 40, 60, 80 and 100 cm at harvest under rain fed (Dryland) and irrigated conditions at Potchefstroom Experimental Farm during 2006/07 summer growing season

Figure 3.5 gives an example of the typical changes in volumetric soil water content throughout the growing season. Volumetric soil water content showed a normal trend of depletion by evapotranspiration processes and re-hydration by precipitation throughout the growing season. There was a clear distinction between 30 and 60 cm depths except during weeks 16, where all depths showed more or less similar soil water content. Soil water content depletion and hydration was similar to the trend reported by Songsri *et al*. (2008). Usually, the topsoil layers had lower water content because of the soil water evaporation and of the fact that majority of plant roots are concentrated in these layers. This assumption confirmed by Jordan & Ritchie (1971) who reported that the majority of roots were localized in the upper 25 cm of the profile where soil water content was more depleted than bottom layers of the profile. However, when the topsoil layers become too dry, soil water may move up because of differences in soil water potential that move water from regions of high water potential to the regions of low water potential.

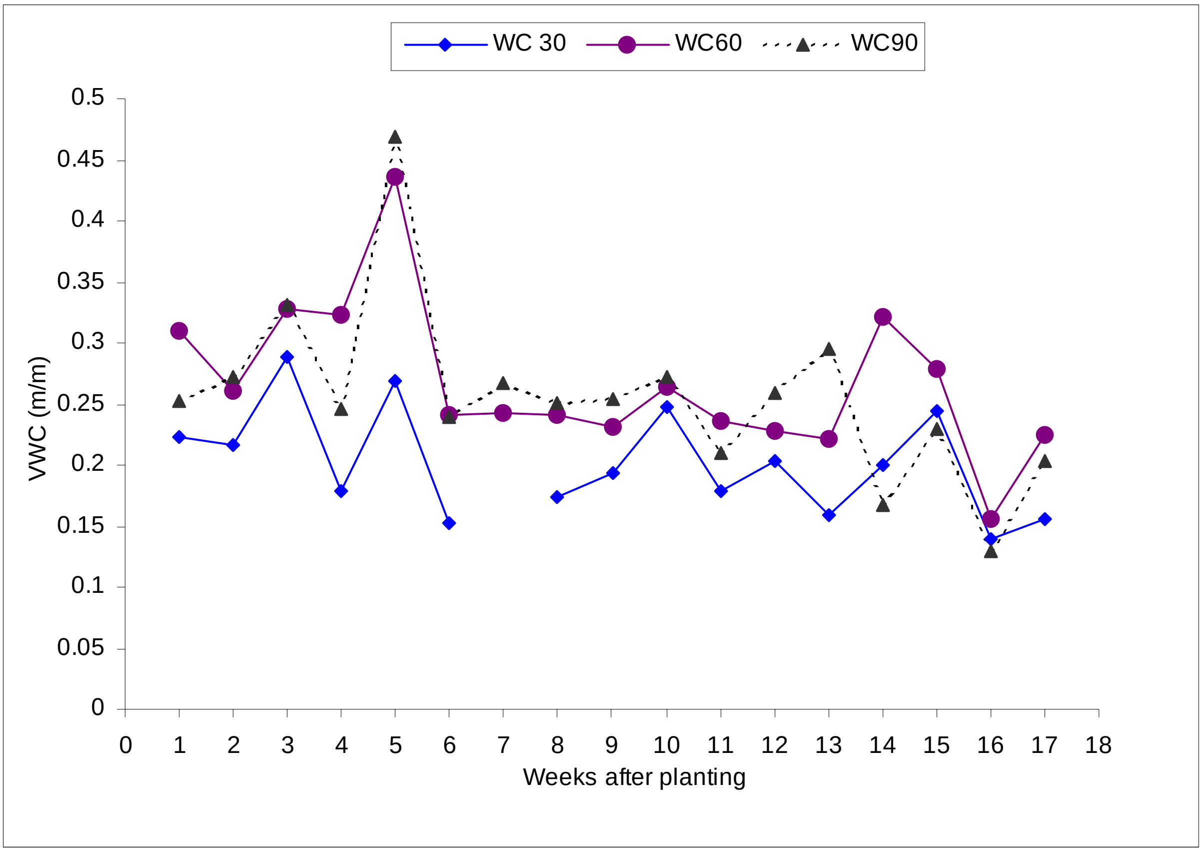

Figure 3.5 Example of measured volumetric soil water content (VWC) of three different depths 30, 60 and 90 cm of the soil as measured by neutron water meter under rain fed conditions at Potchefstroom Experimental Farm during 2006/07 summer growing season

3.3 PERFORMANCE OF GENOTYPES

At Potchefstroom under rain fed conditions, the analysis of variance showed significant variation among genotypes regarding all traits evaluated, with exception of days to 50% flowering, harvest index and relative water content, while under irrigated conditions genotypes significantly varied regarding all traits evaluated except harvest index and relative water content (Table 3.1). At Taung under rain fed conditions, genotypes varied significantly with regard to all traits evaluated except grain yield, harvest index and relative water content. However, under irrigated conditions genotypes exhibited significant variation with regard to all traits evaluated except harvest index and relative water content. At Potchefstroom grain yield, plant height, panicle exertion, relative water content and harvest index were significantly reduced by drought stress; however, most of the vegetative traits such as leaf area, biomass yield, panicle length, panicle exertion and stem diameter were not significantly affected (Table 3.1). At Taung, significant reduction of grain yield, plant height, panicle exertion, relative water content and 1000 seed mass due to drought stress was observed.

Combined analysis of variance showed significant differences among genotypes with regard to all traits measured with the exception of relative water content at both Potchefstroom and Taung (Table 3.1). At Potchefstroom, significant interactions between genotypes and soil water regimes for plant height, panicle length, biomass, stem diameter, leaf area, harvest index, panicle exertion and 1000 seed mass were observed, while at Taung the significant interactions between genotypes and soil water regimes were observed only for panicle exertion, leaf area, stem diameter and plant height.

At Potchefstroom under rain fed conditions, genotypes varied significantly with respect to grain yield, which ranged from 1.10 to 2.33 t ha^{-1} (Table 3.2). Genotypes M153 and M48r expressed the highest and lowest grain yield, respectively. However, under irrigated conditions, genotypes varied significantly with regard to grain yield, which ranged from 1.10 to 2.87 t ha^{-1}. Genotypes M105 and M48r showed the highest and lowest grain yield, respectively. At Taung under irrigated conditions, genotypes varied significantly with regard to grain yield (Table 3.2). Under rain fed conditions, grain yield among genotypes ranged from 0.80 to 2.67 t ha^{-1}, while under irrigated conditions grain yield among genotypes varied from 1.53 to 4.07 t ha^{-1}. Under rain fed conditions, genotypes M74 and M51 expressed the highest and lowest yield, while under irrigated conditions genotypes M153 and M89 showed the highest and lowest grain yield, respectively. At Potchefstroom, the performance of the genotypes across the treatments with respect to grain yield varied from 1.10 to 2.59 t ha^{-1}, while at Taung the performance of the genotypes across the treatments with respect to grain yield varied from 1.55 to 3.20 t ha^{-1}. Genotypes M105 and M48r obtained highest and lowest yield at Potchefstroom, while genotypes M105 and M89 showed highest and lowest yield at Taung, respectively.

Table 3.1 Mean square for agronomic traits of 20 sorghum genotypes evaluated at Potchefstroom Experimental Farm and Taung Crop Production Center during 2006/07 summer growing season

Locality	Treatment	Source of variation	Df	Mean square										
				GYLD (t ha^{-1})	PH (cm)	PL (cm)	BM (kg/ m^2)	DF	SD (cm)	LA (m^2)	HI	PEx (cm)	TSM (g)	RWC %
Potchefstroom Experimental Farm	Rain fed	Rep	2	0.08	57.95	9.07	1.17	51.45	0.78	422.15	0.0006	0.99	23.52	157.07
		Gen	19	0.39***	2102.31***	21.00***	105.23***	50.86	35.51***	639.69***	0.0005	14.03***	80.19***	17.25
		Error	38	0.09	61.06	4.96	16.81	46.33	3.69	64.05	0.0005	0.42	3.78	26.57
	Irrigation	Rep	2	0.23	174.87	10.65	0.72	16.07	1.75	10.43	0.0129	0.17	0.42	0.48
		Gen	19	0.53***	1334.11***	25.49***	92.51***	81.09***	27.81***	507.86***	0.005	33.79***	46.42***	1.05
		Error	38	0.11	23.24	3.27	13.99	8.19	4.76	71.15	0.002	0.36	3.33	1.36
	Combined	Trt	1	3.10*	12560.39**	39.90	1.76	90.13	5.99	1767.80	0.15*	292.97**	2.22	7843.91*
		Trt x Rep	4	0.16	116.41	9.86	5.87	33.76	1.27	216.29	0.007	0.58	11.97	258.77
		Gen	19	0.82***	2072.85***	37.26***	162.84***	86.74**	41.59***	836.71***	0.003*	27.18***	112.28***	8.80
		Trt x Gen	19	0.11	1363.57***	9.24*	34.90*	45.22	21.73***	310.85***	0.003*	20.64***	14.32**	9.50
		Error	76	0.09	42.15	4.11	15.40	27.26	4.22	67.60	0.001	0.39	3.56	13.96
Taung Crop Production Center	Rain fed	Rep	2	0.22	33.72	3.63	270.70	8.02	2.28	26.04	0.0002	0.87	2.82	160.71
		Gen	19	0.54	1548.71***	40.89***	935.85***	130.97***	6.95***	505.92***	0.004	1.70***	26.24***	24.48
		Error	38	0.34	20.02	3.59	201.24	23.03	2.41	59391.0	0.003	0.13	4.11	25.38
	Irrigation	Rep	2	0.50	41.35	3.35	2970.89	65.22	0.59	10.98	0.017	0.27	22.67	6.65
		Gen	19	0.71**	2472.40***	31.92***	2131.48***	113.59***	11.21***	258.13***	0.009	19.20***	54.57***	5.79
		Error	38	0.24	24.88	5.57	910.92	15.99	3.04	44.13	0.004	0.44	8.26	9.39
	Combined	Trt	1	15.69*	4864.13**	38.99	13154.60	52.01	156.64**	747.05*	0.012	419.63***	518.25*	4313.04*
		Trt x Rep	4	0.36	37.54	3.49	1620.79	36.62	1.43	18.51	0.009	0.57	12.75	83.68
		Gen	19	0.87**	3829.06***	66.25***	2456.80***	214.78***	8.46**	614.59***	0.009**	13.03***	70.26***	14.64
		Trt x Gen	19	0.38	192.05***	6.56	610.53	29.78	9.69**	149.45**	0.005	7.87*	10.55	15.63
		Error	76	0.29	22.45	4.58	556.08	19.51	2.72	51.76	0.004	0.29	6.18	17.38

Trt = treatment, Rep = replication, Gen = genotypes, df = degree of freedom, GYLD = grain yield, PH = plant height, PL = panicle length, BM = biomass, DF = days to 50% flowering, SD = stem diameter, LA = leaf area, HI = harvest index, PEx = panicle exertion, TSM = 1000 seed mass, *, **, ***, = significant at 0.05, 0.01, 0.001, respectively

Table 3.2 Mean of genotypes on grain yield (t ha^{-1}), drought susceptibility index with their rankings and percentage yield reduction at Potchefstroom Experimental Farm and Taung Crop Production Center measured during 2006/07 summer growing season

Genotype	Potchefstroom Experimental Farm					Taung Crop Production Center				
	Rain fed	Irrigated	Means	DSI	%YR	Rain fed	Irrigated	Mean	DSI	%YR
K919-7	1.50 (6)	1.53 (13)	1.52 (10)	0.11 (3)	1.96	2.43	2.77 (6)	2.60 (5)	0.45 (5)	12.27
K927-3	1.63 (4)	1.97 (6)	1.80 (5)	0.95 (11)	17.26	1.50	2.57 (10)	2.04 (15)	1.52 (18)	41.63
K928-40	1.47 (7)	1.67 (9)	1.57 (8)	0.66 (7)	11.98	2.20	2.43 (12)	2.32 (8)	0.35 (4)	9.47
M100	1.50 (6)	1.57 (12)	1.54 (9)	0.25 (4)	4.46	1.90	2.53 (11)	2.22 (11)	0.91 (8)	24.90
M105	2.30 (2)	2.87 (1)	2.59 (1)	1.10 (13)	19.86	2.33	4.07 (1)	3.20 (1)	1.56 (19)	42.75
M153	2.33 (1)	2.20 (3)	2.27 (2)	-0.33 (1)	-5.91	1.83	2.87 (5)	2.35 (7)	1.33 (16)	36.24
M26	1.20 (10)	1.53 (13)	1.37 (14)	1.19 (14)	21.57	2.23	3.03 (3)	2.63 (4)	0.97 (11)	26.40
M48r	1.10 (13)	1.10 (18)	1.10 (17)	0.00 (2)	0.00	1.80	2.53 (11)	2.17 (13)	1.06 (12)	28.85
M48w	1.20 (10)	1.63 (10)	1.42 (12)	1.46 (16)	26.38	2.23	2.57 (10)	2.40 (6)	0.48 (6)	13.23
M51	1.13 (12)	1.23 (17)	1.18 (16)	0.45 (5)	8.13	0.80	2.63 (9)	1.72 (17)	2.54 (20)	69.58
M53	1.37 (8)	1.60 (11)	1.49 (11)	0.80 (10)	14.38	1.43	2.13 (15)	1.78 (16)	1.20 (14)	32.86
M66	1.10 (13)	1.97 (6)	1.54 (9)	2.44 (20)	44.16	1.63	2.77 (6)	2.20 (12)	1.51 (17)	41.16
M71	1.30 (9)	1.50 (14)	1.40 (13)	0.74 (9)	13.33	1.87	2.73 (7)	2.30 (9)	1.15 (13)	31.50
M72	1.30 (9)	1.43 (15)	1.37 (14)	0.50 (6)	9.09	2.27	2.23 (14)	2.25 (10)	-0.07 (2)	-1.79
M74	1.90 (3)	2.17 (4)	2.04 (3)	0.69 (8)	12.44	2.63	2.77 (6)	2.70 (2)	0.18 (3)	5.05
M78	1.07 (14)	1.33 (16	1.20 (15)	1.08 (12)	19.55	1.77	2.37 (13)	2.07 (14)	0.93 (9)	25.32
M80	1.60 (5)	2.33 (2)	1.97 (4)	1.73 (17)	31.33	1.97	2.67 (8)	2.32 (8)	0.96 (10)	26.22
M84	1.37 (8)	1.80 (8)	1.59 (7)	1.32 (15)	23.89	2.13	3.20 (2)	2.67 (3)	1.22 (15)	33.44
M89	1.17 (11)	1.87 (7)	1.52 (10)	2.07 (19)	37.43	1.57	1.53 (16)	1.55 (18)	-0.10 (1)	-2.61
M99	1.40 (7)	2.07 (5)	1.74 (6)	1.79 (18)	32.37	2.30	2.90 (4)	2.60 (5)	0.76 (7)	20.69
Mean	1.45	1.77	1.61	-	-	1.94	2.67	2.31	-	-
SE	0.29	0.30	0.30			0.58	0.49	2.30		
LSD 0.05	0.48	0.60	0.40			n/s	0.82	0.50		
CV%	20.20	19.10	19.60			29.90	18.50	23.40		

DSI = drought susceptibility index, %YR = percentage yield reduction, n/s = not significant, number in brackets = rankings

3.4 DROUGHT RESISTANCE

Drought resistance or susceptibility of the genotypes depends on drought stress intensity and its time of occurrence. Drought intensity with respect to grain yield was 18 and 27% at Potchefstroom and Taung, respectively. Most traits measured suffered moderately from drought stress, with the exception of the panicle exertion at both localities. At Potchefstroom, drought susceptibility index (DSI) values among genotypes with regard to grain yield varied from –0.33 to 2.44, while at Taung the DSI values among genotypes varied from –0.10 to 2.54. Genotypes with DSI values < 1 are classified as drought resistant, while genotypes with DSI values > 1 are classified as susceptible to drought stress. At Potchefstroom, genotypes M153, M48r, K919-7, M100, M51, M72, K928-40, M74, M71, M53, and K927-3 were drought resistant. However, genotypes M78, M105, M26, M84, M48w, M80, M99, M89 and M66 were susceptible to drought stress. At Taung, genotypes, M89, M72, M74, K927-40, K919-7, M48w, M99, M100, M78, M80 and M26 were classified as drought resistant. However, genotypes M48r, M71, M53, M84, M153, M66, K927-3, M105 and M51 were classified as susceptible to drought stress. Percentage yield reduction due to drought stress resulted to average yield loss of 18 and 27% for Potchefstroom and Taung, respectively. The analysed percentage yield reduction among genotypes could not be presented because of high variations among replications within the treatments. Unanalysed percentage yield reduction are presented to show reduction margin trend among the genotypes. At Potchefstroom, percentage yield reduction among the genotypes varied from –5.91 to 44.16%, while at Taung percentage yield reduction among the genotypes varied from –2.61 to 69.58%. At Potchefstroom, genotypes M66 and M153 experienced highest and lowest percentage yield reduction, respectively. However, at Taung genotypes M51 and M89 experienced highest and lowest percentage yield reduction due to drought stress, respectively. The negative DSI and percentage yield reduction values indicate that genotypes produced larger grain yield under rain fed than when planted under near optimal growing conditions.

3.5 RELATIONSHIP AMONG MEASURED TRAITS

At Potchefstroom under rain fed conditions, grain yield was positively and significantly associated with plant height, biomass, 1000 seed mass and harvest index (Table 3.3). However, it showed significantly negative association with panicle length. Under irrigated conditions, an almost similar trend was observed that grain yield was positively and significantly related to plant height, biomass, 1000 mass and harvest index, respectively. At Taung under rain fed conditions, grain yield was positively and significantly associated with biomass, 1000 seed mass and harvest index, while under irrigated conditions grain yield was only significantly and positively related to 1000 seed mass and harvest index (Table 3.4). Grain yield across the treatments was positively and significantly correlated with plant height, biomass, 1000 seed mass and harvest index at Potchefstroom (Table 3.5). However, at Taung grain yield across the treatments was positively and significantly correlated with panicle exertion, stem diameter, biomass and 1000 seed mass as well as harvest index.

Table 3.3 Correlation coefficients estimated among agronomic traits measured at Potchefstroom Experimental Farm during 2006/07 summer growing season

Traits	DF	PH	PL	PEx	SD	LA	BM	GYLD	TSM	HI
					Rain fed conditions					
DF										
PH	0.008									
PL	0.061	-0.411**								
PEx	0.099	0.133	-0.075							
SD	0.218	0.030	0.306**	0.013						
LA	0.356**	0.279*	-0.070	0.104	0.299*					
BM	0.157	0.392**	-0.289*	0.187	-0.048	0.143				
GYLD	**0.139**	**0.406****	**-0.320***	**0.209**	**-0.080**	**0.126**	**0.975*****			
TSM	0.068	0.462***	-0.519***	0.255*	0.119	0.197	0.652***	**0.624*****		
HI	-0.017	0.169	-0.317*	0.102	-0.190	-0.009	0.247	**0.437*****	0.075	1.000
					Irrigated conditions					
DF										
PH	0.051									
PL	0.019	0.002								
PEx	0.123	-0.019	-0.045							
SD	0.335**	-0.253	0.052	0.182						
LA	0.483***	-0.076	-0.046	0.123	0.305*					
BM	0.022	0.513***	-0.441***	0.107	-0.061	0.122				
GYLD	**0.085**	**0.456*****	**-0.241**	**-0.019**	**-0.033**	**0.133**	**0.790*****			
TSM	0.062	0.344**	-0442***	0.167	-0.212	0.200	0.432***	**0.998*****		
HI	0.130	0.055	0.239	-0.175	-0.034	0.052	-0.052	**0.375****	0.376**	1.000

*, **, *** Significant at 0.05, 0.01 and 0.001 levels respectively, DF = days to 50% flowering, PH = plant height, PL = panicle length, PEx = panicle exertion, SD = stem diameter, LA = leaf area, BM = biomass, GYLD = grain yield, TSM = 1000 seed mass, and HI = harvest index

Table 3.4 Correlation coefficients estimated among agronomic traits measured at Taung Crop Production Center during 2006/07 summer growing season

Traits	DF	PH	PL	PEx	SD	LA	BM	GYLD	TSM	HI
					Rain fed conditions					
DF										
PH	-0.417***									
PL	-0.437***	-0.176								
PEx	-0.244	-0.199	0.228							
SD	0.017	-0.001	0.035	-0.098						
LA	0.439***	0.273*	-0.331**	-0.289*	0.165					
BM	0.451***	0.587***	-0.392**	-0.010	-0.106	0.184				
GYLD	**-0.026**	**0.069**	**0.031**	**-0.026**	**0.184**	**0.156**	**0.297***			
TSM	0.285*	0.251	-0.290*	-0.078	0.051	0.056	0.600***	**0.316***		
HI	-0.352**	-0.423***	0.297*	-0.010	0.238	-0.035	-0.530***	**0.610*****	-0.146	1.000
					Irrigated conditions					
DF										
PH	0.480***									
PL	-0.303*	-0.124								
PEx	0.018	-0.173	-0.018							
SD	0.178	0.152	-0.112	-0.271*						
LA	0.468***	0.419***	-0.089	-0.167	0.110					
BM	0.420***	0.538***	-0.026	0.069	0.077	0.575***				
GYLD	**0.104**	**0.226**	**-0.110**	**0.168**	**0.196**	**0.008**	**0.251**			
TSM	0.150	0.319*	-0.301*	0.262*	0.143	0.022	0.376**	**0.352****		
HI	-0.336**	-0.398**	-0.064	0.036	-0.048	-0.356**	-0.703***	**0.558*****	-0.075	1.000

*, **, *** Significant at 0.05, 0.01 and 0.001 levels respectively, DF = days to 50% flowering, PH = plant height, PL = panicle length, PEx = panicle exertion, SD = stem diameter, LA = leaf area, BM = biomass, GYLD = grain yield, TSM = 1000 seed mass, and HI = harvest index

Table 3.5 Correlation coefficients estimated among agronomic traits measured across the treatments at Potchefstroom Experimental Farm and Taung Crop Production Center during 2006/07 summer growing season

Traits	DF	PH	PL	PEx	SD	LA	BM	GYLD	TSM
	Potchefstroom Experimental Farm								
DF									
PH	0.077								
PL	0.065	-0.134							
PEx	0.160	0.229	0.038						
SD	0.273*	-0.058	0.190	0.125					
LA	0.426***	0.213	-0.012	0.213	0.307*				
BM	0.100	0.414***	-0.353**	0.128	-0.053	0.134			
GYLD	**0.149**	**0.495*** **	**-0.199**	**0.211**	**-0.031**	**0.198**	**0.832*** **		
TSM	0.069	0.395**	-0.468***	0.185	-0.017	0.198	0.558***	**0.478*** **	
HI	0.141	0.301*	0.174	0.224	-0.016	0.175	0.035	**0.559*** **	0.050
	Taung Crop Production Center								
DF									
PH	0.409**								
PL	-0.382**	-0.104							
PEx	-0.094	0.057	0.132						
SD	0.046	0.191	0.032	0.195					
LA	0.455***	0.268*	-0.252	-0.254*	0.025				
BM	0.356**	0.580***	-0.096	0.271*	0.170	0.278*			
GYLD	**-0.014**	**0.251**	**0.041**	**0.419*** **	**0.379** **	**-0.020**	**0.376** **		
TSM	0.140	0.363	-0.190	0.439***	0.296*	-0.057	0.517***	**0.574*** **	
HI	-0.345**	-0.357**	0.111	0.117	0.118	-0.210	-0.559***	**0.461*** **	-0.025

*, **, *** Significant at 0.05, 0.01 and 0.001 levels respectively, DF = days to 50% flowering, PH = plant height, PL = panicle length, PEx = panicle exertion, SD = stem diameter, LA = leaf area, BM = biomass, GYLD = grain yield, TSM = 1000 seed mass, and HI = harvest index

At Potchefstroom, drought susceptibility index (DSI) had a weak and positive relationship with mean grain yield; however, at Taung DSI showed a weak and negative association with mean grain yield (Table 3.6). At Potchefstroom, DSI showed a negative and weak association with grain yield under rain fed conditions, while under irrigated conditions DSI showed a weak and positive relationship with grain yield. At Taung under rain fed conditions, DSI exhibited a negative and significant association with grain yield; however, under irrigated conditions DSI showed a weak and positive relationship with grain yield (Table 3.6). At Potchefstroom, DSI showed a positive and significant association with plant height only under irrigated conditions.

Table 3.6 Correlation coefficients estimated between DSI and agronomic traits measured at Potchefstroom Experimental Farm and Taung Crop Production Center during 2006/07 summer growing season

	Potchefstroom Experimental Farm			**Taung Crop Production Center**		
	DSI			DSI		
Traits	Rain fed	Irrigated	Mean	Rain fed	Irrigated	Mean
DF	-0.1584	0.0909	-0.0222	-0.0375	0.0241	-0.0100
PH	-0.2022	0.4909*	0.1342	0.3215	0.2518	0.2877
PL	0.1019	0.0806	0.1025	-0.1501	-0.1928	-0.1803
Pex	-0.3109	0.0182	-0.1479	-0.0183	-0.2316	-0.2146
SD	-0.1508	-0.1111	-0.1604	-0.1948	-0.2440	-0.3296
LA	0.0035	-0.0166	-0.0721	-0.1925	-0.0955	-0.0564
BM	-0.2846	0.3342	0.0055	0.0735	0.0153	0.0437
GYLD	**-0.3335**	**0.3346**	**0.0275**	**-0.5805****	**0.3607**	**-0.0726**
TSM	-0.1791	-0.1490	-0.1760	-0.0273	0.3213	0.1913
HI	-0.3461	-0.0483	-0.0413	-0.3765	0.3533	0.2201

*, ** Significant at 0.05 and 0.01 level respectively, DSI = drought susceptible index, DF = days to 50% flowering, PH = plant height, PL = panicle length, Panicle exertion, SD = stem diameter, LA = leaf area, BM = biomass, GYLD = grain yield, TSM = 1000 seed mass, HI = harvest index

Table 3.7 Correlation coefficients estimated between grain yield under rain fed, irrigated conditions and across the treatments at Potchefstroom Experimental Farm and Taung Crop Production Center during 2006/07 summer growing season

	Potchefstroom Experimental Farm			Taung Research Station		
GYLD	Rain fed	Irrigation	%YR	Rain fed	Irrigation	%YR
Rain fed	-	-	-	-		
Irrigated	0.7706***	-	-	0.3875		
Mean	0.9313***	0.9498***	0.0332	0.8064***	0.8576***	-0.0721
%YR	-0.3283	0.3400	-	-0.6364**	0.4406	-

*, **, *** Significant at 0.05, 0.01and 0.001 level respectively, GYLD = grain yield, %YR = percentage yield reduction

Grain yield under rain fed and irrigated conditions and across the treatments at both Potchefstroom and Taung was correlated (Table 3.7). At Potchefstroom the results showed that grain yield under rain fed conditions were significantly correlated with grain yield under irrigated conditions and mean grain yield across the treatments, but weakly and negatively associated with percentage yield reduction. However, grain yield under irrigated conditions was significantly related to mean grain yield across the treatments and weakly associated with percentage yield reduction. At Taung, grain yield under rain fed conditions was weakly associated with grain yield under irrigated conditions but significantly and positively associated with mean grain yield across the treatments, while significantly and negatively related with percentage yield reduction. However, grain yield under irrigated conditions was significantly associated with mean grain yield across the treatments, but weakly and positively related to percentage yield reduction.

DISCUSSION

Based on annual precipitation data, this region received summer rainfall, which was characterized by erratic and unpredictable seasonal distribution patterns (Figures 3.1 & 3.2). Drought resistance in this study was quantified based on relative grain yield under rain fed and irrigated conditions so as to obtain an estimate of drought stress intensity in addition to estimated drought resistance and yield potential of the genotypes in the targeted area as suggested by Wenzel *et al*. (1999) in sorghum. Generally, severe drought stress leads to enhanced depression in grain yield production and other vegetative traits (Sinclair *et al*., 1990; Abdelmula & Sabiel, 2007). The sorghum genotypes evaluated in this study were quite different with regard to various traits under rain fed and irrigated conditions at both Potchefstroom and Taung. At Potchefstroom, genotypes experienced relatively mild drought stress that occurred from mid season until end of the season, which resulted in an average yield reduction of 18%. However, at Taung drought stress intensity was slightly more severe because of lower and erratic rainfall distribution pattern throughout the season, which resulted in an average yield reduction of 27%. Although the rainfall was erratically distributed at both localities, generally, it coincided with critical crop growth stages; therefore resulted in mild drought stress. Potchefstroom received remarkable amount of rainfall at weeks 12, 13 and 14, which coincided with flowering period and at weeks 18 which coincided with grain filling period (Figure 3.2). Taung crop was relieved of drought stress at weeks 12 and 13, which coincided with flowering period and at weeks 16 and 18 which coincided with grain filling period (Figure 3.1). These rainfalls reduced the effect of drought stress on grain yield at both localities. The results in this study conform to those of Chennafi *et al*. (2006) who reported that in wheat good rainfall distribution pattern within the season usually matches the crop water needs and it contributes to a yield improvement although it may allow little drought stress to develop.

The observed significant differences among genotypes with regard to grain yield under rain fed and irrigated conditions, and across the treatments at Potchefstroom and Taung represent the source of genetic variability and the presence of variations for all other yield related traits. This is similar to the findings by Wenzel (1999) in sorghum and Khaliq *et al*. (2004) in wheat. Furthermore, the variations among genotypes emphasized the different genotypic responses to drought stress conditions as reported by Amiri Fahliani & Assad (2005) in wheat. These differences provide an opportunity for selecting suitable genotypes with better performance for the traits (Tyagi & Khan, 2010). This implies that grain yield reduction due to drought stress was genotypic based and influenced by accumulation/ decrease of other yield related traits. This conforms to Wenzel (1999) who found that both number of seeds and seed mass determine grain yield. Before yield improvements can be achieved, the cause of variability in grain yield among genotypes should be identified at a targeted area since environmental fluctuation may affect yield primarily through its components (Tyagi & Khan, 2010).

In this study, positive and significant association of grain yield with other yield related traits under rain fed and irrigated conditions and across the treatments confirm these findings (Tables 3.3, 3.4 & 3.3). The correlations provide information of interrelationships of the important traits, which directly or indirectly help in improvement of grain yield as reported by Khan *et al*. (2003) in wheat. Furthermore, the greater magnitudes of variability among genotypes for all traits associated with grain yield provide large scope of selection based on these traits (Wenzel, 1999 and Tariq *et al.,* 2007). The results in this study showed that the influence of each trait, which was significantly associated with grain yield, varied depending on growth conditions at both Potchefstroom and Taung, i.e. rain fed and irrigated conditions (Tables 3.4 & 3.5). At Potchefstroom under rain fed conditions, grain yield was strongly associated with biomass (r = 0.975***), 1000 seed mass (r = 0.624***) and harvest index (r = 0.437***). However, under irrigated conditions grain yield was strongly associated with 1000 seed mass (r = 0.998***), biomass (r = 0.790*** and harvest index (r = 0.375**). At Taung under rain fed conditions, grain yield was strongly associated with harvest index (r = 0.610***), 1000 seed mass (r = 0.316*) and biomass (r = 0.297*). However, under irrigated conditions grain yield was strongly associated with harvest index (r = 0.558***) and 1000 seed mass (r = 0.352**), and weakly associated with biomass (r = 0.251). At Potchefstroom, weak and positive association between days to 50% flowering and grain yield was observed, while at Taung negative but weak relationship was observed. Usually, negative and significant relationship between days to 50% flowering and grain yield is expected under drought stress conditions. Potchefstroom results agreed with Silim &

Saxena (1993) who found in chickpea weak and positive association between days to 50% flowering and grain yield when precipitation received was 330 and 504 mm during 1986/87 and 1987/88 growing season but found a negative and significant association when precipitation received was 234 mm during 1988/89 season. This implies that the positivity and the negativity of the relationship between days to 50% flowering and grain yield depend on the intensity of drought stress. Potchefstroom and Taung results are evidence of this observation. Taung drought stress intensity was slightly more severe than Potchefstroom though it was not severe enough to cause negative and significant relationship between days to 50% flowering and grain yield under drought stress. Direct selection for these various traits could be misleading; therefore, indirect selection based on yield related traits with high heritability may be more effective than direct selection for yield (Toker & Cagirgan, 2004). Tyagi & Khan (2010) in *Lens culinaris* Medik added that knowledge of nature and magnitude of associations among different traits are important hence the importance of indirect selection when desirable traits are having low heritability. In the present study, the positive significant associations of grain yield with biomass and harvest index under rain fed and irrigated conditions at both localities showed that grain yield production was mainly dependent on sink size of the crop. This is similar to the findings reported by Silim & Saxena (1993) in chickpea. In addition, these relationships signified the crop capacity to fill the sink during drought conditions as reported by Gonzalez *et al*. (2007) in barley. However, the magnitude of sink contributions varied depending on occurrence of the drought stress and/ or growth conditions. These results conform to Silim & Saxena (1993) in chickpea who reported varying degree of biomass contributions to genotypes' grain yield when planted under rain fed (r = 0.685 in 1986/87) and irrigated (r = 0.758 in 1986/87) conditions.

At Potchefstroom under rain fed conditions, the five high yielding genotypes were M153, M105, M74, K927-3 and M80 with 2.33, 2.30, 1.90, 1.63 and 1.60 t ha^{-1}, respectively (Table 3.2). However, under irrigated conditions the five high yielding genotypes were M105, M80, M153, M74 and M99 with 2.87, 2.33, 2.20, 2.17 and 2.07 t ha^{-1}, respectively. At Taung under rain fed conditions, the five high yielding genotypes were M74, K919-7, M105, M99 and M72 with 2.63, 2.43, 2.33, 2.30 and 2.27 t ha^{-1}, respectively (Table 3.2). However, under irrigated conditions the five high yielding genotypes were M105, M84, M26, M99 and 72 with 4.07, 3.20, 3.03, 2.90

and 2.87 t ha^{-1}, respectively. Yield under rain fed and irrigated conditions in the best yielding genotypes represent favourable growing conditions (Blum *et al*., 1989) because they are most adapted to the prescribed target conditions. At Potchefstroom, four of the five genotypes were able to maintain their yield potential when planted under rain fed conditions though changes in their rankings were observed. The above findings are in agreement with Omanya *et al*. (1996) who reported in sorghum high yielding varieties under irrigation conditions were also found to be high yielding varieties under drought stress conditions. This could be attributed to the significant correlation between grain yield under rain fed and irrigated conditions (Table 3.7). However, at Taung three of the five high yielding genotypes under irrigated conditions did not maintain their high yield potential when planted under rain fed conditions. Wenzel (1997) observed in sorghum similar trends among varieties. This implies that high yielding genotypes under near optimum growing conditions may be recommended for those particular conditions, while high yielding genotypes under drought stress may also be recommended for drought stress conditions since they are well adapted to those particular target areas as reported by Toker & Cagirgan (1998) in chickpea. These findings are in agreement with Zangi (2005) in cotton who reported that yield selection in non-stressed conditions increased yield only in non-stressed conditions. These results confirmed that high potential yield under irrigated conditions does not necessarily result in high yield under drought stress conditions, as was found by Sio-Se Mardeh *et al*. (2006) in wheat and Talebi *et al*. (2009) in wheat. This could be attributed to the weak association between grain yield under rain fed and irrigated conditions (Table 3.7). Zangi (2005) in cotton reported similar findings. The Potchefstroom and Taung result contradictions are based on the intensity of drought stress. This means that the significance or weakness of the correlations could be attributed to the severity of drought stress prevailing at the target area. The more severe the drought stress, the weak the correlation between grain yield under rain fed and irrigated conditions. Similarly, Wenzel *et al*. (1999) in sorghum reported varying association of r = 0.72 and r = 0.54 between grain yield under dryland and irrigated conditions when drought stress intensity was 27 and 10%, respectively.

Drought resistance is defined as the ability of the genotypes to minimize yield reduction in the absence of optimal soil water content conditions (Clarke *et al*., 1984). It is used to evaluate relative stress injury because it accounts for variations in yield potential and drought stress intensity (Bruckner & Frohberg, 1987) and it helps identifying stable and responsive genotypes under drought stress conditions (Osmanzai, 1994). Since the productivity of grain sorghum is inherent to the varieties, the marginal yield reduction of the varieties under drought stressed conditions is an essential strategy of measuring drought resistance than the direct comparison of grain yield (Inuyama, 1978). The greater the DSI value, the larger the percentage yield reduction under stress conditions. At Potchefstroom, the five most resistant genotypes were M153, M48r, K919-7, M100 and M51; while at Taung the five most resistant genotypes were M89, M72, K928-40, K919-7 and M48w (Table 3.2). These genotypes were able to tolerate soil water deficits either by increasing number of seeds or increasing seed weight, depending on the timing of soil water deficits (data not shown). Pre-flowering moisture deficits reduce the number of seeds per ear and post-flowering is likely to reduce grain weight hence variability in the rate and duration of grain development could explain some differences in post-flowering drought tolerance (Tuinstra *et al*., 1997). M100 and K919-7 improved their yield by increasing grain weight while M51 and M48r improved their yield by increasing number of seeds per ear. M153 improved its yield through both increased number of seeds and grain weight. At Taung, K928-40, M72 and M89 improved their yield by increasing the number of seeds per ear, while M48w and K919-7 were intermediate because the number of seeds per ear and grain weight under rain fed conditions did not change significantly as compared to irrigated conditions (data not shown). The resistance of the genotypes to soil water deficits could be regarded as a full representation of the integrated plant response to drought stress in crop production. Even though DSI can be able to separate drought resistant genotypes from susceptible ones, it has its own limitations because it is solely based on minimizing yield reduction under drought stress (Dencic *et al*., 2000). Consequently, genotypes with similar proportional yield reduction because of drought stress will show similar DSI value, even if one is a higher yielding genotype than the other (Lopez *et al.*, 2003). Example: in Taung, genotypes M26 and M80 obtained similar DSI values but M26 obtained better yield than M80. In addition, it cannot differentiate potentially drought resistant genotypes from those with low yield potential because of other factors than drought stress. In this study, different trends of genotypes that had high drought resistance (DSI < 1) in addition to low yield potential and genotypes with low drought resistance (DSI > 1) in addition to high yield potential at both Potchefstroom and Taung were observed (Table 3.2). Selection based on DSI values would likely reduce yield under favourable conditions (Ramirez-Vallejo & Kelly, 1998; Talebi *et al*., 2009). This is because of negative association between yield under drought stress and DSI as reported by Talebi *et al*. (2009) in wheat. This is similar to Taung results, but contrary to Potchefstroom results (Table 3.6). However, its success depends on the severity of drought stress at a target area (Wenzel, 1999; Sio-Se Mardeh *et al*., 2006). This means that the more severe the drought stress, the likelihood of DSI to separate susceptible genotypes from resistance ones is higher. The findings in this study agreed with the above report. The negativity and positivity of relationship between grain yield under drought stress conditions and drought susceptibility index depends on the severity of the drought stress (Talebi *et al*., 2009). Potchefstroom and Taung results confirmed this report that the more severe the drought stress become the stronger and negative the association between grain yield under drought stressed conditions and drought susceptibility index. Lack of response of genotypes such as M48r to irrigation at Potchefstroom could be attributed to poor adaptation to optimum soil water conditions that prevailed in the target area, as suggested by Clarke *et al*. (1992) in wheat. Genotypes that obtained negative DSI values produced higher yield under rain fed conditions than when planted under irrigated conditions (Table 3.2). It could be attributed to timing and intensity of drought stress occurrence. The survival of the resistant genotypes could be attributed to their ability to channel assimilates reserved to the developing grain during drought stress period. This conforms to results reported by Clarke *et al*. (1984) for wheat and Wenzel (1997) for sorghum that accumulation and efficient translocation of non-structural carbohydrates reserve to the developing grain is one of avenues of maintaining yield during drought stress.

Since selecting for drought stress aimed at improving productivity with increasing level of drought stress, productivity under drought stress does not depend only on stress tolerance, but also on maximum productivity (Baker, 1994). Genotypes that exhibit high yield potential and yield stability with increasing drought stress as well as sensitivity towards improved soil water conditions are more favourable than genotypes that exhibit low yield potential and insensitive to improved soil water conditions though they exhibit drought resistant trait (Wenzel, 1999). The relationship of drought resistance or susceptibility and yield potential is very crucial in maintaining yield stability in sorghum production hence grain sorghum is planted for grain production. At Potchefstroom, M153 and M74 were the only genotypes that exhibited combination of high yield potential and resistant traits; however, at Taung majority of genotypes were able to stabilised yield but did not respond positively to irrigation applied (Figures 3.6 & 3.7). Yield stability by the genotypes could be regarded as adaptive traits to the particular environmental conditions. The findings of this study are in agreement with Wenzel (1997) who found that in sorghum resistant genotypes had sacrificed yield in favour of the capacity to respond positively to drought stress. Genotypes that exhibit low yield potential with high drought resistance trait may be productive under more severe drought stress conditions (Wenzel, 1999; Talebi *et al.*, 2009). Genotypes should be selected based on drought stress severity at targeted environmental conditions.

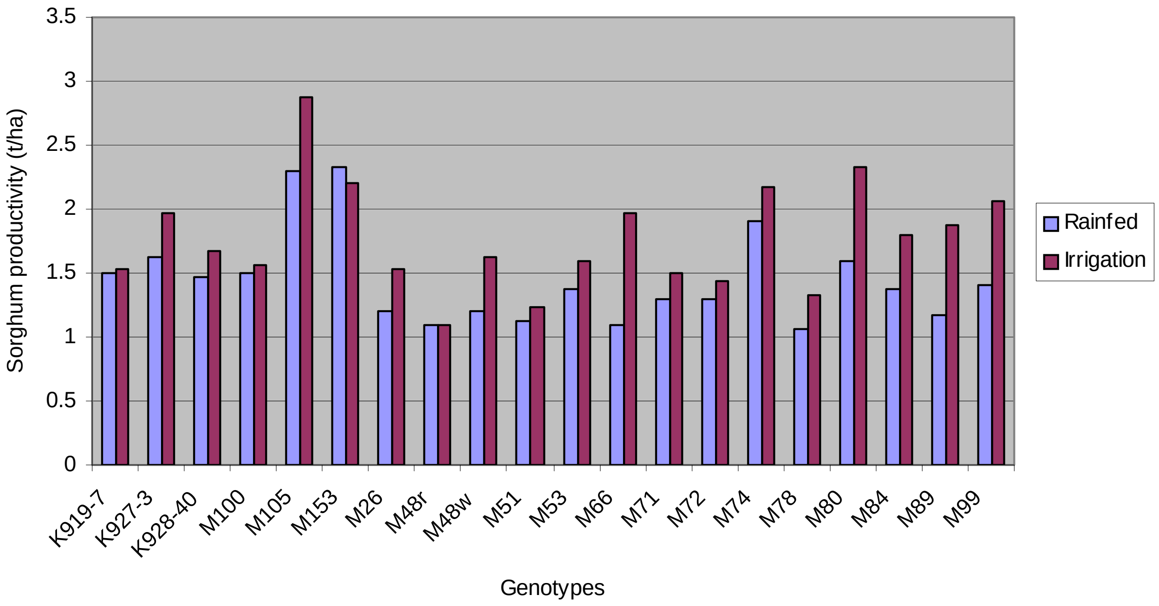

Figure 3.6 Grain yield observed under rain fed and irrigated conditions at Potchefstroom Experimental Farm during 2006/07 summer growing season

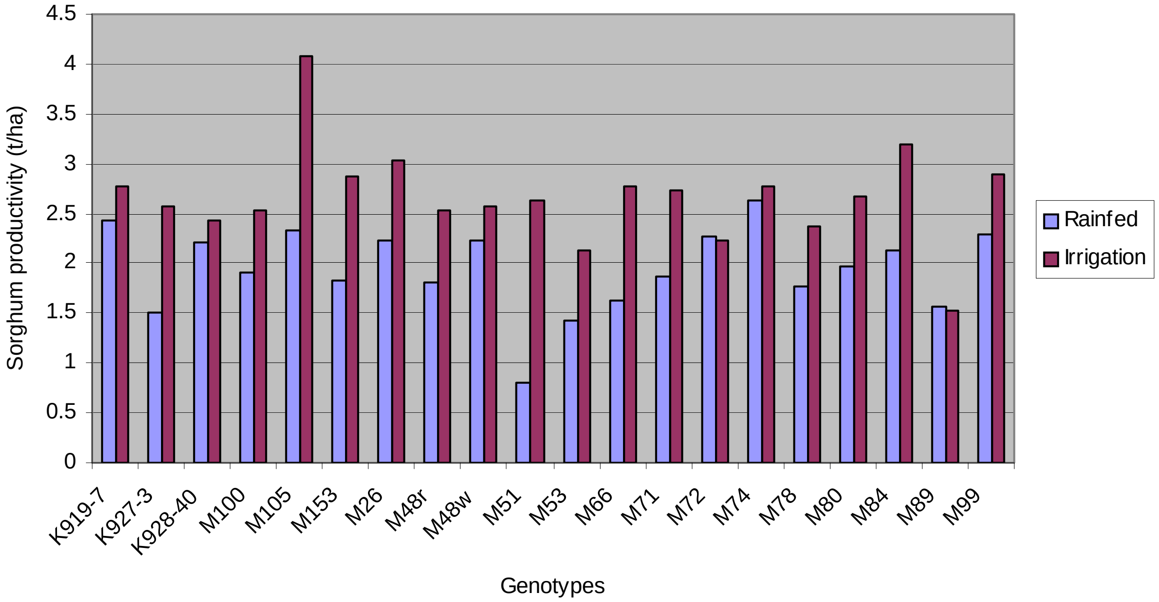

Figure 3.7 Grain yield observed under rain fed and irrigated conditions at Taung Crop Production Center during 2006/07 summer growing season

For breeding purpose, genotypes that exhibited high drought resistant traits though they have low yield potential should be selected. This would help the breeders to incorporate resistant traits into genotypes that exhibited high susceptibility traits.

OVERALL DISCUSSION AND CONCLUSIONS

Potchefstroom and Taung regions are characterized by erratic and unpredictable seasonal rainfall distribution pattern. It makes these regions relevant for screening for drought resistance. Drought resistance in this study was quantified on grain yield under rain fed related to grain yield under irrigated conditions. At Potchefstroom, genotypes experienced mild drought stress that occurred from mid season until end of the season and caused an average yield loss of 18%. However, at Taung genotypes suffered slightly more severe drought stress, which caused an average yield loss of 27%. More research should be conducted under variable environmental conditions to enable us to evaluate and select high yield potential and stable genotypes. The mild drought stress experienced at both Potchefstroom and Taung was because rainfall coincided with critical crop growth stages. Selection for drought resistance is regarded as an economic and efficient way of eradicating agricultural problems particularly in dry areas (Ali *et al*., 2009). To achieve this goal a set of reliable traits that can be rapidly screened are needed. For successful selection, presence of remarkable magnitude of variability within the available germplams should exist (Ali *et al*., 2008) Genotypes evaluated in this study were quite variable with respect to principal traits (grain yield and yield components). The variations among genotypes represent diverse genetic background, which brought different adaptability among genotypes. In environmental conditions that are similar to that of Potchefstroom under rain fed conditions, genotypes M153, M105, M74, K927-3 and M80 may be recommended. However, genotypes that may be recommended for environmental conditions that are similar to that of Potchefstroom under irrigated conditions are M105, M80, M153, M74 and M99, respectively. High yield potential genotypes under either rain fed or irrigated conditions show better adaptability to those particular conditions. Genotypes that may be recommended for environmental conditions that are similar to that of Potchefstroom under rain fed and irrigated conditions are M153 and M74. This is because the performance of these genotypes under both rain fed and irrigated conditions was relatively high. In addition, these genotypes showed good drought resistance in combination with high yield potential.

In environmental conditions that are similar to that of Taung under rain fed conditions, genotypes M74, K919-7, M105, M99 and M72 may be recommended, while in environmental conditions that are similar to that of Taung under irrigated conditions, genotypes M105, M84, M26, M99 and 72 may be recommended. In environmental conditions that are similar to that of Taung under both rain fed and irrigated conditions, genotypes M74, M26, K919-7, M99 and M48w may be recommended. These genotypes showed combination of high yield potential with drought resistance traits. Further research should be commissioned to evaluate these genotypes under more severe drought stress. Since the objective of evaluating and selecting genotypes for drought resistance is to improve yield in severe drought stress environment, genotypes should be evaluated and selected in the target area of concern. In environmental conditions that are far apart from that of Potchefstroom and Taung adaptive trials should be conducted for that specific region or area. The results in this study showed that grain yield under rain fed and irrigated conditions is controlled by several morphological and physiological traits, which should form part of indirect selection criterion. All traits, which are highly heritable and significantly associated with grain yield under rain fed conditions, would indirectly increase yield under severe drought stress. Since grain yield is determined by both number of seed per ear and their mass, they should form part of the selection criteria because they are heritable components of grain yield (Wenzel, 1999). The study showed that genotypes exhibiting combination of yield potential and drought resistance (adaptive) traits should be selected because they can provide superior germplasm bases for a breeding programme. This is similar to Kimurto *et al.* (2005) concluding remarks. For irrigated conditions, genotypes that positively responded to irrigation should be recommended. For rain fed conditions, intermediate genotypes should be recommended because they can able to produce satisfactory yield even though low rainfall is expected during the growing season. For the breeders who are breeding for drought resistance, genotypes that are in extremes (highly resistance and highly susceptible) should be recommended so that breeders can incorporate resistance genes into high yield potential genotypes with high drought susceptibility traits.

SUMMARY

Twenty sorghum genotypes were planted under rain fed and irrigated conditions at Potchefstroom and Taung during 2006/07 summer growing season. At Potchefstroom under rain fed conditions, significant variations were observed among genotypes with regard to all traits measured except on days to 50% flowering, harvest index and relative water content. However, under irrigated conditions, significant variations among genotypes were also observed on all traits with the exception of harvest index and relative water content. At Taung under rain fed conditions, genotypes varied significantly with regard to all traits evaluated except grain yield, harvest index and relative water content, while under irrigated conditions genotypes varied significantly with regard to all traits measured except harvest index and relative water content. At Potchefstroom, significant effects of soil water deficits were only observed on grain yield, plant height, harvest index, panicle index and relative water content; however, at Taung the significant effects of soil water deficits were only observed on plant height, stem diameter, leaf area, panicle exertion, 1000 seed mass and relative water content. At Potchefstroom, the performance of the genotypes across the treatments was significant for all traits measured with the exception of relative water content. However, at Taung significant variations among genotypes across the treatments were observed for all traits measured except relative water content. At Potchefstroom, genotypes significantly interacted with soil water regimes for plant height, panicle length, biomass, stem diameter, leaf area, harvest index, panicle exertion and 1000 seed mass. However, at Taung genotypes significantly interacted with plant height, stem diameter, leaf area and panicle exertion. At Potchefstroom, drought susceptibility index (DSI) values among genotypes varied from –0.33 to 2.44 for M153 and M66, respectively. However, at Taung DSI values among genotypes varied from –0.10 to 2.54 for M89 and M51, respectively. Genotypes that obtained DSI values < 1 are regarded as drought resistant, while genotypes that obtained DSI values > 1 are regarded as drought susceptible. At Potchefstroom percentage yield reduction among genotypes varied from –5.91 to 44.16%, while at Taung percentage yield reduction among genotypes varied from –2.61 to 69.58%. Negative values means that genotypes yield more under rain fed than under irrigated conditions.

At Potchefstroom under rain fed conditions, correlation coefficients estimated among all traits measured revealed that grain yield was significantly associated with plant height, panicle length, biomass, 1000 seed mass and harvest index. However, under irrigated conditions grain yield was significantly correlated with plant height, biomass, 1000 seed mass and harvest index. At Taung under rain fed conditions, grain yield was significantly related to biomass, 1000 seed mass and harvest index, while under irrigated conditions grain yield was significantly associated with 1000 seed mass and harvest index. Across the treatments, grain yield was significantly correlated with plant height, biomass, 1000 seed mass and harvest index. However, at Taung grain yield was significantly correlated with panicle exertion, stem diameter, biomass, 1000 seed mass and harvest index. At Potchefstroom under rain fed conditions, negative and weak relation between grain yield and DSI was observed. However, under irrigated conditions weak and positive relationship between grain yield and DSI was observed. Across the treatments, DSI was weakly associated with all traits measured. At Taung under rain fed conditions, DSI was significantly and negatively associated with grain yield, while under irrigated conditions DSI showed weak and positive association with grain yield. Across soil water regimes, DSI was weakly and negatively associated with grain yield.

Correlation coefficients estimated among grain yield under rain fed and irrigated conditions, and across soil water regimes showed that grain yield under rain fed conditions was significantly and positively related to grain yield under irrigated conditions and grain yield across moisture regimes, while grain yield under irrigated conditions was significantly and positively related to grain yield across the treatments at Potchefstroom. However, at Taung grain yield under rain fed conditions was significantly and positively associated with grain yield across the treatments, while grain yield under irrigated conditions was significantly and positively associated with grain yield across the treatments. All traits that are directly and indirectly associated with grain yield under rain fed and irrigated conditions should be part of the selection criteria.

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APPENDIX

Appendix table 1 Mean of genotypes for agronomic traits evaluated for drought resistance at Potchefstroom Experimental Farm during 2006/07 summer growing season

Genotype	Days to 50% flowering		Plant height (cm)		Panicle length (cm)		Panicle exertion (cm)		Stem diameter (cm)		Leaf area (m^2)	
	Dry	Irr	Dry	Irr	Dry	Irr	Dry	Irr	Dry	Irr	Dry	Irr
K919-7	78	89	117.5	119.2	24.9	23.9	2.3	7.9	24.5	23.1	2.51	2.87
K927-3	71	77	121.5	158.5	20.5	23.1	5.3	0.0	14.2	13.2	1.09	2.11
K928-40	73	78	146.8	134.4	22.1	22.5	0.0	2.1	16.1	18.5	1.37	1.35
M100	84	79	104.0	115.9	26.2	27.6	0.0	4.5	20.9	23.1	2.08	2.54
M105	75	78	179.5	169.1	17.8	22.1	2.5	2.6	17.7	17.1	1.73	2.02
M153	84	78	143.5	157.7	19.5	19.0	4.4	5.7	20.5	17.1	2.29	2.48
M26	71	75	138.3	153.6	24.9	27.8	0.0	1.3	15.1	17.8	1.91	2.13
M48r	74	69	113.8	125.4	25.6	24.8	8.1	8.8	13.9	19.7	1.18	1.33
M48w	69	76	120.2	131.2	23.0	24.6	0.7	10.3	19.7	19.2	1.54	1.87
M51	77	70	83.9	97.8	25.3	26.7	0.7	2.7	20.4	13.7	1.13	2.00
M53	79	77	173.7	114.9	21.3	22.1	0.8	2.3	19.8	19.3	2.55	2.16
M66	78	77	95.0	173.7	29.0	26.0	1.0	0.0	23.2	15.9	1.89	2.07
M71	74	78	99.5	129.3	24.1	23.5	2.4	2.1	18.9	15.1	1.68	1.53
M72	72	79	108.2	130.6	24.6	23.3	0.0	0.3	17.2	18.5	1.55	1.99
M74	74	73	112.3	160.8	24.1	28.5	0.3	6.6	12.1	16.5	1.75	1.56
M78	81	84	147.7	167.9	24.3	31.7	1.5	6.1	19.1	17.3	2.09	2.02
M80	80	83	124.2	142.1	23.1	24.0	4.2	3.5	17.2	22.2	2.49	2.25
M84	77	78	111.6	148.8	21.1	24.9	1.7	3.7	17.8	22.6	1.63	1.79
M89	76	72	88.6	160.7	20.6	20.7	0.8	9.4	11.1	14.6	2.05	1.86
M99	76	88	94.9	142.5	25.1	23.7	0.0	11.3	17.2	21.2	1.23	2.68
Mean	76	78	121.2	141.7	23.4	24.5	1.6	4.8	17.8	18.3	1.79	2.03
SE	6.8	2.9	7.8	4.8	2.2	1.8	0.7	0.6	1.9	2.2	0.25	0.27
LSD 0.05	n/s	4.7	12.9	8.0	3.7	3.0	1.1	0.9	3.2	3.6	0.42	0.4
CV (%)	8.9	3.7	6.4	3.4	9.5	7.4	39.5	12.6	10.8	11.9	14.2	13.1

Dry = dryland conditions, Irr = irrigated conditions, and n/s = not significant

Appendix table 2 Mean of genotypes for plant biomass and TSM evaluated for drought resistance at Potchefstroom Experimental Farm during 2006/07 summer growing season

	Plant biomass (Kg/ m^2)		TSM (g)	
Genotype	Dry	Irr	Dry	Irr
K919-7	0.85	0.67	27.1	23.2
K927-3	0.90	0.94	28.5	23.2
K928-40	0.73	0.71	20.6	20.5
M100	0.81	0.71	18.6	18.0
M105	1.25	1.03	34.8	29.3
M153	1.20	1.11	33.3	32.2
M26	0.71	0.69	19.4	18.8
M48r	0.58	0.59	17.1	23.1
M48w	0.67	0.72	19.0	18.8
M51	0.63	0.49	16.8	19.9
M53	0.69	0.72	19.4	22.5
M66	0.65	0.85	18.9	19.7
M71	0.71	0.65	20.1	20.2
M72	0.71	0.71	16.6	17.9
M74	1.02	0.85	18.3	18.2
M78	0.57	0.56	21.5	24.9
M80	0.86	0.97	20.8	21.6
M84	0.73	0.83	21.2	19.0
M89	0.64	1.09	22.0	27.7
M99	0.74	0.92	20.0	21.1
Mean	**0.78**	**0.79**	**21.7**	**22.0**
SE	0.13	0.12	1.9	1.83
LSD 0.05	0.21	0.20	3.2	3.02
CV (%)	16.6	15.0	9.0	8.3

Dry = dryland conditions, Irr = irrigated conditions and TSM = thousand seed mass

Appendix table 3 Mean of genotypes for agronomic traits evaluated for drought resistance at Taung Crop Production Center during 2006/07 summer growing season

	Days to 50% flowering		Plant height (cm)		Panicle length (cm)		Panicle exertion (cm)		Stem diameter (cm)		Leaf area (m^2)	
Genotype	Dry	Irr	Dry	Irr	Dry	Irr	Dry	Irr	Dry	Irr	Dry	Irr
K919-7	82	76	111.7	128.3	21.6	22.5	0.0	9.0	22.3	21.5	2.2	1.82
K927-3	69	67	121.9	146.9	21.7	21.7	0.0	2.0	20.2	22.0	2.2	1.36
K928-40	76	69	128.9	161.9	23.1	24.5	0.3	1.3	18.7	22.4	2.2	1.77
M100	69	71	97.6	97.8	26.6	26.7	0.0	2.1	20.3	21.5	1.6	1.63
M105	89	85	154.5	166.9	15.5	16.6	0.0	5.9	20.2	26.4	2.0	1.88
M153	86	85	116.8	152.3	13.1	16.9	0.3	3.9	20.1	22.4	2.3	2.17
M26	70	74	106.5	116.2	22.3	26.2	0.0	2.3	19.4	25.3	1.9	1.72
M48r	68	67	98.8	97.0	27.2	26.1	3.3	9.5	20.2	22.2	1.4	1.60
M48w	69	71	100.5	97.9	23.8	23.8	0.3	6.5	22.1	21.8	1.4	1.20
M51	71	69	87.9	81.7	21.5	21.7	0.0	1.7	18.8	20.1	1.1	1.60
M53	82	89	165.3	188.9	20.5	25.0	0.0	2.4	21.1	22.5	2.1	2.14
M66	75	74	147.5	148.5	24.4	24.1	0.0	3.7	18.7	21.7	1.4	1.65
M71	71	71	96.3	110.7	24.8	25.3	0.3	2.7	23.0	25.3	1.5	1.60
M72	76	72	109.0	122.0	24.7	22.6	0.0	1.0	19.3	25.8	1.7	1.59
M74	71	71	109.9	127.5	24.6	27.3	0.3	4.7	19.6	22.6	1.8	1.47
M78	86	75	131.1	143.1	25.1	30.1	0.0	3.5	23.0	22.9	2.9	2.42
M80	76	79	105.5	125.9	23.1	22.8	0.0	2.7	22.5	24.3	1.9	1.91
M84	73	74	111.7	121.9	28.4	26.3	0.0	8.1	22.2	18.6	1.9	1.35
M89	80	73	70.9	82.7	18.8	21.1	0.0	4.9	20.2	22.2	2.2	1.71
M99	78	80	103.2	111.9	22.1	24.3	1.0	3.3	18.1	24.2	1.9	1.80
Mean	**76**	**75**	**113.8**	**126.5**	**22.6**	**23.8**	**0.3**	**4.1**	**20.5**	**22.8**	**1.9**	**1.720**
SE	4.8	4.0	4.5	5.0	1.90	2.36	0.4	0.7	1.6	1.7	0.2	0.21
LSD 0.05	7.9	6.6	7.4	8.2	3.13	3.90	0.6	1.1	2.6	2.9	0.4	0.35
CV (%)	6.3	5.4	3.9	3.9	8.4	9.9	113.8	16.4	7.6	7.7	13.0	12.2

Dry = dryland conditions, Irr = irrigated conditions, TSM = thousand seed mass and n/s = not significant

Appendix table 4 Mean of genotypes for plant biomass evaluated for drought resistance at Taung Crop Production Center during 2006/07 summer growing season

	Plant biomass (Kg/ m^2)		TSM (g)	
Genotype	Dry	Irr	Dry	Irr
K919-7	1.91	3.42	23.8	25.5
K927-3	2.01	2.56	22.7	28.7
K928-40	2.05	2.48	20.4	26.0
M100	1.78	1.90	20.4	22.3
M105	3.58	3.86	31.7	37.7
M153	2.84	4.20	23.0	34.8
M26	2.02	2.58	20.2	24.6
M48r	2.00	1.84	21.1	25.9
M48w	1.65	2.01	23.5	25.8
M51	0.83	1.36	17.2	23.9
M53	2.56	3.73	17.5	19.9
M66	2.14	2.28	21.9	25.7
M71	1.97	2.53	23.7	25.5
M72	1.95	2.30	21.0	22.9
M74	2.17	2.72	21.5	26.4
M78	1.61	4.38	20.9	25.4
M80	1.74	2.20	20.1	21.4
M84	1.75	2.37	20.9	28.1
M89	1.29	1.64	19.9	20.7
M99	1.93	2.64	21.4	24.9
Mean	**1.99**	**2.65**	**21.7**	**25.8**
SE	0.45	0.95	2.0	2.9
LSD 0.05	0.74	1.58	3.4	4.8
CV (%)	22.6	36.0	9.4	11.1

Dry = dryland conditions, Irr = irrigated conditions and TSM = thousand seed mass

Appendix table 5 Mean of genotypes for relative water content and harvest index evaluated for drought resistance at Potchefstroom Experimental Farm and Taung Crop Production Center during 2006/07 summer growing season

	Potchefstroom						Taung					
	Relative water content %			Harvest index			Relative water content			Harvest index		
Genotype	Dry	Irr	Mean	Dry	Irr	Mean	Dry	Irr	Mean	Dry	Irr	Mean
K919-7	82.23	96.32	89.27	0.31	0.41	0.36	83.45	95.53	89.49	0.23	0.20	0.22
K927-3	82.62	97.54	90.08	0.33	0.38	0.36	82.95	92.73	87.84	0.14	0.18	0.16
K928-40	75.34	96.99	86.17	0.35	0.43	0.39	85.76	93.64	89.70	0.19	0.19	0.19
M100	82.59	97.74	90.16	0.33	0.39	0.36	88.99	95.97	92.48	0.19	0.24	0.22
M105	81.50	96.51	89.00	0.33	0.49	0.41	81.38	96.59	88.98	0.13	0.21	0.17
M153	82.24	97.67	89.95	0.35	0.36	0.36	76.30	96.61	86.46	0.12	0.13	0.13
M26	77.68	96.63	87.15	0.30	0.41	0.36	87.91	94.52	91.22	0.19	0.21	0.20
M48r	79.36	97.70	88.53	0.33	0.32	0.33	84.77	94.71	89.74	0.18	0.25	0.22
M48w	78.84	96.50	87.67	0.33	0.41	0.37	82.16	97.23	89.70	0.24	0.23	0.24
M51	83.96	95.76	89.86	0.33	0.44	0.39	82.06	95.43	88.75	0.19	0.37	0.28
M53	78.54	97.57	88.05	0.35	0.39	0.37	85.05	95.23	90.14	0.12	0.12	0.12
M66	77.88	96.05	86.96	0.30	0.41	0.36	86.59	97.34	91.96	0.14	0.23	0.19
M71	79.80	96.93	88.37	0.33	0.40	0.37	85.49	95.72	90.60	0.17	0.20	0.19
M72	81.98	97.13	89.56	0.33	0.37	0.35	84.06	95.45	89.75	0.21	0.18	0.20
M74	80.40	96.25	88.32	0.33	0.45	0.39	84.29	97.25	90.77	0.21	0.19	0.20
M78	81.37	96.59	88.98	0.33	0.43	0.38	79.43	94.07	86.75	0.20	0.10	0.15
M80	78.06	97.23	87.65	0.33	0.44	0.39	83.97	98.18	91.07	0.20	0.24	0.22
M84	83.19	96.21	89.70	0.33	0.39	0.36	81.82	95.57	88.69	0.22	0.26	0.24
M89	81.93	96.89	89.41	0.33	0.32	0.33	85.28	96.42	90.85	0.22	0.17	0.20
M99	84.26	96.94	90.60	0.33	0.40	0.37	83.95	97.30	90.62	0.21	0.21	0.21
Mean	**80.69**	**96.86**	**88.77**	**0.33**	**0.40**	**0.36**	**83.78**	**95.77**	**89.78**	**0.18**	**0.21**	**0.19**
SE	5.16	1.17	3.74	0.02	0.05	0.04	5.038	3.06	4.17	0.06	0.07	0.06
Lsd (0.05)	n/s	n/s	4.29	n/s	0.08	0.04	n/s	n/s	4.79	n/s	0.11	0.07
Cv (%)	6.4	1.2	4.2	6.6	11.9	10.1	6.0	3.2	4.6	29.9	31.8	31.0

Dry –dryland conditions, Irr = irrigated conditions, ns = not significant

Appendix table 6 Analysis of variance for the effect of drought stress on agronomic traits measured at Potchefstroom Experimental Farm and Taung Crop Production Center during 2006/07 summer growing season

	1 SOURCES OF VARIATION					
	POTCHEFSTROOM			TAUNG		
Traits	Genotype	Drought effect %	Interaction	Genotype	Drought effect %	Interaction
Days to 50% flowering	**	2.56ns	ns	***	-1.33ns	ns
Plant height	***	14.67**	***	***	10.04**	***
Panicle length	***	4.49ns	*	***	5.04ns	ns
Panicle exertion	***	66.67**	***	***	92.68***	*
Stem diameter	***	2.73ns	***	**	10.09**	**
Leaf area	***	11.82ns	***	***	-11.77*	**
Plant biomass	***	1.27ns	*	***	24.91ns	ns
TSM	***	1.36ns	***	***	15.89*	ns
Harvest index	*	17.5*	*	**	14.29.3ns	ns
RWC%	ns	16.69*	ns	ns	12.52*	ns

RWC% = relative water content, TSM = thousand seed mass, ns = not significant, *, **, *** significant at p = 0.05, 0.01 and 0.001 respectively

Appendix table 7 Mean of agronomic traits of genotypes evaluated across treatments for drought resistance at Potchefstroom during 2006/07 summer growing season

Genotype	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	Panicle exertion (cm)	Stem diameter (cm)	Leaf area (m^2)	Plant biomass (kg/ m^2)	TSM (g)
K919-7	84	118.3	24.4	5.1	23.8	2.7	0.76	25.2
K927-3	74	140.0	21.8	2.6	13.7	1.6	0.92	25.8
K928-40	76	140.6	22.3	1.0	17.3	1.4	0.72	20.5
M100	81	110.3	26.9	2.3	22.0	2.3	0.76	18.3
M105	76	174.3	20.0	2.6	17.4	1.9	1.14	32.0
M153	81	150.6	19.3	5.1	18.8	2.4	1.16	32.8
M26	738	145.9	26.4	0.7	16.4	2.0	0.70	19.1
M48r	725	119.6	25.2	8.5	16.8	1.3	0.59	20.1
M48w	72	125.7	23.8	5.5	19.5	1.7	0.69	18.9
M51	73	90.9	26.0	1.7	17.1	1.6	0.56	18.3
M53	78	144.3	21.7	1.6	19.6	2.4	0.71	20.9
M66	78	134.4	27.5	0.5	19.6	1.9	0.75	19.3
M71	76	114.4	23.8	2.2	17.0	1.6	0.68	20.1
M72	75	119.4	24.0	0.2	17.9	1.8	0.71	17.3
M74	74	136.5	26.3	3.5	14.3	1.7	0.94	18.3
M78	83	157.8	28.0	3.8	18.2	2.1	0.57	23.2
M80	82	133.2	23.6	3.8	19.7	2.4	0.91	21.2
M84	77	130.2	23.0	2.7	20.2	1.7	0.78	20.1
M89	74	124.7	20.7	5.1	12.9	1.9	0.86	24.8
M99	82	118.7	24.4	5.7	19.2	1.9	0.83	20.5
Mean	**77.0**	**141.7**	**23.9**	**3.2**	**18.1**	**1.9**	**0.79**	**21.8**
SE	5.2	6.5	2.0	0.6	2.1	0.3	0.12	1.9
LSD 0.05	6.0	7.5	3.3	0.7	2.4	0.3	0.14	2.17
CV (%)	6.8	4.6	8.5	19.5	11.4	13.6	15.8	8.6

TSM = thousand seed mass

Appendix table 8 Mean of agronomic traits of genotypes evaluated across treatments for drought tolerance during 2006/07 summer growing season at Taung Crop Production Center

Genotype	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	Panicle exertion (cm)	Stem diameter (cm)	Leaf area (m^2)	Plant biomass (kg/ m^2)	TSM (g)
K919-7	79	120.0	22.1	4.5	21.9	2.0	2.67	24.7
K927-3	68	134.4	21.7	1.0	21.1	1.8	2.28	25.7
K928-40	73	145.4	23.8	0.8	20.5	1.9	2.27	23.2
M100	70	97.7	26.7	1.0	20.9	1.6	1.84	21.4
M105	87	160.7	16.1	2.9	23.3	1.9	3.72	34.7
M153	86	134.6	15.0	2.1	21.3	2.2	3.52	28.9
M26	72	111.3	24.3	1.3	22.4	1.8	2.30	22.4
M48r	68	97.9	26.7	6.4	21.2	1.5	1.92	23.5
M48w	69	99.2	23.8	3.4	21.9	1.3	1.83	24.7
M51	69	84.8	21.6	0.8	19.4	1.4	1.10	20.6
M53	86	177.1	22.8	1.2	21.8	2.1	3.15	18.7
M66	75	148.0	24.3	1.8	20.2	1.5	2.21	23.8
M71	71	103.5	25.1	1.5	24.1	1.5	2.25	24.6
M72	74	115.5	23.7	0.5	22.5	1.6	2.12	21.9
M74	71	118.7	26.0	2.5	21.1	1.6	2.45	23.9
M78	81	137.1	27.6	1.7	22.9	2.6	2.99	23.2
M80	77	115.7	23.0	1.3	23.4	1.9	1.97	20.8
M84	74	116.8	27.4	4.0	20.4	1.6	2.06	24.5
M89	77	76.8	20.0	2.5	21.2	1.9	1.46	20.3
M99	79	107.5	23.2	2.2	21.3	1.9	2.29	23.1
Mean	**75**	**120.1**	**23.2**	**2.2**	**21.6**	**1.8**	**2.32**	**23.7**
SE	4.4	4.7	2.1	0.5	1.7	0.2	0.75	2.5
LSD 0.05	5.1	5.5	3.5	0.6	1.9	0.3	0.86	2.9
CV (%)	5.9	3.9	9.2	24.4	7.6	12.7	32.2	10.5

TSM = thousand seed mass