SELECTION OF DROUGHT RESISTANT WHEAT THROUGH SHOOT AND ROOT CHARACTERISATION AT SEEDLING STAGE

A THESIS

SUBMITTED TO GRADUATE SCHOOL EGERTON UNIVERSITY IN
PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF
MASTER OF SCIENCE IN CROP SCIENCE (CROP PRODUCTION).

IN

THE DEPARTMENT OF

AGRONOMY

BY

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Bsc Hort. EGERTON UNIVERSITY 1995.

AUGUST 2000.

DECLARATION

I hereby declare that this thesis is my original work except where due reference has been made and is not substantially the same as any other thesis that has been submitted for a degree or diploma in any other University

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ABSTRACT

Bread wheat (*Triticum aestivum*) is the second most important cereal in Kenya after maize. For more than twenty years its demand has exceeded production. Production can be increased through development of drought tolerant varieties for arid and semi-arid areas. The conventional selection method for drought resistant wheat is slow and expensive necessitating the search for a faster and less expensive method. Therefore, this study was initiated with an aim of developing a method of selection for drought resistance at seedling stage.

This research was carried out at the National Plant Breeding Research Station Njoro in a greenhouse between October 1998 and April 1999. To determine the most effective box size for root screening, variety Duma was grown in boxes of different sizes. The most effective and efficient planting method for shoot screening was determined by growing three commercial varieties (Duma, Kenya Mbweha and Mbuni) and three advanced breeding lines (R830, R831 and R748) all grown in one box, each genotype per single row in a planting box and each genotype in double rows in a planting box. Data for shoot and root characterisation was taken. For root characterisation, the six genotypes (the three commercial varieties and lines) were assessed 49 days after germination. Data on root depth, total root length, root spread at six centimetres depth, widest root spread and root concentration were collected. For shoot studies, plants were grown up to seedling establishment then left for three weeks without watering. Data on plant height, leaf area index, number of plants wilted, dead and revived was taken. Watering resumed for three more weeks after which revived plants were counted.

The most ideal planting method and box was the double row planting method and the box measuring 0.03mx1mx0.3m. Shoot and root characteristics of all the genotypes showed significant difference ($p=0.05$) with variety Duma emerging as the most drought resistant. Generally drought resistant wheat genotypes had more roots in the crown region with the nodal and seminal roots concentrated between the soil surface and 70cm deep. The susceptible genotypes had fewer roots in the crown region and the nodal and seminal roots were concentrated between the soil surface and 84cm deep. This study has shown that selection of drought resistant wheat through shoot and root characterisation at seedling stage is possible.

ACKNOWLEDGEMENTS

I acknowledge the great contribution that Dr. Miriam G. Kinyua provided in form of guidance, supervision and support throughout my research work and thesis write up. I also gratefully acknowledge Dr. Ochanda Ogolla's help and critique in the final stages of the thesis write up.

Many thanks go to the Kenya Agricultural Research Institute (K.A.R.I), National Plant Breeding Research Station's (Njoro) Director Dr Kimani Wanjama for the material and financial support in my field work. Special thanks go to the Vice Chancellor of Egerton University for availing the chance to enrol for the MSc. programme and the financial support during course work and thesis write up.

I highly appreciate the contributions of Mr Kamundia (K.A.R.I) for assistance in the analysis of data, Mr Dan. Manyasi (K. Breweries) for his assistance in literature search and members of staff in Egerton University Department of Horticulture for their co-operation.

I acknowledge with gratitude my wife Margaret, brothers and sisters for their patience, encouragement and understanding during the busy time of my study.

I dedicate this work to my dear father Gesimba, J. and mother Nyaboke, S. who tirelessly worked hard to build a firm educational foundation for me.

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CHAPTER 1

INTRODUCTION

Bread wheat (*Triticum aestivum*) is classified under the Graminae family in the genus *Triticum* which has several species (Duke, 1997). This self pollinated crop with 1% cross pollination, is believed to have originated in the far east and was taken to the new world by explorers and emigrants (Kinyua, 1991). Presently it is among the most important cultivated (Anon, 1992) and widely grown crops in the world because of its ability to adapt to many environments (Njoroge, 1998). The bread wheat grain is nutritious, readily stored and transported (Bajaj, 1990).

In Kenya, bread wheat was originally grown in Nakuru and Kitale areas, both in the Rift Valley Province (Leakey, 1970). However present production areas include the high potential areas which cover about 15% of the total land area of Kenya where it occupies approximately 140,000 ha making it the second most widely grown crop after maize (Anon, 1992). In these areas, the crop is usually exposed to drought spells due to poor distribution of rain (Anon, 1998). Dry spells cause up to eighty percent reduction in yields (Pleiffer, 1991). These losses together with high population, increased subdivision of large farms and urbanisation leading to changes in food preferences are some of the reasons why production has not met domestic demand for many years (Ndegwa, 1992). Self-sufficiency in wheat could be achieved through increasing production per unit area and expansion of the existing wheat production areas (Khamidi, 1997). Production per unit area in the high potential areas can be increased through reduction of losses caused by poor rainfall distribution (Pleiffer, 1991). This is possible through introduction of drought tolerant wheat varieties. Expansion of the production areas is possible if wheat was to be introduced to the arid and semiarid lands (ASAL's) (Anon, 1992). This is because of the vast unexploited agricultural potential existing in this land mass that represents 83% of the total land area in Kenya (Anon,1998). However, full exploitation of the ASAL's is only possible when well-adapted wheat varieties to these areas as well as appropriate production technologies are developed and farmers educated on the potential of wheat as a competitive enterprise (Anon, 1998). Production technologies such as irrigation can be introduced in the ASAL's. Unfortunately such technology is expensive and beyond the capabilities of most small scale farmers. This makes the development of drought tolerant wheat the most appropriate option. Ongoing research is geared towards introduction of drought tolerant wheat for the marginal and the high potential areas because of the usual drought spells within the growing season (Anon, 1999).

Research on drought tolerance started in the early nineties (Kinyua and Ayiecho, 1991). Since then 'Duma' and 'Ngamia' have been recommended for the marginal areas (all the areas that receive between 200 and 400mm of rainfall annually) (Anon, 1999). Preliminary selection of these varieties for drought resistance was based on yield components but current selection is mainly through yield comparison of test material grown in different sites over time (Kinyua, 1991). This conventional method is rather slow and a faster method for evaluating large populations of wheat lines is being sort. If developed such a method will be of great advantage (Anon, 1998). Root and shoot characteristics have been used successfully in the screening of drought resistant cowpea (Singh, 1998). From work done by Winter *et al.* (1988), Singh (1998), El-Hafid *et al.* (1998) and Combellini *et al.*

(1998) there is a clear indication that a procedure for screening wheat through root and shoot characteristics can be developed. However, such work has not been done. Such a screening method especially at seedling stage would provide a faster means of identifying possible drought resistant genotypes in breeding programs. This will enable breeders to eliminate large numbers of lines, which are not promising without performing field trials. This process will not only save on funds but also on time. The promising lines can thereafter be tested in the marginal areas and suitable candidates identified for production. In an effort to search for a faster and effective method for screening drought resistant genotypes for the ASAL's of Kenya, this study was initiated with the following objectives:

1.1.0 Main Objective.

To study the root and shoot characteristics of drought resistant and susceptible bread wheat varieties.

1.1.1 Specific Objectives.

1. To screen different bread wheat selections for their response to drought at seedling stage.
2. To study the rooting pattern for drought resistant and drought susceptible bread wheat selections.
3. To study the relationship between rooting pattern and the overall yield of bread wheat selections under dry environment.
4. To develop an appropriate and simple technique for testing drought tolerance in bread wheat selections at seedling stage.

CHAPTER 2

LITERATURE REVIEW

2.1 Drought and Plant Growth

Drought is defined as insufficient availability of moisture storage in the soil for optimum plant growth (Singh, 1998). Drought resistance on the other hand is a general term and would refer to any of the several methods of survival under drought such as water stress avoidance, dehydration avoidance and dehydration tolerance (drought tolerance) (Bartels and Ingram, 1999). Taiz and Zeigler (1991) suggest that drought avoidance can be referred to as another form of drought tolerance since drought is a meteorological condition that is tolerated by all plants that survive it and avoided by none.

Water stress avoidance is an adaptive mechanism for most xerophytes. In these plants water stress is avoided through morphological features and physiological mechanisms, which ensure that the plant maintains a high water potential in the tissues. Plants that are able to maintain a high internal water content exhibit dehydration avoidance (Pessarakli, 1995). These plants achieve this through use of physiological and morphological features, which increase their water use efficiency (ability to conserve water by reducing transpiration losses or by increasing water uptake). The morphological features include hairiness, high light reflectance, rolling of the leaves (Blum and Arkin, 1984; Giearsen, 1995; Amazallag and Learner, 1995), controlled stomatal conductance and increased water uptake through the roots (Kozlowski, 1983). Dehydration tolerance is achieved by plants which are capable of surviving with a low cell water content (Kramer, 1983; Pessarakli, 1995). Low water content is attributed to increased sugar concentration and high levels of total free amino acids and to a lower extent by carboxylic acids, potassium ions and chlorine ions (Bartels and Ingram, 1999).

2.2 The Bread Wheat Seedling

A growing wheat crop can be divided into a number of growth stages i.e. emergence, seedling stage, stem elongation (inter-node formation), flowering, heading and ripening (Harder, 1974). A normal ripened bread wheat grain sowed an inch or one and a half inches deep in good soil begins to germinate two to three days under ideal field conditions. The coleoptile and first leaf appear above the ground in about ten days (Emam and Tafazoli, 1996). The seedling stage starts immediately the coleoptile emerges from the soil and ends at the beginning of stem elongation (Harder, 1974). Growth of the wheat seedling has a direct relationship with the physiological processes in the plant (Porter and Lowlor, 1991). These physiological processes have a direct influence on the final yield and are affected by several external factors. These external factors (e.g. water for cell expansion, temperature, e.t.c.) and internal factors (heredity and hormones) affect the extent of growth (dry matter accumulation vertically and horizontally) which correlates positively with yield (Tanner and Nicholas, 1985).

2.3 Rooting Pattern of Bread Wheat

Percival (1921) described the roots of wheat as primary, seminal and nodal roots according to the place of origin on the seedling. However most researchers refer to only two kinds of roots on wheat i.e. seminal and crown (Plag and Aspinall, 1999). Seminal roots are usually five in number and seldom more than eight as was shown by Weaver's (1928) classic experiment. He also showed that under dry surface conditions crown roots may not form and the plant is limited to seminal roots only. However, under favourable conditions crown roots develop from the nodes and can reach a large number.

Mac-Key (1973) researched on root depth and shoot height of wheat in different media. In experiments with six types of media, he showed that 7 days after germination wheat roots grow to a maximum of 20 cm, in a soil medium, 15 cm deep in Vermiculite, 13 cm in Polytherm, 11 cm in aerated water 10 cm in sand and 8 cm in Perlite. Two weeks after germination the roots grow to a depth of 37 cm in the soil medium, 35 cm in Vermiculite 28 cm in Polytherm 19 cm in aerated water, 18 cm in sand and 15 cm in Perlite. The trend was maintained and at seven weeks after germination the roots stopped increasing in depth with the soil medium achieving a maximum of 120 cm depth and the lowest was 20 cm achieved by aerated water.

2.4 Factors affecting Root Development

Total root length, density, structure and distribution is highly influenced by the genetic make-up (i.e. dicots have a tap root system, while the monocots have a fibrous root system) (Ridge, 1991). According to Mac-Key (1980) large differences exist in rooting patterns between different genotypes and within the same genotype providing opportunity for breeding and selection. It has also been shown that most root characteristics are quantitatively inherited and therefore controlled by a number

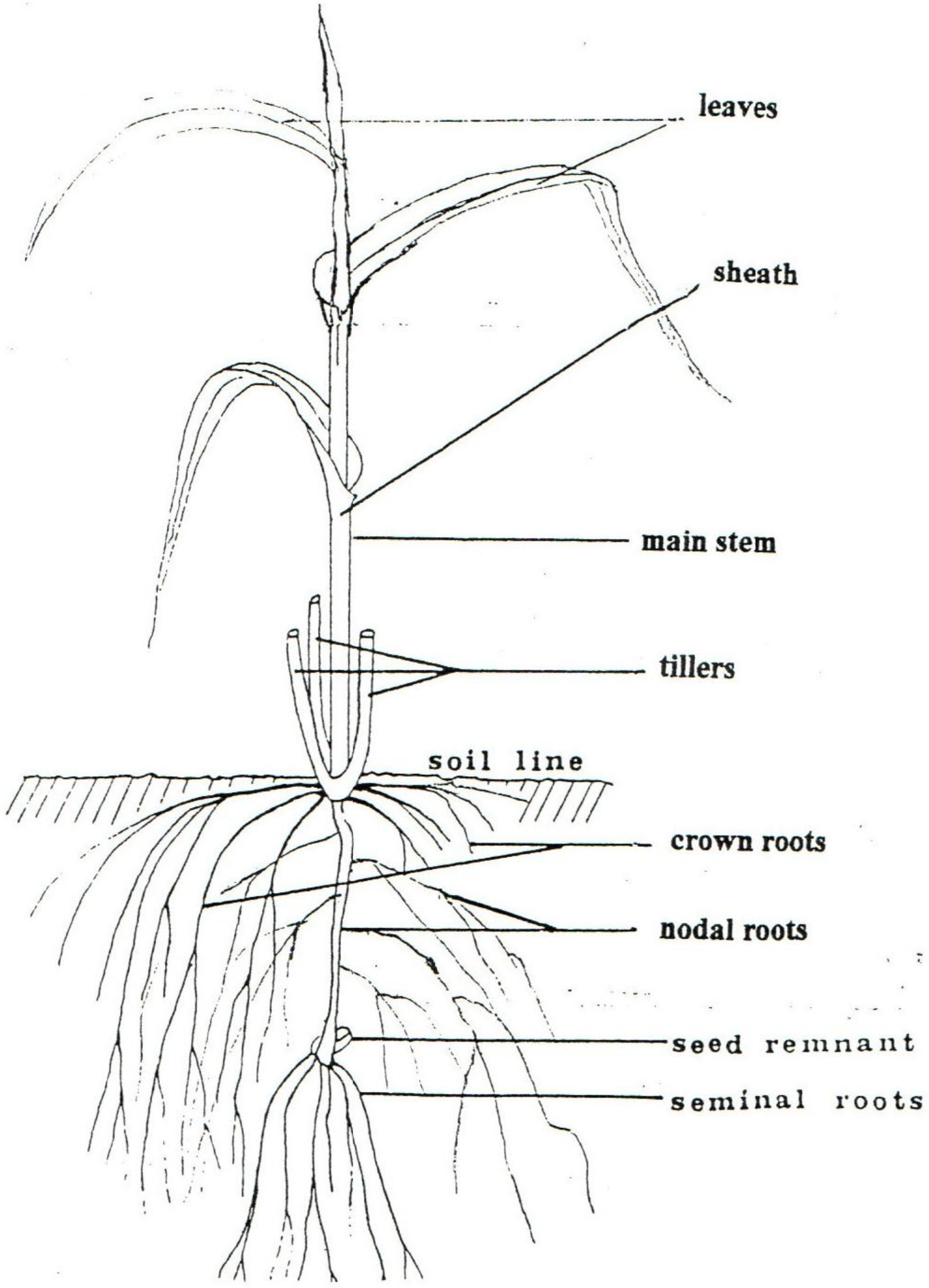

Figure 1: Main parts of a wheat seedling.

of genes (Troughton, 1956). Hormones on the other hand dictate the expression of the inherited genetic set up of plants (Street and Opik, 1984). Ridge (1991) and Weaver (1928) showed that roots of the same genotype have different rooting patterns under different soil structure and water status. Therefore, at different soil water conditions roots of the same genotype grow to varied widths. The soil water status also directly affects the root development because it affects mechanical impedance, nutrient availability and transport in the roots as well as soil aeration (Deniz *et al.*, 1997). Soil nutrients are taken up by plants as ions dissolved in water (Russell, 1995). Since roots tend to grow where the nutrients are, soils with adequate supply of available nutrient in a solution form encourage maximum genetic expression of the roots (Taiz and Zeigler, 1991). Relative humidity, diseases, management aspects and soil characteristics (e.g. texture, structure, pH), flooding, allelopathy, root interaction and soil organisms also affect root development.

2.5 Factors affecting Shoot Development

The genetic set up has a direct influence on shoot development (Emam and Tafazoli, 1996). Hormones on the other hand dictate the expression of the inherited genetic set up of plants (Street and Opik, 1984). Water availability influences the plant's ability to adapt to different conditions and also the plants overall success in terms of yields because it has a direct relationship with nutrient uptake efficiencies, cell growth and cooling (Wein, 1997). Temperature and light also affect the general shoot development (Bos and Neuteboom, 1998). The type of media (Mac-Key, 1973), pests, diseases and the general management affect the ability of a genotype to express its full genetic potential (Street and Opik, 1984).

2.6 Wheat Shoot and Root response to Drought at Seedling stage

Newly germinated seedlings can tolerate drought for a period of three to four days. However, those that are colonised by absculor mycorrhiza show greater tolerance (Alkaraki *et al.*, 1998). If seedlings are subjected to drought five days after germination the survival period is slightly longer depending on the genotype and amount of phosphorous in the soil (Gutierezbuin and Thomas, 1998). Generally relative loss of moisture through evapotranspiration is highest at the beginning of the seedling stage and continues to decrease as the leaf area index increase to a value of 2.5 (Petti, 1998). Therefore, as wheat becomes older the length of tolerance becomes longer.

Moisture stress has an adverse effect on shoot growth and root length development in wheat seedlings. Shoot development is affected more than the roots (Natr, 1997). Under high moisture stress levels, the root length development was adversely affected in durum than aestivum wheat (Blum *et al.*, 1998). Blaha and Janacak (1997) indicated that the effects of water stress on root development are made more severe by the presence of aluminium ions as well as low pH conditions, which retard root growth. This is true although different genotypes respond differently to water stress (Gardner *et al.*, 1985; Taiz and Zeigler, 1991). Bartels and Ingram (1999) showed that the apparent resistance to drought in some genotypes is due to differences in root growth. On the other hand, Plag and Aspinall (1999) indicated that drought resistant wheat species are such that they have a large proportion of their total mass as roots and also a deep rooting habit coupled by high numbers of seminal roots. However, work needs to be done to establish the exact rooting pattern of drought resistant wheat species (Singh, 1998). Blum and Sullivan

(1997) showed that short genotypes are affected less than taller genotypes by water stress. They attributed this to the ability of short genotypes to resist drying of the tap-root although absolute biomass and yield under stress was greater in tall genotypes because of relatively greater potential.

Blum and Sullivan (1997) indicated that the tap-root plays the major role in drought resistance while Volkmar (1997) showed that the nodal and seminal roots also have an effect. The latter found that soil drying around the nodal and seminal root systems affects the leaf relative water content and leaf elongation rate one week after germination. However, drying the seminal roots gave more impaired leaves and poor growth rates than drying the nodal roots. It was also found that when water stress was applied there was slightly more nodal root growth than seminal root growth. Drought affects leaf elongation and expansion in wheat seedlings (Bos and Neuteboom, 1998) although different genotypes are affected differently (Gardner *et al.*, 1985; Taiz and Zeigler, 1991). Leaf elongation and expansion affect shoot growth. Blum and Sullivan (1997) showed that shoot growth reduction by osmotic stress is inversely related to plant size while the extent of osmotic adjustment during osmotic stress is directly related to plant size.

Other factors that affect shoot and root growth include relative humidity, diseases, management aspects and soil characteristics (e.g. texture, structure, pH), flooding, allelopathy, root conditions and soil organisms. Interaction between these factors and the internal factors affect crop response to drought. This makes the study of drought complex (Pleiffer, 1991), difficult and long term (Taiz and Zeigler, 1991).

2.7 Root Screening for Drought Resistance

Root characteristics as an alternative screening technique for drought resistance has been recommended for use in many crops. However, the association between root characteristics and drought resistance has not been fully understood (Singh, 1998).

Juradat (1984) screened wheat (*Triticum aestivum*) genotypes for drought tolerance and yield response. This study involved testing F_4, F_5, F_6, F_7 and F_8 generation lines from crosses of Urganies and Tobasi, Sowtall and Totabis varieties. Seedling and mature plants were screened in the laboratory and mist chambers for seminal root characteristics. It was shown that the seminal and mature root characteristics of Tobasi the parent with a vigorous root system were transmitted to the progeny. It was also shown that there was a significant correlation between the seedling root system and mature plants root depth while Kouter (1933) had showed that growth rate varies at different times during development. Studies on rooting depth, growth cycle duration and timing of the jointing stage in wheat in search of traits that can contribute to early drought tolerance were conducted by Margin (1991) in Argentina. This study involved 3 varieties (Las Rosas, Marcoz Juarez and Trigal). The proportion of roots 78.75cm deep was found to be high in the Las Rosas and in Trigal than in Marcoz Juarez. The root: shoot ratio increased with drought in all cultivars and was greatest in Marcoz Juarez than in the other cultivars. The proportion of the jointing phase exposed to drought was 63% in Las Rosas, 53 % in Trigal and 42 % in Marcoz Juarez. It was concluded that early drought did not affect yields when there was late joining and deep rooting. Phemmer (1943) had studied the relationship between root length and depth. He found out that the species that had higher total root length showed a deeper penetration and wider spread at the surface. He concluded that under certain root environments the lateral root growth is highly predictable. Phemmer's (1943) finding were supported by Russell (1997).

Root attributes of bread wheat seedlings studied by Al-Hakimi and Manneux (1992) showed that the number of roots and depth of the rooting pattern was different between species tested. Main *et al.* (1993) further demonstrated that there are differences in fresh root weight, fresh shoot weight, number of roots longer than 40cm, longest root length and total root length in the 40 winter wheat genotypes grown in hydrophobic cultures for four weeks. They concluded that root attributes could be used in selection procedures in breeding programs.

Mukharjee *et al.* (1991) tested ten exotic Indian wheat varieties sown in pots and watered daily or at restricted intervals of 5 days. After collecting data for 5 root characters he showed that there were large genetic difference with regard to the root attributes although heritability and genetic advance decreased. He also showed that heritability increased for root length and dry weight. Wang and Mas (1992) studied the effects of water supply on the root system development in wheat grown in pots, it was found that drought reduced the amount of roots in the surface and increased the number of roots in deeper layers. Secondary roots developed quickly when the relative soil water content (RSWC) was 60.8%, decreased at RSWC greater than 60% and was severely retarded at RSWC greater than 50%. Root system activity was reduced, as RSWC was the lower limit Index for severe drought in the later stages of wheat growth.

2.8 Techniques for Root Screening

There are many different methods of investigating root systems although there is no consensus as to the best method. The main methods are escavation, cone sampling, visual and indirect methods (Wolfgang, 1979). Singh (1998) modified the escavation method with excellent results. Instead of growing the plants on the ground they were grown in boxes. The digging of a trench is substituted with removal of one side of the box, which is usually joined to the remaining parts with soft nails. This makes the whole procedure much easier and faster. Washing is done after replacing the removed side with a pin board made of nails spaced at 2.5 cm. Then the box is made to rest on the pin board and washing is done.

Core sampling described by (Wolfgang, 1979) involves removing soil samples at depths and positions required with either an auger or cylindrical core sampler. Roots and soil are separated by dispersing the soil if necessary by soaking in sodium pyrophosphate solution and washing it through a fine sieve, which retains the roots. Separation of live roots from dead roots has to be done manually on the basis that live roots are whiter and elastic. After separation the length can be determined by Newmans (1966) method of intersections. The visual methods involve direct observation of growing roots against glass or transparent plastic which forms the face of a large box filled with soil or the side of underground trench as was explained by Taylor and Ratlift (1969). This method is good for studying root growth over time. The indirect methods measure root activity rather than the weight or length. Most common is the water extraction profile which is determined either by sampling and oven drying or by use of Bouyous blocks, Soil water tensiometers or Neuton moisture meter (Goldworthy, 1984). The change in soil water content during the drying cycle is assumed to be an indication of root activity at that depth. Alternatively ^{32}P (Races *et al.*, 1964) or ^{86}Rb (Russel and Ellis, 1968) can be fed to the shoot, allowed to distribute throughout the root system and assessed in soil cores without washing and separating them. ^{32}P or other radioactive tracers are placed at known positions in the soil and removal through plant uptake after suitable period of growth give an indication of the active roots (Nye and Foster, 1961).

2.9 Shoot Screening for Drought Resistance

Several methods have been used for screening for drought tolerance at seedling stage. They include use of grain weight, yield and spike weight in laboratory experiments (Combellini *et al.*, 1988). These results correlated weakly (positively) with those from the field. Kinyua *et al.* (1993) screened twenty-five wheat varieties and four introduced lines using yield components as the parameters for comparison. In this study, cultivars Kenya Mbweha, Kenya Chiriku, and Mbuni performed the best (highest grain yield) among the commercial varieties. Later Kinyua and Kirigwi (1993) showed that yield components become unstable over the years and locations. Kinyua (1991) recommended the use of yield as the best method for selection after showing that the environment interacts with the genotype. Therefore selection should be based on climatic and edaphic conditions which meant performance trials at target sites are important. Senopion and Planchon (1984) worked on the physiological responses of six bread wheat and durum wheat genotypes to water stress. In this research, soil moisture (H), leaf water potential (PS1W), photosynthesis (PN), stomatal resistance (RS) and transpiration were measured on leaf 2 and 8 as leaf 9 was growing. They found that the genotypes differed in their stress avoidance

(PS1W-H) and their stress tolerance (PN-PS1W and RS-PS1W relationship). In the resistant varieties PSIW values were highest, PN were least altered and RS was lowest. Tanner and Nicholas (1985) used visual vigor scores to screen for drought tolerance. They found that visual scores of early vigour were closely correlated to dry matter accumulation per unit area by the 5th leaf with dry weight per plant in the final plant population. Dry matter was also positively correlated to grain yield at physiological maturity.

Stomatal conductance net radiation, vapour pressure deficit of the atmosphere and leaf water potential were used by Castrignano *et al.* (1987) while Acevedo (1987) used the relative water content. Al-Hakimi and Manneux (1992) and Pasture *et al.* (1989) worked on chlorophyll amounts. In these two studies, chlorophyll was found to differ between different species. Taiz and Zeiger (1991) attributed the change in colour to an increase in carotinoids and xanthopylls and a reduction in the amount of chlorophyll's a and b in the chloroplast lamellae which result in a decreased photosynthetic rate and also a reduced rate of photodestruction. Morntag *et al.* (1995) used protein content as a physiological trait for drought tolerance. They noted that proline accumulated in seedlings subjected to stress. They also found out that proline accumulated when the plants suffered from diseases and this led to the conclusion that protein level as a physiological trait cannot be used and when used, it should be treated with caution. Winter *et al.* (1988) and Singh (1998) investigated survival or growth of seedlings subjected to drought. Winter *et al.* (1988) screened several cultivars of wheat known to be drought resistant and several others, which were known to be susceptible. The authors concluded that although water loss from excised leaves and leaf water potential were found to be effective, seedling survival after desiccation was the most suitable technique for screening large wheat populations for drought resistance at seedling stage. They recommended this method for testing advanced lines. Singh's (1998) review on cowpea indicated that seedling survival after desiccation has great potential in screening for drought resistance in many plants. El Hafid *et al.* (1998) worked on attributes associated with early season drought tolerance in spring wheat in Mediterranean environments. They found out that the drought resistant cultivars had a higher leaf area index in the early vegetative period. High grain yield was also found to be associated with high leaf area at seedling stage and at the end of tillering. They concluded that leaf area index under water stress can be used as a selection criteria for breeding for improved early season drought resistance. Leaf area is determined by phenology but its morphology, rate of emergence and potential size is affected by drought. This is because leaf area plasticity is an important means by which a drought stressed plant maintains control over water use (Blum, 1996).

Other studies on shoot screening include use of heat shock on seedling wheat (Borghi, 1994). In this study that included 16 resistant ant 10 susceptible varieties, they concluded that this method, though applicable, did not explicitly separate the resistant varieties from the susceptible varieties. Saldiva (1989) screened wheat shoots immediately after germination. In these experiments two osmotic media varying in concentration were used. The author found out that by using this method it was possible to study the different shoot characteristics although the method was not appropriate for large wheat populations.

2.10 Shoot Screening Techniques

Many scientists have used several techniques to screen wheat and other crops for drought resistance but only Singh (1998) and Singh *et al.* (1998) have recommended two procedures for screening cowpea. The first procedure is the box screening method for drought tolerance. In this method the cowpea seedling are planted in boxes and watered until the first trifoliate leaves emerge. Then watering is stopped and a daily count of the permanently wilted plants is made until all the plants of the susceptible lines are dead. Watering is then resumed to ascertain regeneration percentages of each variety. Then based on days taken to wilting and percent recovery, the varieties are rated as drought tolerant or susceptible. The second procedure involves planting the cowpea in pots. The plants are then stressed at different stages of growth and ability to survive is compared. This method helps in providing vital information that can be used to identify drought tolerant cowpea lines at seedling stage, mid-season and reproductive stages.

CHAPTER 3

MATERIALS AND METHOD.

3.1.0 Materials

The materials for this study comprised of six bread wheat (*Triticum aestivum* L.) selections acquired from the Kenya Agricultural Research Institute, National Plant Breeding Research Center (NPBRC), Njoro.

3.1.1 Genotypes

The genotypes included three varieties and three advanced generation breeding lines. They were:

(1) Duma ; this is the highest yielding commercial variety in the semi-arid areas in Kenya at present. It was released in 1994.

(2) Kenya Mbweha; this variety is among those originally developed for the traditional wheat growing areas in Kenya. In the initial screening trials in 1989 it was recommended alongside other more tolerant varieties for marginal areas.

(3) Mbuni; this was originally an introduction from CIMMYT-Mexico. It was released as a commercial variety in Kenya in 1987 after adaptability trials. It is drought susceptible.

(4) R830, (5) R831, (6) R748 are lines acquired from the International Dry Land Nurseries and are included in performance trials in Njoro with an aim of releasing those that will tolerate drought for growing in the marginal areas of Kenya. They have shown great potential in terms of drought tolerance in the preliminary trials.

3.1.2 Experimental Site

This research was carried out at the National Plant Breeding Research Centre Njoro in Nakuru District located in the Rift Valley Province, Kenya. The station is 2160 m above sea level, on 0^0 20'S and 35^0 56'E and is within the high potential Agro ecozone LH3. It receives a bimodal rainfall of 931 mm with a mean minimum temperature of 7.9^{0}C and mean maximum of 23.6^{0}C and a mean diurnal temperature range of 5^{0}C. The soils are heavy textured friable silt clay to clay with humic topsoil (Kinyua, 1991). The top soils are also high in phosphorous (12.48 ppm - 15.26 ppm) but low in potassium (128 g/kg) with a pH of 5.6 to 6. This station co-ordinates all research work on wheat in Kenya and it is from here that all wheat varieties are released for commercial production. They are either lines developed at the centre or introductions from foreign research institutions like the International Maize and Wheat Research Centre (CIMMYT) after adaptability tests. The studies were done in a greenhouse in two seasons. The temperature and relative humidity were controlled in a range of between 24-26^{0}C and 60-75% respectively in the greenhouse. An equivalent of 30mm rainfall per month (amount received in Katumani) was applied using a watering can. Pests and diseases were controlled uniformly. The first trials were carried out between September 1998 and December 1998 while the second trial was carried out between January 1999 and April 1999.

Grain yield from Lanet, Mogotio and Elementaita were taken and used for correlation with root characteristics. Lanet is 1890 m above sea level on 0^0 20'S and 35^0 56'E. It is within the low potential Agro ecozone LH4. It receives a bimodal rainfall of 700-800 mm with a mean minimum temperature of 16.6^{0}C and mean maximum of 23.5^{0}C and a mean diurnal temperature range of 5^{0}C. The soil is mainly developed from sediments from volcanic ashes. It is well drained, moderately deep to deep dark brown friable and slightly gravely sandy clay loam's with humic top soil. Elementaita is 1849 m above sea level on 0^0 30'S and 36^0 20'E. It is within the low potential Agro ecozone LH5. It receives a bimodal rainfall of 650-700 mm with a mean minimum temperature of 16.6^0C and mean maximum of 25.5^0C and a mean diurnal temperature range of 8^0C. The soil is mainly developed from undifferentiated tertiary volcanic rocks mainly Olivine, Rlyolites and Andesites. They are well drained, shallow and very calcareous stony loam's to clay loam's which in many places are saline. Mogotio is 1834 m above sea level on 0^0 20'S and 35^0 56'E. It is within the low potential Agro ecozone UM4. It receives a bimodal rainfall of 800-900 mm with a mean minimum temperature of 18.6^0C and mean maximum of 27.5^0C and a mean diurnal temperature range of 5^0C. It has typical volcanic plain soils mainly developed on ashes and pumice. The soil is well drained, moderately deep to deep brown to dark brown very friable loam to sandy loam Andosols.

3.1.3 Experimental Design

3.1.3.1 Shoot Screening for Drought Resistance

Complete randomised design (C.R.D) with three replications was used in the shoot screening experiments. A method similar to the one described by Singh (1998) was used but with some slight modifications. This is because Singh (1998) worked on cowpea. Before conducting the shoot screening the best planting method to achieve this objective was first determined. Wooden boxes measuring 75 cm by 50 cm and 15 cm deep made of 2.5 cm thick planks were used. The boxes were lined with polyethylene sheets and filled with a 1:2 mixture of sand and top soil with an average composition of about 7.5% clay, 84% sand, 8.5 percent silt and 0.8 percent organic matter. The boxes were filled up to 12 cm deep leaving 3 cm space on top to help avoid runoff during watering. The polyethylene lining along the sides and at the bottom of the boxes was to ensure even distribution of water within the boxes. A builder's level was used to ensure a flat soil surface after slight compaction achieved by shaking the box two times. By using a ruler, straight rows 10 cm apart were made. Then a specially made wooden stick was pushed into the soil up to a stopper (2 cm deep) to ensure equal planting depth.

EXPERIMENT 1. In this set of experiments the seeds were sown such that a single box contained all the six selections replicated three times (Appendix 1). In this case one planting box had five rows spaced ten centimeters apart. Each row was 75 cm long. The three inner rows represented the trial material while the two outer rows, each on one side represented guard rows. All the entries were included in each row, where each entry was planted at a length of 12 cm. Thus each row formed a replicate and the entries were randomised in each row. The guard rows were planted with variety Duma which was the check variety.

EXPERIMENT 2. In this set of experiments, the selections were planted such that each genotype occupied a row in a planting box (Appendix 2). In each planting box the rows were ten centimetres apart where 36 seeds were drilled along each row. The whole experiment consisted of three planting boxes each representing a replicate where the entries were randomised. The rows were 50 cm long and the two outer rows, one on each side, formed the guard rows. In these guard rows which were 2.5 cm away from the sides of the box variety Duma was planted since it was the check variety.

EXPERIMENT 3. In this set of experiments, each genotype was sown in double lines in a planting box (Appendix 3). In each planting box the rows were ten centimetres apart where 36 seeds were drilled along each row. The whole experiment consisted of six planting boxes two representing a replicate where the entries were randomised. The rows were 50 cm long and the two outer rows one on each side formed the guard rows. In these guard rows which were 2.5 cm away from the sides of the box variety Duma was planted as the check variety.

The boxes were then uniformly watered by applying one litre of water per box, twice every week until 28 days (end of the seedling stage). At twenty-one and twenty-eight days after germination four plants were sampled at random and their dry weights taken. Twenty-eight days after germination watering was stopped for three weeks after which it was resumed for three more weeks. Data on parameters 1-9 was then collected (section 3.1.3.3). The results were analysed and the planting method that least interfered with seedling growth was determined and used for shoot characterisation experiments.

3.1.3.2 Root Screening for Drought Resistance

Root screening trials were carried out in a complete randomised design (C.R.D) with three replicates. To evaluate the rooting pattern on a two-dimensional plane, the root box pin method described by Singh (1998) was modified and used. Before conducting root studies the best method to achieve this objective was first determined, considering that Singh (1998) had worked on cowpea. Boxes of varying sizes were constructed because Wolfgangs's (1979) effectively used boxes of size 3 cm by 30 cm by 105 cm to study wheat roots while Mac-Key (1980) indicated that wheat roots grow to a maximum of 1.3 m seven weeks after emergence. The boxes used were 5 cm by 30 cm by 130 cm (T1), 7 cm by 30 cm by 130 cm (T2), 3cm by 30 cm by 130 cm (T3), 5.0 cm by 30 cm by 100 cm (T4), 7 cm by 30 cm by 100 cm (T5), 3 cm by 30 cm by 100 cm (T6), 5 cm by 30 cm by 70 cm (T7), 7 cm by 30 cm by 70 cm (T8) and 3 cm by 30 cm by 70 cm (T9). These boxes were made by nailing two plywood sheets onto a frame of wooden stakes 5cm thick. One sheet was fixed with soft nails with the inner sides of the plywood sheets lined with polythene. The topside of the box was left uncovered. The boxes were filled with sand and topsoil (1:2) and in all the boxes variety Duma was planted four seedlings per box at a spacing of 5 cm. Then an equivalent of 6.5 mm of rain was applied to all the boxes two times a week. Forty-nine days after planting (time when maximum development of rooting pattern is achieved (Mac-Key, 1980)) the boxes were opened and a nail board fixed to replace the removed side. This was to hold the roots in place and avoid their collapse. Then carefully the box was made to rest at an angle of 60^0 on the side with the nail board after which the remaining parts of the box were lifted. Using a hand sprayer the soil covering the roots was gently washed away making sure minimum damage was done to the roots. Finally the roots were separated from the shoots after which both parts were dried in an oven at 60°C for twenty four hours and weighed. The results were analysed and the box size with the least interference to seedling root growth determined. Then eighteen boxes similar to the one that had the least effect on root growth were made. In each box eight hand picked seeds of each of the six selections were then planted 5 cm apart (2 seeds per hill per box). In this case one planting box accommodated only one genotype and six boxes represented one replicate. The boxes were randomly arranged in the greenhouse. The whole experiment contained three replicates. One week after germination one seedling from each hill was removed to leave only healthy seedlings (vigorous and decease free). Then an equivalent of 6.5 mm of rainfall was applied per box per week up to 49 days from planting which has been reported as the end of seedling establishment by Mac Key (1973). After that the boxes were opened as described above and data collected.

3.1.3.3 Data Collection

Data on temperature and relative humidity was collected throughout the experimental period by use of a thermohydrograph. Before mixing the soil with the sand the soil was first analysed for percent sand, silt and organic matter content using the fraction separation method where water was the medium for separation (Landon, 1984). General observations were made on the wheat seedlings throughout the experiment. The parameters assessed on shoot and root characteristics were;

1. Growth rate: This was the average rate of dry weight increase per week for four plants sampled at random for each genotype. This data was collected between twenty one and twenty eight days after emergence.
2. Plant height: This was the average length in centimetres between the start of the crown and the beginning of the highest fully developed leaf for four plants sampled at random for each genotype. This data was collected at 28 days after emergence.
3. Leaf area index: This was the average ratio of total area of the leaves divided by the total land occupied by the canopy for four plants sampled at random for each genotype. The ratio was obtained by measuring the length and width of all the

leaves of four plants sampled at random for each genotype and multiplying them with the correction factor 0.75. This data was collected twenty one days after emergence.

4. Number of wilted plants: This was the number of plants with at least 50% wilted and drooping leaves from each genotype. This data was collected after the three weeks of no water application (i.e. 49 days after emergence). From the number of wilted plants the percentage of normal plants (un-wilted plants) was calculated. The data was transformed using the arc sine transformation because the percentage range was more than seventy (Gomez and Gomez, 1983).

5. Number of dead plants: This was the number of plants with all the leaves completely dead. This was done through visual judgement after the three weeks of no water application (i.e. 49 days after emergence). From the number of plants dead the percentage of live plants was calculated. The data was transformed using arc sine transformation because the percentage range was more than seventy (Gomez and Gomez, 1983).

6. Number of plants revived: This is the number of plants considered dead that produced new leaves after re-watering for three weeks (i.e. 70 days after emergence).

7. Number of tillers per plant: This was the average number of tillers of four plants sampled at random for each genotype four weeks after emergence.

8. Number of leaves per plant: This was the average number of leaves of four plants sampled at random 28 days after emergence.

9. Root depth: This was the average furthest point the roots explored the soil profile for the four seedlings in each box 28 days after emergence.

10. Length of the longest root: This was the average length of the longest root in centimetres for the four seedlings in each box 49 days after emergence.

11. Root spread six at sixcentimetres depth: This was the average widest distance in centimetres the roots spread at six centimetres depth for four seedlings in each box 49 days after emergence.

12. Widest root spread: This was the average widest spread in centimetres achieved anywhere along the soil profile for the four seedlings in each box 49 days after emergence.

13. Concentration of most roots: This was the average depth in centimetres from the ground level where 95% of the roots were distributed. This was done for four seedlings in each box measured at 49 days after emergence.

14. Shoot to root ratio: The average ratio of the shoot weight against the root weight for the four seedlings in each box 49 days after emergence.

15. Relative absorptive surface area: This was determined by dipping the roots in 500 ml of 0.2 M calcium nitrate for one minute and re-weighing the solution to get the amount that adhered to the root surface (Mac-Key, 1973). The average relative absorptive surface area for the four seedlings in each box was then calculated in mm^3. This data was collected 49 days after emergence

16 Root number: This was the number of roots at the crown emerging directly from the plant base 49 days after emergence.

17 Root total length : This was the average root total length per plant. This data was collected 49 days after emergence.

18 Number of days to emergence: This was the average number of days from planting to 50% emergence for the four seedlings in each box.

Yields from National performance trials conducted by KARI in 1998 were also acquired for use in correlation analysis.

3.2 Data Analysis

Data collected were subjected to analysis of variance tests (ANOVA) using the SAS software package (SAS, 1996) where the general linear model (GLM) procedure was used and probability tested at 95% level. In experiments on the effects of planting methods on shoot characteristics genotypic effects were treated as fixed while planting methods were random. However, in shoot characterisation experiments genotypic effects were considered random while the planting method was fixed. For the experiments on the effect of box size on root characteristics box sizes were considered random while the genotypic effects were fixed. Finally in root screening experiments the genotypes were considered random while the box size was fixed. The model for the analysis was

$$Y_{ij} = u_i + ti + \delta_{ij}$$

Where i = all the treatments.

j = all the replicates.

Y_{ij} => the variety mean of~~the i~~th treatment at the j^{th} environment.

u_i => i^{th} variety mean over ~~all~~ environments.

δ_{ij} => deviation from the ~~i^{th} va~~riety at the j^{th} environment.

i_j => the environment index.

ti => the i^{th} treatment effect.

Assumption $\delta_{ij} \approx I\ N\ (0,\ \delta^2)$. That is. δ_{ij} values are approximately independent (I) normally distributed (N) with a mean not equal to zero and a standard deviation (δ^2).

Treatment means where there was a significant difference were separated using the Duncan' multiple range test at the significance level of p=0.05. Correlation analysis with field yield results was done using the SAS software package (SAS, 1996) where the Pearson's correlation was used to find out if there was any relation between the tested parameters and the genotype's general performance in marginal areas.

CHAPTER 4

RESULTS AND DISCUSSION

4.1.0 Effect of Planting Methods on Shoot Characteristics

4.1.1 Effect of Planting Methods on Plant Height

Plant height differed significantly in the three planting methods tested with the single row planting method having the highest average plant heights (6.3 cm, 4.89 cm, 6.09 cm, 5.55 cm) in seasons 1, 2, 3, and across the three seasons respectively. The double row planting method had the second highest average plant heights (5.7 cm, 4.85 cm, 4.79 cm, 5.06 cm) while the planting method where all the genotypes were planted in one row had the lowest plant heights (5.48 cm, 3.02 cm, 5.38 cm, 4.27 cm). In season one and two there was no significant difference between the single row planting method and the double row planting method. The two planting methods however differed significantly with the planting method where all the genotypes were planted in one row (Table 1).

The difference between the planting method with all the genotypes in one row and the other two planting methods might have been due to varied levels of competition for environmental resources like nutrients, light and water. The single row planting method provided an environment where different genotypes were planted next to each other. This might have caused competition between the rows since some genotypes might have been more vigorous than the others. The double row planting method had two rows of the same genotype next to each other. This might have created a situation where plants with the same growth vigour grew together leading to uniform competition for light, water and nutrients. The method

Table 1: Mean separation for the effect of planting methods on seedling characteristics of bread wheat seedlings planted in seed boxes at Njoro in 1998 and 1999

Parameter	Method	Season 1	Season 2	Season 3	Seasons 1, 2&3.
Plant height (cm)	Single	6.30a	4.89a	6.09a	5.55a
	Double	5.74ab	4.85a	4.79b	5.06b
	All	5.49c	3.02b	5.38b	4.27c
	MSE	0.55	0.55	0.33	0.86
	CV	12.6	5.82	12.6	13.9
Leaf area index	Single	1.93ab	1.52b	1.24b	1.56b
	Double	2.04a	2.44a	2.18a	2.22a
	All	1.95a	2.22a	2.12b	2.09ab
	MSE	0.06	0.23	0.05	0.13
	CV	14.11	19.8	10.7	13.9
Growth rate (g/week)	Single	0.008a	1.308a	0.109b	0.475a
	Double	0.106a	0.574b	0.377a	0.352a
	All	0.009a	0.262b	0.100b	0.125b
	MSE	0.226	0.0025	0.0026	0.003
	CV	12.8	19.8	13.4	15.4
Percent wilted Plants	Single	72.0a	58.8a	54.4a	61.2b
	Double	63.8c	50.0b	64.4ab	59.2b
	All	78.8a	60.0a	74.0a	71.0a
	MSE	0.57	0.45	1.18	0.731
	CV	21.4	18.4	16.3	19.2
Percent dead plants	Single	70.6a	58.8a	82.2a	82.0a
	Double	61.8b	47.6b	70.0a	66.4a
	All	70.6a	47.6b	95.6a	82.0a
	MSE	0.25	0.46	17.30	5.98
	CV	14.36	15.4	15.6	14.5
Number of revived plants	Single	8.72a	8.38a	3.06b	6.48b
	Double	9.06a	5.94a	9.72a	8.24a
	All	1.06c	1.29c	2.33b	1.76c
	MSE	2.47	2.91	1.71	1.70
	CV	18.5	22.1	17.8	19.3

Values followed by the same letter in each column are not significantly different at p=0.05. Single, Double and All refer to the single row/ genotype/ box, double row/genotype/box, method with all the genotypes in one row one after the other respectively.

Table 2: Performance of six wheat genotypes planted in different planting patterns (methods)

	Genotype	Single	Double	All
Plant height (cm).				
	Duma	5.73	3.67	4.06
	R830	6.02	4.71	4.46
	R831	4.99	4.74	4.14
	R748	5.73	5.71	4.26
	Kenya Mbweha	5.82	5.78	5.21
	Mbuni	6.09	5.21	5.67
Number of leaves				
	Duma	2.00	2.00	2.00
	R830	2.00	2.00	2.50
	R831	3.00	2.67	2.00
	R748	2.33	1.92	2.00
	Kenya Mbweha	1.42	1.58	2.00
	Mbuni	2.00	1.73	2.00
Leaf area index				
	Duma	1.89	2.06	1.86
	R830	1.11	1.66	1.60
	R831	1.53	3.06	2.78
	R748	1.92	2.41	2.36
	Kenya Mbweha	1.28	1.35	1.33
	Mbuni	1.63	2.77	2.60

with all the genotypes in one row had different genotypes next to each other. This might have led to within and between row competition for light, nutrients and water. Similar results were found by Yunusa (1989), Rwamugira and Massawe (1990) and Lang'at (1992) who showed that mixing different genotypes resulted in a situation where the vigorous genotypes had an advantage in light competition over the less vigorous genotypes.

High plant heights for genotypes like Duma and R831 in the single row planting method (Table 2) might have been as a result of etiolation caused by shade from taller genotypes like Kenya Mbweha and Mbuni. On the other hand the low plant heights for all the genotypes in the method where all the genotypes were planted in one row was probably as a result of extreme competition which might have resulted in depressed growth. This is because Wein (1997) indicate's that when plants compete for light the taller genotypes usually have an advantage over the shorter ones. This is because the potential light gained by each genotype is determined by relative height where taller genotypes intercept more light depending on the distribution and inclination of their foliage. The shorter disadvantaged plants may be etiolated but in case of very high shading retarded growth or death may occur (Chandel *et al.*, 1993). The double row planting method might have provided moderate competition for light leading to moderate growth since the average plant heights for the three seasons were not significantly different from the plant heights achieved in the double row planting method. This was a better situation than when growth was exaggerated either negatively as was the case when all the genotypes were in one row or positively as was the case when the genotypes were planted in single rows.

4.1.2 Effect of Planting Method on Leaf Area index

The double row planting method had the highest leaf area indices in all the seasons (2.04 in season one, 2.44 in season two, 2.18 in season three and 2.22 across the seasons). It was followed by the planting method with all the genotypes in one row (1.95 in season one, 2.22 in season two, 2.12 in season three and 2.09 across the three seasons) and finally the single row planting method (1.93 in season one, 1.52 in season two, 1.24 in season three and 1.56 across the seasons). There was no significant difference between the planting methods in season one but in season two and across the three seasons the double row and the planting methods with all the genotypes in one row differed significantly with the single row planting method. In season three the double row planting method differed significantly with the other two methods (Table 1).

The low leaf area indices in the single row planting method in the three seasons and across all the seasons might have been due to higher number of leaves per plant in genotype R748 and a smaller number of leaves per plant for variety Kenya Mbweha (Table 2). Narrow leaves probably caused by competition for light might also have been the cause for the low leaf area indices in the single row planting method. Higher leaf numbers in the planting method with all the genotypes in one row might have caused extreme competition for light leading to death of some genotypes and as such reduced competition for light in the few seedlings remaining hence higher leaf area indices. This was in agreement with Chandel *et al.* (1993) who indicates that in a mixed plant population competition for light is mainly between the leaves rather than other plant parts. Leaf area indices in double row planting method in all the seasons were between 2.0 and 2.4. This was simmiler to what Olugune (1988) found in wheat seedlings at four weeks after germination under field conditions. This suggested that the double row planting method provided growing conditions similar to field conditions.

4.1.3 Effect of Planting Methods on Relative Growth Rate

The single row planting method provided growth conditions which favoured the highest growth rate in season two (1.31 g/week) and across the three seasons (0.475 g/week). The double row planting method had the second highest growth rate in season two (0.57 g/week) and across the seasons (0.352 g/week) although it had the highest in season one (0.106 g/week) and three (0.377 g/week). The planting method with all the genotypes in one row finally had the lowest growth rate in all the seasons (0.0085 g/week in season one, 0.26 g/week in season two, 0.1 g/week in season three and 0.124 g/week across the seasons). In seasons one and three growth rate in the single line planting method did not differ with that of the planting method that had all the genotypes in one row. However, in season two there was significant difference (Table 1).

The high growth rate in the single row planting method across the three seasons was most likely as a result of the very high growth rate in season two. This planting method did not have growth rates above 0.15 g/week in the other two seasons. This suggested that the growth rate in season two might have been influenced by other factors which did not affect the other planting methods. The high growth rate in the double row planting method in season one and three might have been as a result of the high carbon dioxide fixation from the higher leaf area indices. The planting method with all the genotypes in one row had low growth rates despite the plants having high leaf area indices. This might have been due to very high competition caused by planting all the genotypes on the same row. Very high competition for water and nutrients might in turn have lead to poor growth or stunted plants. On the other hand the lower growth rates recorded in the single row planting method and the planting method with all the genotypes in one row in the other two seasons might have been due to low accumulation of dry matter as a result of competition for light. As was found by Wein (1997), dry matter accumulation might have been reduced in the single row planting method because alternating short genotypes (e.g. R830 and R748) and tall genotypes (e.g. Mbuni and Kenya Mbweha) might have resulted in shading of the lower leaves in the short genotypes thus making them sinks rather than sources.

Plants in the single row planting method had low dry matter accumulation while they had high plant heights indicating that they were etiolated. Without etiolation the high plant heights would have been accompanied with high dry matter accumulation. On the other hand plants in the planting method were all the genotypes were planted in one row had the lowest growth rate indicating that this could have been the reason for the low plant heights.

4.1.4 Effect of Planting Method on Percent Number of Wilted plants

Generally the planting method with all the genotypes in one row had the highest percentage of wilted plants (78.8% wilted in season one, 60% in season two, 74% in season three and 71% across the three seasons). The single row planting method had the second highest percentage of wilted plants (72% wilted in season one, 58.8% in season two, 54.4% in season three and 61.2% across the seasons) while the double row planting method had the least number of wilted plants (62% wilted in season one, 50% wilted in season two, 64% wilted in season three and 59% wilted across the seasons). In seasons one and two there was significant difference between the double row planting and the single row and the planting method with all the genotypes were planted in one row. Season three had no significant difference in the three planting methods although across the three seasons there was significant difference between the single and double row planting method (Table 1).

High percentages of wilted plants in the planting method with all the genotypes in one row might have been as a result of high leaf area indices or the high competition between the different genotypes between and within the rows. Higher plant heights and competition for water between the rows might have lead to the high percentages of wilted plants in the single row planting method. On the other hand the double row planting method provided the least competition for water leading to the lower percentages of wilted plants. In season three there was no significant difference in the planting methods indicating that the number of wilted plants might have been affected by other factors like the amount of water absorbed by the roots and the rate at which the plant losses the water into the atmosphere apart from competition brought about by the different planting methods. Higher water losses due to higher leaf area indices might have caused the no significant difference between the single and double row planting methods across the three seasons. These findings were in agreement with findings of Chandel *et al.* (1993). According to Chandel *et al.*'s (1993) the ability of a genotype to compete for nutrients, water and light varies with variety and planting patterns such that a genotypes ability to compete for these environmental resources is higher in alternate planting than in paired rows.

4.1.5 Effect of Planting method on Percentage of Plants Dead

The planting method with all the genotypes in one row had the highest percentage of dead plants in all the seasons (70.6%, 47.6%, 82%, 82% in seasons 1,2,3 and across the three seasons) while the double row planting method had the least percentage of dead plants. In season one the percentage of dead plants in single row planting method did not differ significantly with the planting method where all the genotypes were grown in one row. In season two the single row planting method differed significantly with the other two planting methods but in the third season and across the three seasons, there was no significant difference in all the three planting methods (Table 1).

High percentages of wilted plants probably lead to the high percentages of dead plants in the planting method with all the genotypes in one row. On the other hand low percentages of wilted plants might have been the reason why there was a low percentage of dead plants in the double row planting method. Apart from the different environmental conditions subjected to the plants by the different planting methods, the difference in the plant populations might have been the reason why there was no significant difference in the three planting methods in season three and across the three seasons. Having all the genotypes in one row limited the number of plants per genotype in a replicate. This lead to a condition where the double row planting method had more plants than the single row planting method and the planting method with all the genotypes in one row. In this case fewer surviving plants in the planting method with all the genotypes in one row represented a higher percentage than more plants in the double row planting method. No significant difference in all the three planting methods across the three seasons suggested that although different levels of competition affected seedling death, other factors like the rate of moisture loss in the medium in the three planting methods might have affected the number of plants dead.

4.1.6 Effect of Planting Method on Number of Revived plants

The double row planting method had the highest average number of plants revived (9.06, 5.94, 9.72, 8.24) in seasons 1, 2, 3 and across the three seasons. The planting method with all the genotypes in one row had the lowest average number of plants revived (1.06, 1.29, 2.33, 1.76) in seasons 1, 2, 3 and across the three seasons. In all seasons the double row planting method differed significantly with the planting method where all the genotypes were planted in one box (Table 1).

The double row planting method had the highest number of revived plants probably because it had the least number of wilted and dead plants. This suggested that either (a) the planting method subjected the genotypes to the least amount of competition for light, water and nutrients compared to the other two methods or (b) the soil in this planting method loss moisture less gradually than the other planting methods. Good leaf development as shown by the leaf area indices indicated that this planting method which might have subjected the genotypes to the least amount of competition. Very little or no competition for light as might have been the case for the other two planting methods might have been the cause of the low plant heights in seasons two and three. On the other hand rapid plant height development in the single row planting method might have lead to a higher water requirement.

Higher water requirement probably lead to more wilted and dead plants after withholding watering for three weeks. The planting method with all the genotypes in one row provided conditions, which probably led to retarded plant growth due to very high competition. This might have led to poor development and ability to survive the dry period.

4.1.7 General performance of wheat seedlings under the three planting methods

From the findings of the effect of planting methods on different seedling characteristics, the double row planting method gave the best growth conditions. Therefore, it was the method that was recommended for screening wheat seedlings for drought tolerance.

4.2.0 Shoot Characterisation

4.2.1 Effect of Variety on Plant Height

In all the seasons variety Mbuni had the tallest (6.32 cm, 6.85 cm, 5.97 cm, 6.38 cm) in seasons 1, 2, 3 and across the three seasons. Kenya Mbweha had the second tallest (6.24 cm, 5.83 cm, 5.33 cm, 5.81 cm) in season 1, 2, 3, and across the three seasons while Duma was the shortest (4.58 cm, 2.49 cm, 3.65 cm, 3.66 cm) in season 1, 2, 3, and across the three seasons. In season one variety Mbuni was significantly taller than variety Duma while in season two and across the three seasons it was significantly taller than the advanced breeding lines R748, R830 and R831. In season three variety Mbuni was significantly taller than all the other genotypes (Table 3).

Drought susceptible genotypes Mbuni and Kenya Mbweha generally were taller than the drought resistant Duma and the advanced breeding lines R748, R830 and R831. Taller plants in varieties Mbuni and Kenya Mbweha than Duma, R748, R830 and R831 over the same period of time indicated that the two varieties were increasing in height faster than the rest. Since high growth rates are a result of higher rates of cell division and expansion which require water, the observed difference in the genotypes must have been due to the physiological and metabolic differences in the genotypes. Differences in the cell wall elasticity might also have been the cause of this difference. This finding agreed with Wein (1997) indication that most phenological characteristics are genetically controlled.

Genotypes environmental interactions might have taken place in seasons. In season one it was generally cooler and more humid which might have encouraged the

Table 3: Mean separations for shoot characteristics of six wheat genotypes at seedling stage grown in three seasons between September 1998 and April 1999 in Njoro

Parameter	Season	Duma	R830	R831	R748	Kenya Mbweha	Mbuni	MSE	CV(%)
Plant height (cm).	1	4.58b	5.91ab	5.31ab	5.85ab	6.24a	6.32a	0.61	13.66
	2	2.49c	4.87b	4.58b	4.41b	5.83ab	6.85a	0.67	16.88
	3	3.65d	5.09b	4.47c	4.96bc	5.33b	5.97a	0.82	5.82
	Mean	3.66d	5.29bc	4.79c	5.077bc	5.81a	6.38a	0.67	14.70
Leaf area index	1	1.44c	2.08a	2.19a	1.84ab	0.98c	1.19cd	0.0035	3.66
	2	1.67de	2.78ab	3.17a	2.12cd	0.95f	1.38e	0.0095	4.84
	3	0.81cd	2.33ab	2.65a	0.45de	0.82f	0.19e	0.0070	4.60
	Mean	1.64cd	2.39ab	2.67a	1.80c	0.92e	1.49d	0.6350	13.82
Growth rate (g/week)	1	0.629a	53.40a	0.626a	0.526a	0.501ab	0.469b	0.0047	2.19
	2	0.138a	0.128a	0.093a	0.126a	0.865a	0.067a	0.0026	15.32
	3	0.398a	0.396a	0.397a	0.397a	0.392a	0.312a	0.0019	14.19
	Mean	0.422a	0.385ab	0.338ab	0.382bc	0.316c	0.283c	0.0036	15.15
% Normal plants (un-wilted)	1	60.0bc	53.40bc	66.60b	100a	53.40bc	50.0c	0.23	15.25
	2	53.40ab	46.60b	53.40ab	66.60a	40.00b	46.6b	0.18	17.00
	3	66.60ab	60.00b	66.60ab	80.00a	53.40b	60.00b	0.18	13.48
	Mean	3.63b	3.77b	3.33b	4.55a	2.44c	2.22c	0.28	16.75
% Live Plants	1	66.60ab	73.40ab	60.00bc	80.00a	46.60cd	40.00d	0.15	12.91
	2	53.40b	53.40b	46.60b	86.60a	20.00c	20.00c	0.24	21.06
	3	86.60bc	100.0a	93.4abc	100.0a	80.0bcd	73.40d	0.23	10.73
	Mean	3.00a	2.66b	3.11b	4.11a	2.44b	2.55b	0.73	28.00
Number of plants revived	1	10.67a	10.69a	10.00a	11.69a	6.33b	5.00b	4.06	22.23
	2	13.00a	1.00b	9.67ab	4.67ab	4.67ab	2.67ab	24.62	28.98
	3	10.00abc	11.67ab	9.00bc	12.00a	8.000c	7.66c	2.25	15.44
	Mean	11.87ab	7.78ab	9.58ab	9.44ab	6.33b	5.11b	1.68	25.00

Values followed by the same letter in each row are not significantly different at p=0.05.

Table 4:Pearson correlation coefficients for seedling shoot characteristics of six wheat genotypes grown in three seasons between September 1998 and April 1999 in Njoro and yields from three experimental sites

Site	Season	Plant Height	Leaf area index	Growth rate	Percentage of normal plants	Percentage of plants alive	Number of plants revived
Elementaita	(1)	0.65	-0.73**	0.82**	0.54	0.86**	0.84**
	(2)	0.90	-0.69**	0.83**	0.64**	0.63**	0.68**
Lanet	(1)	-0.40	0.02	0.14	0.54*	0.27	0.09
	(2)	-0.03	0.03	0.06	0.34	-0.07	0.01
Mogotio	(1)	-0.12	0.19	0.77**	0.74*	0.69*	0.59
	(2)	-0.07	-0.10	0.38	0.44	-0.32	0.13

*, ** significant at p=0.05 and 0.01 levels of probability respectively.

advanced breeding lines R748, R830 and R831 to grow faster leading to no significant difference between them and the susceptible Mbuni. The genotype Kenya Mbweha may also have differed in growth rate at different times of the day and periods of growth depending on the greenhouse environment thus influencing the plant heights in different seasons. This might have been the reason why it did not significantly differ with the advanced breeding lines in season two and three. This observation was in agreement with Krug's (1995) finding that different genotypes have different growth rates at different times of the day and night depending on the environmental conditions.

There was an insignificant negative correlation with grain yield Lanet and Mogotio with the plant heights (-0.4 and -0.12) and (-0.034 and -0.069) in season one and two respectively while yields from Elementaita were highly positively correlated to plant heights (0.65 and 0.9) in season one and two respectively (Table 4). Generally short genotypes R831, R830, R748 and Duma recorded higher yields in Lanet and Mogotio. These short genotypes might have had a higher photosynthetic conversion ratio than the taller genotypes or by having less vegetative matter the plants might have had less water lost through transpiration. Similar results were recorded by Mac-Caig and Ramagosa (1989), Kinyua (1991) and Blum and Sullivan (1997) findings that genotypes, which perform well in marginal areas, are usually short. The positive correlation between plant height and yields from Elementaita suggested that the taller and more susceptible Mbuni and Kenya Mbweha had higher yields than variety Duma. This meant that although variety Duma is known to be resistant to drought, the resistance was not proportional to the grain yield in Elementaita. Blum (1996) indicated that genotype difference affects grain filling and development at high temperatures. This could have been the case in Elementaita implying that although Duma was resistant to drought, conditions during grain filling might have affected the yields. On the other hand Mac-Caig and Ramagosa (1989), Kinyua (1991) and Blum and Sullivan (1997) findings might not have been applicable to all genotypes especially variety Duma because these previous authors worked on mature wheat while this study dealt with seedling plant heights.

Genotypes R830, R831 and R748 were comparable to variety Duma in terms of drought resistance because they all had high yields in the marginal areas. Their resistance may have been due to their (a) ability to resist drying of the taproot thus giving the genotypes ability to absorb the little moisture available for a longer time (Blum and Sullivan, 1997) (b) ability to take advantage of their plant heights thus enabling the genotypes to store more carbohydrates in fewer cells which could easily be maintained in times of scarcity (Mac-Caig and Ramagosa, 1989; Kinyua, 1991).

4.2.2 Effect of Varieties on Leaf Area Index

Line's R831 and R830 had significantly higher leaf area indices than variety Duma, Kenya Mbweha and Mbuni in season one while in season two and three they had significantly higher leaf area indices than variety Duma, Kenya Mbweha, Mbuni and line R748 (Table 3).

Variety Mbuni had short broad leaves, mostly 5-7mm wide, while Duma had long and narrow leaves, mostly 2mm wide. The other varieties R830, R831 and Mbweha had slightly wider but fewer leaves than variety Mbuni. Line R748 had narrow (mostly 2-3mm) but more leaves than all the other varieties. In general the more drought resistant genotypes (Duma, R830, R831 and R748) had higher leaf area indices in this early vegetative period. Difference in leaf area index might have been as a result of the difference in the leaf shapes, numbers and sizes. This observation agreed with El-Hafid *et al.* (1998) findings that drought resistant varieties had higher leaf area index in the early vegetative period and at the end of tillering were more tolerant to drought.

High leaf area indices indicated a higher ground cover and consequently less soil moisture loss through evaporation. Low soil moisture loss may have resulted to a condition where Duma, R830, R831 and R748 seedlings had moisture in the soil for a longer period. On the other hand Kenya Mbweha and Mbuni had the lowest leaf area indices indicating that there was less ground cover and consequently more water loss. This could be the reason why they are drought susceptible. Similar findings were recorded by Lang'at (1992). Although these results agreed with Lang'at's (1992) findings, they seemed to contradict Volkmar's (1997) findings. According to Volkmar, a small leaf area transpires less water and thus effectively conserving the limited supply of water in the soil for use over a longer period. It seemed that this finding was true only when leaf areas per unit length were compared. This is because tolerant genotypes (Duma, R830, R831 and R748) had a lower leaf area per unit leaf length than the susceptible Mbuni. Genotypes (Duma, R830, R831 and R748) also had smaller leaves, which according to Volkmar (1997) transpired less water. This advantage coupled with the better ground cover from the higher number of leaves must further contributed to the drought resistance of genotype Duma, R830, R831 and R748. On the other hand varieties Kenya Mbweha and Mbuni had larger leaves which probably resulted in resulted in more water loss through transpiration while their poor ground cover due to their few number of leaves may have resulted to more water loss through evaporation. This could have contributed to their susceptibility to water stress.

There was an insignificant positive correlation between grain yields from Lanet and Mogotio and leaf area index (0.02 and 0.19 in both places in season one respectively and 0.032 in Lanet in season two). However there was a significant negative correlation between grain yields from Elementaita and leaf area index in both seasons (-0.73 and –0.69) (Table 4). The positive correlation between leaf area index and grain yield in Lanetand Mogotio concurs with the observations by El-Hafid *et al.* (1998) and Acevedo (1993). However, results from Elementaita did not follow this trend. The different field environmental conditions might have influenced the yields in these areas.

4.2.3 Effect of varieties on Growth rate

Varieties Duma, R830 and R831 had significantly higher growth rates than varieties R748, Kenya Mbweha and Mbuni over the seasons. However the first three varieties were not significantly different from each other. In season one variety Duma had the highest growth rate but it did not differ significant with all the other genotypes except variety Mbuni. Lack of no significant differences were seen in seasons two and three although growth rates were different for the different genotypes (Table 3). Similar results among genotypes in relation to growth rate have been observed in other studies by Wein (1997). This may have been because the genotypes differed in growth rates at different times of the day and periods of growth depending on the environments (Krug, 1997). Variety Duma and line R830 had relatively high growth rates, which must have resulted in high plant biomass. On the other hand line R831, R748 and variety Kenya Mbweha had relatively low growth rates resulting in lower plant biomass while variety Mbuni had the lowest growth rate. Results show that although variety Duma and line R830 had high growth rates, they did not have the highest plant heights. This finding suggests that these genotypes did not invest most of their photosynthate's in vertical plant growth. Variety Duma might have directed most of its photosynthate's in stem diameter and leaf length development resulting to slightly bigger stems and the long but narrow leaves. Genotype R830 might have invested in the development of wider leaves and bigger stems. Variety Mbuni on the other hand had low growth rates and high plant heights indicating that most of its photosynthate's were invested in vertical growth.

The correlation coefficients were highly significant at Elementaita in both seasons and at Mogotio in season one (Table 4). The positive correlation agreed with Tanner and Nicholas's (1985) findings. According to Tanner and Nicholas's (1985) there is a significant positive correlation between dry matter accumulation (growth rate) and grain yields. This suggested the resistant genotypes might have been able to store the carbohydrates, which they remobilize during the reproductive stage.

4.2.4 Effect of Withholding Water the Percentage of Non Wilted Plants

When considered over the seasons, line R748 had the highest percentage of non wilted plants (91%) whereas Kenya Mbweha and Mbuni had the lowest percentage of non wilted plants (40% and 53% respectively) (Table 3).

In all seasons, variety Duma, R830, R831 and R748 were among the most drought resistant with less than 25% wilted (75% non wilted) after three weeks of withholding watering. These results suggested that line R748 was the most drought resistant. Line R748 however was not significantly more resistant than line R831 and variety Duma in seasons two and three. Slight differences in the greenhouse relative humidity between the seasons might have been the reason for the differences in the drought resistant genotypes in season one. Drought tolerant genotypes (lines R748, R830, R831 and variety Duma) generally had a higher biomass production, lower plant heights and medium and narrow leaves. This suggested that their low susceptibility to drought might have been enhanced by their smaller leaf sizes. This is because small leaves increase heat transfer by convection resulting to lower leaf temperatures (Bartels and Ingram, 1999). This in turn may have caused a reduction in transpiration. The large leaves of Mbuni must have provided a thicker leaf boundary layer leading to poor convective heat transfer and hence more transpiration which made them more susceptible to water stress.

Rolling of leaves was also observed in genotypes R748, R830, R831 and Duma. This rolling of leaves might have further helped in the reduction of leaf temperatures, transpiration and photosynthesis. This observation was in agreement with Blum and Arkin (1984), Zeigler (1991), Amazallag and Learner (1995) and Greierson (1995) who noted that rolling of leaves in the drought resistant genotypes contribute to a reduction in photosynthesis and thus enabling the plants to conserve water. Pessarakli (1995) indicated that some plants are able to withstand water deficits through osmotic adjustments. Bos and Neuteboom (1998) on the other hand indicated that as the plant water content decreases, the cells contract and the solutes become more concentrated. Contraction of cells might have contributed to the rolling of leaves and as such there could have been a possibility that genotypes R748, R830, R831 and Duma might have survived water stress through osmotic adjustments.

The correlation was positive and highly significant at Elementaita during season 2 and significant at Lanet and Mogotio (Table 4). Mbuni and Kenya Mbweha had the highest number of wilted plants (lowest percentage of non wilted plants) while the most drought resistant R748 had the lowest plant heights. This could have been because plant height development is influenced to a large extent by plant water content responsible for osmotic pressure which is necessary for cell expansion (Pessarakli, 1995; Krug, 1997). Since a high plant height is a result of high number of cell divisions and expansion, the genotypes that had high plant heights needed more water for cell division and expansion than the ones that had lower plant heights. Therefore, when stress was applied they wilted more. This explains the negative correlation between plant height and the percentage of normal plants after three weeks of withholding water as shown in(Table 9).

4.2.5 Effect of Withholding Water on the Percentage of living Plants

The highest percentage of live plants was achieved by line R748 across the three seasons (90%, 86% and 100% respectively). On the other hand variety Mbuni had the lowest percentage living plants (40%, 20% and 36% respectively). The number of live plants for line R748 were significantly higher than for line R831 and varieties Mbuni and Kenya Mbweha in season one, Duma, Mbuni and Kenya Mbweha in season two, and R830 , R831 Mbuni and Kenya Mbweha across the three seasons. In season two number of live plants for line R748 were significantly higher than for all the other genotypes (Table 3).

Morphological characteristics such as plant height and leaf area index might have contributed to the ability remain alive for genotypes Duma, R830, R831, and R748. Plant height and leaf area index might have interacted with the environment resulting in the difference in the ability to survive water stress. It was also observed that the genotypes that had more tillers (Figure 2) had a higher number of plants alive because there were more shoots. This high number of tillers meant more shoots and a higher ground cover resulting to a better water conservation. This may have contributed to the higher percentage of plants alive after withholding water application for three weeks. These findings were in agreed with Taiz and Zeigler (1991) who indicate that genotypes differ in their ability to withstand water stress because they differ in their yield potentials, morphological characteristics and metabolic activities at different growth stages. Similarly Gardner *et al.* (1985) observed that genotypes differed in their ability to withstand drought.

It was also noted that drought resistant genotypes especially Duma changed colour to greenish-blue while the susceptible Mbuni changed to brown-yellow. Taiz and Zeiger (1991) indicated that changes in leaf colour under drought might be due to an increase in carotinoids and xanthopylls and a reduction in the amount of chlorophyll a and b in the chloroplast lamellae which results in a decreased photosynthetic rate and a reduced rate of photodestruction. The ability to reduce their photosynthetic rates and the rate of photodestruction, may have enabled genotypes Duma, R830, R831 and R748 to have a higher percentage of normal plants after withholding watering for three weeks. This is because they could save on the limited amount of water available and at the same time be able to photosynthesise.

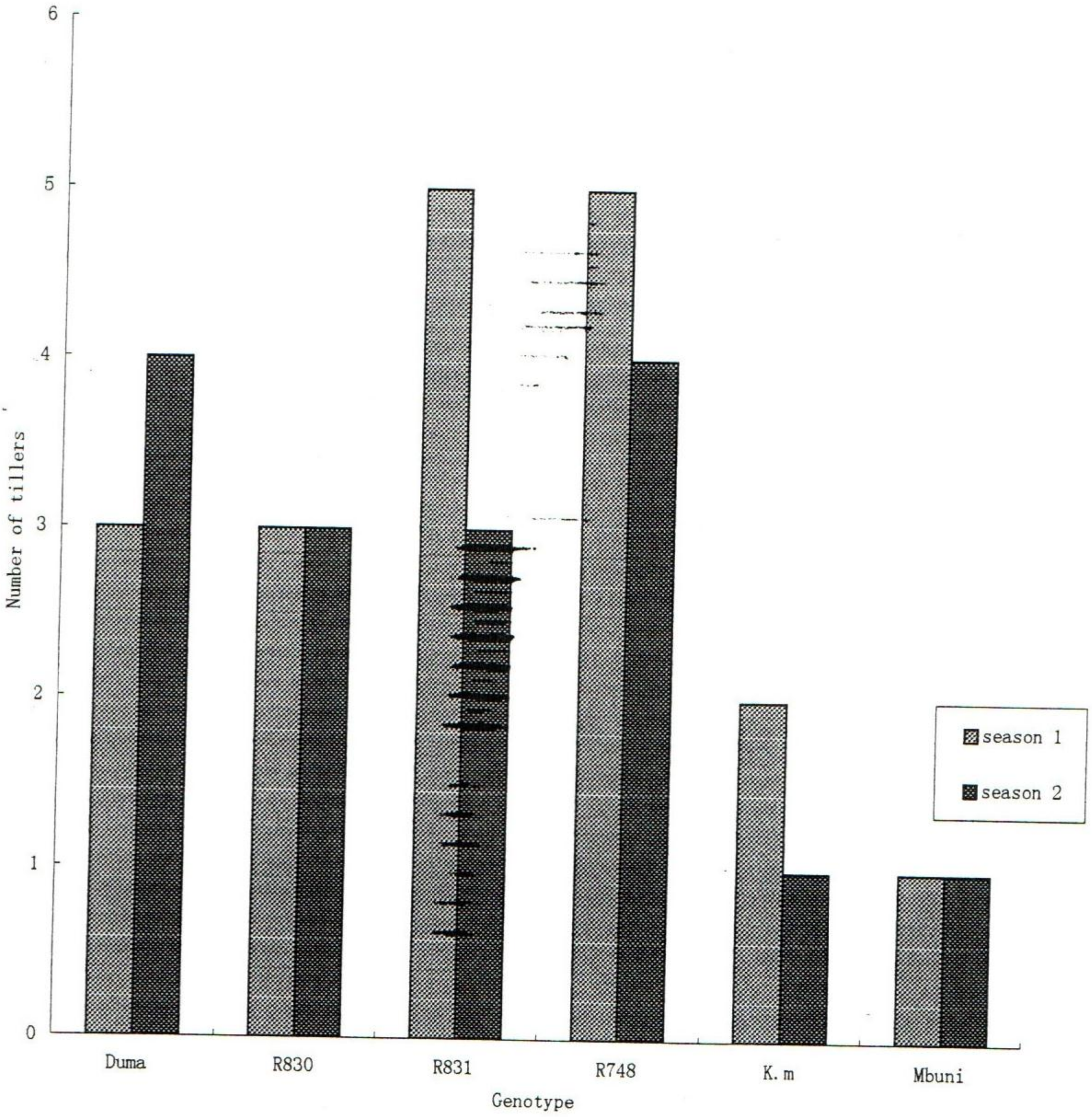

Figure 2: Number of tillers per plant three weeks after emergence .

The susceptible Kenya Mbweha and Mbuni changed to yellow indicating that the chlorophyll had been destroyed. This means that they could not photosynthesis thus resulting in death. This observation was in agreement with Zelich (1971) and Fosket's (1994) findings that chloroplast structure and functions vary under different growth conditions depending on the genotype

4.2.6 Effect of Re-watering on the Number of Revived Plants

Line R748 had the highest average number of revived plants in seasons one and three (11.67, and 12.00 plants) although variety Duma had the highest average number of plants revived over the three seasons. On the other hand variety Kenya Mbweha (6.33, 4.67 and 8) and Mbuni had the lowest average number of plants revived (5, 2.67 and 7.67). In seasons one and three, Kenya Mbweha and Mbuni had significantly fewer plants revived. However there were no significant differences among the other varieties although they had higher numbers of plants revived (Table 3).

Variety Duma and line R830 had among the highest number of revived plants probably because of their ability to tolerate water stress (very low internal osmotic pressures). These two genotypes had the highest pre stress growth rates and plant heights meaning that most of their biomass was concentrated in fewer tissues. They also had average leaf area indices indicating moderate ground cover and soil moisture conservation. As a result of this only 50% of the seedlings wilted after three weeks withholding watering.

High number of revived plants in line R831 might have been due to the genotypes ability to avoid dehydration. This is because it had the highest leaf area index indicating that good ground cover was achieved early resulting to more water conservation in the soil. Its low plant height might have increased its water use efficiency since more water was available for a shorter plant.

Line R748 might have increased its survival chances by maintaining a low internal osmotic potential. This was because leaf rolling was observed which is an indication of reduced cell osmotic potentials. This might have been the case also for genotypes R830, R831 and Duma indicating that some genotypes might have survived water stress through more than one mechanism.

Kenya Mbweha and Mbuni had the lowest number of plants revived as well as low leaf area indices. The low leaf area indices may have led to a higher water loss from the soil leaving less moisture for the seedlings. This could have been worsened by their high plant heights which meant more cells for maintenance in terms of turgidity because the little water available was distributed to more tissues and thus poor water use efficiency.

4.3.0 Effect of Box Size on Root Characteristics

Experiments on the most appropriate box for use in root studies were carried out. Results showed that box size had significant effects on all the root characteristics studied (Table 5)

4.3.1 Effect of Box Size on Total Root Length

In season one the box T5 (2.57 m) had the highest total root length followed by boxes T1 (2.33 m), T2 (2.3 m), T6 (1.88 m), T3 (1.86 m), T8 (1.63 m), T7 (1.6 m), T4 (1.53 m) and finally T9 (1.22 m). In season two the box T3 had the highest total root length (2.19 m) followed by T1 (2.061 m), T5 (2.04 m), T8 (1.71 m), T6 (1.56 m), T9 (1.51 m), T2 (1.4 m), T7 (1.33 m), and T4 (1.2 m). Across the two seasons T5 had the highest total length followed by T1, T3, T2, T6, T8, T7, T4 and finally T9. Total root length was significantly higher for boxes T1 and T5 in seasons one and two. However, there were significant differences between them and boxes T6, T8, T9, T7 and T3, which in turn differed significantly with, box T4. Across the seasons total root length was significantly higher for box T5 than boxes T4, T6, T7, T8 and T9 (Table 5).

It seems that box T5 was comparable to the biggest boxes (T1, T2 and T3) in terms of size. This is because there was no significant difference between them and box T5 across the three seasons. The high total root length in box T5 indicated that this box might have been able to hold enough nutrients and water and probably enough space for the seedlings. This might also have been the case for boxes T1, T3 and T2 since they were among the largest boxes. This observation was in agreement with Deniz *et al.* (1997) and Taylor and Ratlift (1969) observations that

Table 5: Mean separation for the effects of six different box sizes on root characteristics of wheat seedlings (variety Duma) planted in two seasons between September 1998 and April 1999

Parameter	T1	T2	T3	T4	T5	T6	T7	T8	T9	MSE	CV(%)
Total length (cm)											
S 1	2.33ab	2.30abc	1.86bcd	1.53d	2.57a	1.88bcd	1.60d	1.63cd	1.22d	0.13	19.27
S 2	.06ab	1.40bc	2.19a	1.20c	2.04ab	1.56abc	1.33bc	1.71abc	1.51abc	0.14	22.47
Mean	.19ab	1.85abcd	2.02abc	1.36d	2.30a	1.71bcd	1.46d	1.67cd	1.36d	0.15	16.31
Root spread six cm deep. (cm).											
S 1	15.00bcd	15.70abc	17.00ab	13.7bcd	12.30bcd	20.67a	15.30bc	10.33cd	9.67d	8.11	19.76
S 2	14.26b	15.00ab	22.33a	11.3b	11.67b	24.67a	14.20b	9.68b	11.45b	8.58	9.72
Maen	14.63b	15.33b	19.67a	12.5bc	12.00bc	22.17a	14.80b	10.01c	10.56c	8.45	6.50
Widest root spread (cm).											
S 1	22.30bc	24.30b	22.30bc	21.3bcd	24.67b	20.00bcd	17.00d	18.00cd	30.00a	6.33	11.32
S 2	21.50cd	28.00ab	25.67abc	22.7bcd	28.33ab	29.00ab	19.70cd	18.59d	30.00a	11.54	13.70
Mean	21.70bc	26.16ab	24.00abc	22.0bc	26.5ab	24.50abc	18.30d	18.29d	30.00a	9.79	9.30
Root shoot ratio.											
S 1	1.61b	0.31b	0.77b	0.18b	0.09b	1.38b	1.64b	4.07a	3.80a	0.75	56.10
S 2	0.78c	0.22a	0.56a	0.52a	0.18b	0.56a	0.89a	0.89a	0.86a	0.65	7.86
Maen	1.93ab	0.27ab	0.66ab	0.35ab	0.13b	0.97ab	1.27ab	2.48a	2.32a	0.82	6.92
Concentration depth of most roots (cm).											
S 1	46.00a	51.67a	45.00a	30.00bc	36.67b	45.66a	30.00bc	35.00b	27.00c	15.48	10.21
S 2	46.00a	47. 33a	51.33a	36.00ab	45.37a	46.00a	19.667b	41.00a	41.48a	91.22	22.97
Mean	46.00ab	49.50a	48.16a	33.00cd	41.03abc	45.83ab	24.83d	38.05bc	34.23c	59.24	13.00
Root depth (cm).											
S 1	124.70a	120.30a	127.00a	124.00a	124.67a	126.00a	71.667b	63.33b	47.33c	64.69	7.792
S 2	124.33a	106.89a	125.80a	102.00a	103.67a	124.67a	45.63b	69.29b	64.97b	296.76	17.893
Mean	124.50a	113.60a	126.00a	113.00a	114.17a	125.33a	58.65b	66.31b	56.15b	208.37	10.77

Values followed by the same letter in each row are not significantly different when p=0.05. T refers to the box sizes.
S1 and S2 refer to seasons one and two.

the amount of soil available for root growth affects root development. This is because the amount of soil dictates the amount and distribution of nutrients, water and air. Mac-Key (1973) on the other hand indicated genotypes develop good root systems when grown under ideal soil conditions coupled with good climatic and environmental conditions.

Although these results agreed with Deniz *et al.* (1997), Taylor and Ratlift (1969) and Mac–Key (1973) explanations. They however failed to explain why box T5 provided the more ideal conditions for root development than the larger T1, T2 and T3. This observation suggested that apart from the amount of soil, this box had other advantages over the larger boxes. The larger boxes might have provided very good soil conditions leading to slightly more shoot growth which might have led to competition for light leading to reduced root growth although the difference with box T5 was not significant. It was also evident that the boxes with the shortest length (0.7m) had the least total root length. This might have been due to inadequate space which limited nutrient availability for root development in these boxes. Porter and Lower (1991) reached similar conclusions. Generally the boxes with a length of 1.3m and 1m had the longest roots across the two seasons. This suggests that the boxes had enough space for root growth.

4.3.2 Effect of Box Size on Root Spread at 6cm depth

Widest average root spread at six centimetres depth (crown root spread) were achieved in box T6 in all the seasons (20.667 cm, 24.667 cm and 22.17 cm respectively). Box T3 had the second widest root spread at six centimetres depth in all the three seasons (17 cm, 22.33 cm and 19.67 cm respectively). The lowest root spreads at six centimetres depth were in boxes T8 and T9 in all the seasons. Across the three seasons root spread at six centimetres depth in boxes T6, T2 and T3 was significantly wider than in the boxes T8 and T9 (Table 5).

Widest root spread at six centimetres depth for box T6 might have been as a result of the box not being large enough to allow normal growth leading to more root growth or the box just being the right size such that it did not retard root growth. Since root spread at six centimetres depth for box T6 was not significantly wider than the largest box T2 it seemed that the second possibility was true. This implied that this box provided the best growth conditions for the crown roots, which are usually concentrated at the six centimetres depth. Box sizes T3 (17cm and 22.33cm) and T2 (15.667cm and 15cm) were second and third and being among the largest in terms of width and length might have achieved these spreads because of no stress due to space. This finding agreed with Deniz *et al.* (1997) and Taylor and Ratlift (1969) who indicated that the amount of soil available for root growth affects root development.

In both seasons boxes with a length of 0.7m (T9 and T8) performed very poorly. The small soil volume in boxes with a length of 0.7m (T9 and T8) might have resulted in limited nutrients available for root growth. Since roots grow where nutrients are, the limited amounts of nutrients did not encourage maximum genetic expression of the roots in boxes of lengths 0.7m. This finding is supported by that of Deniz *et al.* (1997) who reported that the amount of soil available for plant growth dictates the amount of nutrients, air and water available for root development.

The larger boxes in terms of length might have had better root development because of the availability of more oxygen than the smaller boxes since an equal amounts of water were applied to all the boxes irrespective of their sizes. Generally boxes T1, T2, T4, T5 and T7 all with the widest width (0.05 to 0.07 m) had a lower root spread compared to boxes T3 and T6 which had a width of 0.03 m although box T9 (0.03x0.7x0.3)m was among the lowest across the two seasons. Lower root spread for the wider boxes might have been due availability of more space in all directions resulting in fewer roots coming into contact with the sides of the boxes. Box T9 (0.03x0.7x0.3) m on the other hand had among the lowest roots spreads at six centimetres depth because being the smallest it might have provided the highest level of restriction to the lateral growth of the roots. Similar findings were recorded by Bos and Neuteboom (1998) who showed that when roots come into contact with barriers they either grow back into the media or stimulate more lateral root development in the crown region. Therefore less contact with barriers leads to less root development in the crown region.

4.3.3 Effect of Box Size on Widest Root spread

In both seasons, box size T9, had the widest root spread (nodal root spread) (30.00 cm) followed by boxes T5 (24.67 cm and 28.33 cm), T2 (24.33 and 28 cm), and T3 (22.22 cm and 25.667 cm). Box T8 had the lowest root spread (18.00 cm and 18.59 cm). Across the seasons box T9 had the widest root spread then boxes T5, T2, T6, T3, T4, T1, T7 and T9 (30.0 cm, 26.5 cm, 26.16 cm, 24.5 cm, 24 cm, 22 cm, 21.74 cm, 18.33 cm and 18.29 cm respectively). In season one widest root spread in the largest boxes T1, T2 and T3 were not significantly wider than those achieved by boxes of 1 m except box T7. In season two and across the three seasons the widest root spread in the largest boxes T2 and T3 were significantly wider than those achieved by box T8 (Table 5).

High nodal root development in box T9 might have been because of their small sizes. The small width for box T9 might have stimulated more crown root and nodal root development. Although both box T8 and T7 were the same length with box T9, they had nodal root spreads. This might have been because they were wider. The extra space from the width might have encouraged the growth of the crown roots only but not the nodal roots while the smaller T9 encouraged the growth of the crown roots more than the nodal roots. This result was in agreement with Deniz *et al.* (1997) and Porter and lowler (1991) explanation that the amount of soil available for root growth affects root development.

Across the three seasons nodal root spread for boxes T2 and T3 was not significantly wider in box T9. Since boxes T2 and T3 were among the largest boxes in terms of length and box T9 had the same width with box T3, it seems that the box width was more important than the length with 3 cm being the most ideal width. These results were similar to what Mac-key (1973) obtained for spring wheat. According to Mac-key (1973) nodal root spread is usually between 24 and 26 cm between twenty-one and twenty-eight days after emergence. This suggested that these boxes together with boxes T5 and T6 which were not significantly different from them across the seasons provided an environment that allowed moderate root development.

4.3.4 Effect of box size on Root: Shoot Ratio

In both seasons box size T8, had the highest root: shoot ratios (4.066 and 0.890) followed by box sizes T9 (3.804 and 0.86) and T7 (1.64 and 0.89). Box sizes T5 (0.088 and 0.18), T4 (0.176 and 0.52), T2 (0.312 and 0.22) and T3 (0.765 and 0.56) had the lowest root: shoot ratios in both trials. Across the two seasons box T8 had the highest root shoot: ratio (2.48) followed by boxes T9, T7, T1, T6, T3, T4, T2 and T5 (2.33, 1.26, 1.93, 0.96, 0.66, 0.35, 0.27 and 0.13 respectively). Root: shoot ratios in Boxes T8 and T9 were significantly higher than all the boxes in season one, boxes T1, and T5 in season two and box T5 across the three seasons.(Table 5).

Higher root: shoot ratios in the small boxes T8 and T9 indicated that there was more root than shoot development. This might have been as a result of the higher crown and nodal root growth caused by the roots being restricted by the sides of the boxes. Repeated stimulation of the crown and nodal roots due to the contact with the sides of the boxes might have lead to the plant using more photosynthates in the development of the roots than the leaves. This result agreed with Wein (1997) and Taiz and Zeigler (1991) observations. Wein (1997) indicated that under ideal conditions, a normal growing plant will partition assimilates equally. He explained that in case of any imbalance on the shoot or roots the plant tries to re-establish this equilibrium. Further Taiz and Zeigler (1991) observed that when stress is in the soil, the plant partitions more assimilates to the roots thus resulting to more roots.

Root stress subjected the seedlings by the small boxes T7, T8 and T9 might have lead to the low root lengths, high root spreads and with root: shoot ratios. On the other hand boxes T2, T3, T4, T6, T1 and T5 had the lowest root: shoot ratios indicating that they provided the least stress to the seedlings. Generally boxes with a length of 1 m did not significantly differ with those with a length of 1.3 m. However, in both cases boxes with a width of 0.03 m had higher total root lengths, crown root spread and a nodal root spread that was not significantly wider than those of the to boxes with a width of 0.07 m.

4.3.5. The Effect of Box Size on the Concentration of Most Roots

In both seasons the highest root concentration depth was in boxes T2 (51.66 cm and 47.33 cm) followed by T1 (46 cm and 46 cm), T6 (45.67 cm and 46 cm), T3 (45 cm and 51.33 cm) and T5 (36.667 cm and 45.37 cm) while boxes T9 (27.00 cm and 41.477 cm) and T7 (30 cm and 19.667 cm) had the lowest root concentration depth. Across the seasons box T2 had the highest root concentration depth followed by boxes T3, T1, T6, T5, T8, T9, T4 and T7 (49.5 cm, 48.16 cm, 46 cm, 45.83 cm, 41 cm, 38.05 cm, 34.24 cm, 33 cm and 24.8 cm respectively). In season one there was no significant difference among boxes T1, T2, T3 and T6. This was the same for boxes T4, T5 and T8 and boxes T7, and T9. In season two there was no significant difference among boxes T1, T2, T3, T4, T5, T6 T9 and T8 (Table 5).

High root concentration depths in boxes T1, T2 and T3 all 1.3 m in height in seasons one and two suggested that the plants might have had the roots concentrated deeper due to scarcity of water and nutrients. Scarcity of water and nutrients will have lead to poor root total lengths, crown root development and nodal root development which was not the case. This means that the high root concentration depths was not as a result of any limitation. This might have been the case for box T6 in season one and boxes T4, T5, T6 in season two. Similar results were obtained by Mac-Key (1973) who showed that normal wheat roots in different media concentrate most of their roots up to 55cm forty nine days after emergence.

Generally the boxes with a length of 0.7m (T7, T8 and T9) had lower root concentration depths. These were the boxes that had the least root total lengths, crown, nodal root spreads and poorly developed shoots as shown by the root: shoot ratios. Since the few roots were concentrated more to the surface than was the case for the larger boxes (T1, T2 and T3) and the water applied was equal, it seems that root growth in these boxes might also have been affected by oxygen amounts. This difference in oxygen amounts might have been due to the difference in box sizes. This observation agreed with Squire (1990) who showed that excess water in soil affects availability of oxygen in the soil and thus affecting root development.

4.3.6. Effect of Box size on Root Depth

In both seasons box size T3 had the deepest roots (127cm and 125.8cm) followed by box T6 (126cm and 124.67cm) and T1 (124.667 and 124.33cm) while boxes T9 (47.33cm and 64.97), T8 (63.33 and 69.29cm) and T7 (71.66 and 45.63cm) had the shortest root depths. Across the seasons box T3 had the highest root depth (126cm) followed by boxes T6, T1, T5, T2, T4, T8, T7 and T9 (125.33cm, 124.5cm, 114.16cm, 113.6cm, 113.0cm, 66.3cm 58.6cm and 56cm respectively). In both seasons roots in boxes T1, T2, T3, T4, T5, T6 were significantly deeper than those in boxes T7, T8, and T9 (Table 5).

Deep roots coupled with high total root lengths, crown and nodal root spreads in boxes T1, T3 and T6 indicated that these boxes provided good conditions for root growth. On the other hand the low root depth in the smaller boxes T7, T8 and T9 indicated that the seedling roots in these boxes were obstructed from growth by the limited size of the box leading to low root depths. This was not the case with the boxes of sizes 1m and 1.3m which did not show any significant difference. Probably these boxes provided enough space for root growth and development.

Generally the boxes with the shortest root length might have subjected the plants to some stress. This might have resulted in shallow roots, higher root concentration depth, high root: shoot ratios, low root spread and the low root concentration. In contrast the other boxes might have provided enough soil volume for root development and less stress. Roots in these boxes reached a maximum depth of 1.2m after 7 weeks of growth. Mac-Key (1980) showed that at forty nine days after emergence downward root growth stops or continues at a very slow rate thus it was assumed that this was the highest depth for each genotype. Box T2 (0.07x1.3x0.3) m^3 had a low root depth. This might have been because of the large soil volume allowing the roots to grow in all directions and not necessarily straight down. On the other hand the roots in boxes with 1m length had roots that were coiling upwards due to limited space. It seemed therefore, that obstacles affect root differently at different growth stages. In this case if the roots are obstructed during the early stage of growth the roots stop to grow but at near maximum growth stage they can coil and continue growing. This was also observed by Singh (1998). Boxes of size T1 (0.05x1.3x0.3) m, T3 (0.03x1.3x0.3) m and T2 (0.07x1x0.3) m were ranked among the first three in terms of root total length, root spread six centimetres deep and root depth. They also gave average results for root spread and root shoot ratios. However box size, T6 (0.03x1x0.3) m gave the best results several times although it did not significantly differ with box T3 (0.03x1.3x0.3) m.

4.4.0 Root Screening

Experiments on root characteristics of six bread wheat selections were conducted results showed that genotypes differ significantly in their root characteristics.

4.4.1 Rooting Depth

In both seasons variety Mbuni had the highest average root depth (116cm and 113.03cm) followed by Duma (105cm and 111cm). Line R748 had the lowest average root depth (73.67cm and 82.33cm). Across the two seasons, variety Mbuni had the highest root depth (114.51cm) followed by variety Duma, R831, Kenya Mbweha, R830 and finally line R748 (108.0cm, 105.67cm, 93.67cm, 89.67cm and 77.99cm, respectively). In season one Mbuni's roots were significantly deeper than for all the other genotypes. In season two Mbuni's roots were not significantly deeper than roots of Duma and line R831 but significantly deeper than line R830 and R748 (Table 6).

Deep roots in drought susceptible Mbuni as well as in drought resistant Duma indicated that although some genotypes had significantly deeper roots than others, root depth was not a characteristic of susceptibility or resistance. This observation agreed in part with Mac-Key (1980) findings but differed with Hamlyn (1996) observations. According to Mac-Key (1980) root characteristics are genetically controlled by a number of genes which are inherited quantitatively. However, Hamlyn (1996) observed that many plants successful in dry habitats have no specific adaptations for controlling water loss but rely on the development of very extensive root systems that can obtain water from a large volume of soil deep in the water

Table 6: Mean separation for seedling root characteristics of six bread wheat genotypes grown in two seasons between September 1998 and April 1999 in Njoro

Parameter	Duma	R830	R831	R748	Kenya Mbweha	Mbuni	MSE	CV(%)
Root Depth(cm)								
Season 1	105.00b	75.33d	101.33b	73.67d	91.00c	116.00a	13.78	3.96
Season 2	111.00a	104.67b	107.00a	82.33d	96.33c	113.03a	12.35	3.42
Season 1&2	108.0ab	89.67bc	105.65ab	77.99c	93.67bc	114.52a	55.27	3.56
Total Length (cm)								
Season 1	1206bcd	1351.0ab	1256.3bc	1623.7a	1044.7cd	916.3d	24.00	19.27
Season 2	1068.7cd	2301.0ab	1705.7bc	2522.7a	1297.3cd	774.3d	135.7	22.85
Season 1&2	1137.5ab	1826.0a	1783.7a	2073.2a	1117.1ab	845.3b	2285	20.8
Relative Absorptive Surface Area (mm^3)								
Season 1	4.67bc	5.33ab	4.87b	6.23a	4.13bc	3.50c	0.47	13.807
Season 2	7.97bc	8.47ab	7.77bc	9.57a	4.33c	6.50bc	0.57	9.56
Season 1&2	6.32b	6.90ab	6.32b	7.90a	5.78bc	5.00c	0.42	10.97
Number of Roots								
Season 1	21.00a	21.33a	20.33a	24.00a	17.33b	17.00ab	4.46	19.18
Season 2	14.33c	18.00bc	17.00bc	22.33a	21.67a	10.67c	24.06	27.84
Season 1&2	17.67bc	19.66ab	18.67abc	23.00a	19.50ab	13.83c	27.99	15.53
Root Spread 6cm Deep (cm)								
Season 1	21.33a	23.67a	21.33ab	26.00a	17.33bc	15.00c	6.62	12.26
Season 2	14.67ab	12.00bc	19.33a	19.67a	10.00bc	8.67c	1.00	26.86
Season 1&2	18.00b	17.83b	20.33ab	22.83a	13.66c	11.83c	17.60	16.70
Root Widest Spread (cm)								
Season 1	25.67bc	27.33bc	25.33bc	28.67a	23.33c	20.33d	6.25	5.12
Season 2	27.00ab	28.00ab	26.00ab	29.00a	25.00ab	23.67b	1.41	9.46
Season 1&2	26.33abc	27.67ab	25.67bc	28.83a	24.17cd	22.00d	1.104	5.64
Root Concentration. (cm depth)								
Season 1	65.00bc	54.00c	61.67bc	52.00c	74.33ab	84.00a	58.23	11.71
Season 2	54.67d	70.73c	92.83b	67.50c	88.97b	106.66a	35.19	7.394
Season 1&2	59.83 c	62.36c	77.25b	59.73c	1.65b	95.33a	1.47	6.40
Root Shoot Ratio								
Season 1	0.43a	0.34a	0.54a	0.50a	0.44a	0.46a	0.01	21.31
Season 2	0.28b	0.41a	0.50a	0.46a	0.28b	0.23b	11.03	15.67
Season 1&2	0.36c	0.38bc	0.52a	0.48ab	0.36c	0.343	1.31	13.04

Values followed by the same letter in each column are not significantly different at $p=0.05$.

table. This suggested that variety Duma should have had significantly deeper roots than variety Mbuni. However, this was not the case since Duma's roots were not significantly deeper roots than variety Mbuni and variety Mbuni had the deepest roots in both seasons. Farr (1925) and Russel (1995) showed that genotypes differ in the angle and rate of root growth under different soil conditions. Drought resistant genotypes have been shown to elongate at a higher rate per week than susceptible ones (Gardner, 1985; Hamlyn, 1996). As such variety Mbuni may have had the deepest roots due to the angle of root growth rather than the rate of elongation. Drought resistant Duma had the second deepest roots indicating that its roots might have been growing almost vertically downwards. This might have also been the case for line R831. Roots of lines R748 and R830 might have been growing more to the sides than downward indicating that drought resistant genotypes are not necessarily deep rooted.

The significant difference between variety Duma and lines R748 and R830 in season one suggested that the angle of root growth might have been different for different drought tolerant varieties. This differences in rooting depth between different tolerant varieties might have been responsible for the differences in drought tolerance observed in the shoot characterisation experiments. This finding agreed with Kinyua (1991) finding that lack of significant differences between the rooting depth of variety Duma and Mbuni indicated that root depth as a root characteristic could not be used as reliable guideline to select drought tolerant genotypes.

4.4.2 Total Root Length

Across the seasons line R748 had the highest total root lengths followed by genotypes R830, R831, Duma, Kenya Mbweha and finally Mbuni (2073.2 cm, 1826 cm, 1783 cm, 1137 cm, 1117.1 cm and 845.3 cm respectively). In both seasons line R748 roots were not significantly longer than line R830. However in season one Kenya Mbweha and Mbuni had significantly lower total root lengths. In season two Duma and Mbuni had significantly lower total root lengths although not significantly different from each other (Table 6).

Generally drought resistant genotypes R748, R830, R831 and Duma had higher total root lengths than susceptible genotypes. This finding was partly in agreement with Kujira *et al.*'s (1994) findings who showed that genotypes differ in total root length. These differences reflect morphological variations that impact differences in drought tolerance Gardner *et al.* (1985). Although the total root lengths showed significant difference between different genotypes as was shown by Kujira (1994), they did not achieve total root lengths recorded by Haberle *et al* (1996). This suggested that direct root measurements might be as effective root screening as the intersection method

High total root lengths for genotypes R748, R830, R831 and Duma was probably as a result of good development of either their crown, nodal or seminal roots. This suggested that proper root development might have been important for drought resistance. Similar findings were reported by Blum and Sulliva (1997) and Volkmar (1997). Blum and Sulliva (1997) showed that crown roots play an important role in drought resistance while Volkmar (1997) showed that the nodal and seminal roots also have an effect in Drought resistance.

Low total root lengths for varieties Kenya Mbweha and Mbuni suggested that root elongation in these genotypes was lower than in the resistant genotypes R748, R830, R831 and Duma. Higher elongation rates for R748, R830, R831 and Duma might have enabled these genotypes develop higher surface area for water absorption and hence a higher chance of survival under drought conditions. This observation was in agreement with Gardner (1985) who observed that drought resistant genotypes have higher root growth rate than susceptible ones.

4.4.3. Relative Absorptive Surface Area

In both seasons line R748 had the highest relative absorptive surface area (6.233mm^3 in season one, 9.567mm^3 in season two and 7.90mm^3 in both seasons) while variety Mbuni had the lowest (3.5mm^3 in season one, 6.5mm^3 in season two and 4.25mm^3 in both seasons). In season one line R748's relative absorptive surface area was not significantly larger than for line R830 and R831 as was with Kenya Mbweha and Duma. In season two genotypes R748, R830 and Kenya Mbweha relative absorptive surface areas were significantly larger than all the other genotypes (Table 6).

Generally susceptible genotypes Kenya Mbweha and Mbuni had a lower relative absorptive surface area than the drought tolerant genotypes. This low relative absorptive surface area might have been as a result of a less fibrous root system. Kenya Mbweha and Mbuni were originally bred for high potential areas where water is not a problem this environment might have encouraged a development of a less fibrous root system. Duma and R748 on the other hand were bred for the marginal areas which might have encouraged development of more fibrous root systems hence a large absorptive surface area. Similar results were observed by Hamlyn (1996) who showed that many plants successful rely on the development of very extensive root systems that can obtain water from a large volume of soil. Although this might have been the case, lines R748, R830 and R831 relative absorptive surface areas were significantly larger than Duma. This suggested that although the relative absorptive surface area was generally higher in the more tolerant genotypes, the ability to absorb water was different in some drought tolerant genotypes. This result was in agreement with Wein (1997) observation that roots grow until their demand for photosynthates from the shoot equals supply. Since different genotypes have different rates of photosynthesis the difference between the resistant genotypes (Duma, R830, R831 and R748) may also have been due to difference in their rates of photosynthesis.

Since relative absorptive surface areas for R748 and R830 were not significantly larger than Kenya Mbweha in season two, it meant that the ability to survive drought was probably not only due to the size of the relative absorptive surface area but other factors such as xylem diameter, root fineness and longevity. This observation were similar to Ridge's (1991) who indicated that drought tolerance is a result of many root factors e.g. xylem diameter, root fineness, relative absorptive surface area, actual absorptive surface area, root distribution, density and longevity

4.4.4 Number of Roots

In seasons one and two line R748 (24, 22 and 20 in both seasons) had the most roots followed by line R830 (21, 18 and 19 in both seasons). On the other hand variety Kenya Mbweha (17, 10 and 13 in both seasons) and Mbuni (17, 21 and 19 in both seasons) had the least number of roots. In season one, the number of roots were not significantly different between line R748 and lines R830, R831 and variety Duma but differed for R748 and Mbuni. In season two, there were significant differences between R748 and lines R830, R831 and variety Mbuni (Table 6).

Higher root numbers in the tolerant genotypes suggested that root number might have been a characteristic of drought tolerance. This is because the active absorptive surface area is usually next root tip. Therefore the genotypes that had more roots had more root hence a larger absorptive surface area. This finding was in agreement with Parlychenko (1937) and Hamlyn (1996). Parlychenko (1937) showed that genotypes differ in root number while Hamlyn (1996) observed that although some genotypes have the same total root length, the absorptive surface area differs depending on the number of roots. This meant that Duma's relative absorptive surface area though not significantly larger than that of susceptible Mbuni, variety Duma might have been gaining more from the absorptive surface area because it was distributed in more roots. Lines R830, R831 and R748 had very high relative absorptive surface areas, number of roots and root total length indicating that they had a very fibrous root system. This suggested that they could have been more efficient in water uptake than the drought resistant Duma.

The difference in the number of roots for the same genotypes (e.g. Duma) in different seasons indicated that root number might have been influenced by the soil environment. Similar observations were made by Walhi and Gregory (1995) who showed that most wheat genotypes have their highest number of seminal roots and crown roots immediately after germination after which the number of seminal roots decrease slowly depending on the soil conditions. This implies that differences in the number of roots among the genotypes was probably due to the rate of reduction of the seminal roots counted three weeks after germination.

4.4.5 Root Spread at 6cm depth

In both seasons line R748 had the widest root spread at six centimetres depth (26 cm and 19.67 cm) while variety Mbuni had the lowest (15 cm and 8.66 cm). Across the seasons line R831 had the widest root spread at six centimetres depth followed by R748, Duma, R830, Kenya Mbweha, and finally Mbuni (22.83 cm, 20.33 cm, 18 cm, 17.83 cm, 13.66 cm and 11.83 cm respectively). Line R478's root spread at six centimetres depth was not significantly wider than R830, 831 and Duma in season one but differed with the others. In season two, line R748's root spread at six centimetres depth were significantly wider than for R830, Kenya Mdweha and Mbuni. Across the seasons root spread at six centimetres depth for R748 was significantly wider than for Duma and R830 which in turn were significantly wider than Kenya Mdweha's and Mbuni (Table 6).

Generally the drought resistant genotypes had a wider root spread at six centimetres depth than the drought susceptible genotypes. This implies wide root spread at six centimetres depth might have been a characteristic of drought resistant genotypes. This is because a wider root spreads at this shallow depth meant a larger absorptive surface area is usually next to the soil surface hence more water absorbed during light showers common in the marginal areas. This finding was in agreement with Gardner *et al.*'s (1985) and Oyanagi *et al.* (1995) findings. According to Gardner *et al.* (1985) and Oyanagi *et al.* (1995) a homogeneous barrier free rooting medium root growth produces geometric configurations which either take the shape of a hemisphere, cylinder, cone or an inverted cone depending on the genotype. Therefore genotypes R748 and R830 significantly wider roots spread at six centimetres depth for than those of Duma and R831 was probably a result of each genotypes ability to explore the soil. Drought resistance in genotypes Duma , R748, R830 and R831 might have further been enhanced by their higher total root lengths and lower root depths. Similar findings were reported by Oyanagi (1998) who showed that species with high total root length had a wider spread at the surface (i.e. more crown roots spread than nodal and than seminal roots).

The rate of increase in depth and lateral growth between different spices differed with different plant ages as reported by Kouter (1933). This meant that although the wheat seedlings had attained maximum root depth as was shown by Mac-Key (1973), the drought resistant genotypes may have not reached maximum total root growth stage when the data was collected. It was observed that genotype Duma, R830, R831 and R748 also had the highest number of roots, relative absorptive surface area and root total length. This meant that these genotypes had their fibrous root system concentrated and distributed next to the ground surface more than the susceptible Mbuni and Kenya Mbweha.

4.4.6 Widest Root Spread

In both seasons line R748 had the widest root spread (28.67cm, 29cm) while variety Mbuni had the lowest (20.33cm, 23.66cm). Across the three seasons, genotype R748 had the widest root spread followed by R830, Duma, R831, Kenya Mbweha and Mbuni (28.83cm, 27.67cm, 26.33cm, 25.67cm, 24.17cm and 22cm respectively). In season one genotype R748 differed significantly with all he other genotypes except genotype R830 but in season two it differed significantly with only genotype Mbuni. However across the seasons, line R748 differed significantly with genotypes R831, Kenya Mbweha and Mbuni (Table 6).

Generally the drought resistant genotypes had wider root spreads than susceptible Mbuni. Since the drought resistant genotypes also had the highest root spread at six centimetre's depth, it implied that the drought resistant genotypes generally had a good crown and nodal root spread. Susceptible Mbuni on the other hand had fewer roots, crown root spreads and nodal root spreads. This observation agreed with Gardner *et al.* (1985) and Oyanagi *et al.* (1995). Gardner *et al.* (1985) indicated that in a homogeneous barrier free rooting medium root growth produces geometric configurations, which either take the shape of a hemisphere, cylinder, cone or an inverted cone depending on the genotype. Since the media was the same for all the genotypes, the observed difference was probably due genetic difference.

4.4.7 Root Concentration Depth

In both seasons variety Mbuni had the highest concentration depth (84cm in season one, 106.667cm in season two and 95.33cm in the two seasons) while line R748 had the lowest (52cm in season one, 67cm in season two and 59.83cm in the two seasons). In all the seasons, genotype Mbuni's roots were significantly concentrated deeper than R748's, R830, R831 and Duma (Table 6).

The highest root concentration depths in both seasons susceptible genotypes (Mbuni and Kenya Mbweha suggested that susceptible genotypes their roots distributed over in a larger soil volume. The tolerant genotypes (Duma, R830, R831 and R748) on the other hand had roots next to the soil surface. This observation agreed with the earlier observation that the tolerant genotypes had their absorptive surface area next to the soil surface as most of their roots were concentrated here. Similar observations were made by Olfaiker (1991) who showed that the deep rooted plants respond to drought by extending their roots further into the soil but the cost of growing and maintaining the extra roots is usually not offset by gains in water uptake. This might have been the case for variety Mbuni and Kenya Mbweha because by having most of their roots concentrated deeper into the soil profile in many cases they could not survive conditions with very little precipitation.

It was also observed that genotypes Duma, R830, R831 and R748 were also the genotypes that had the highest total root lengths and spreads. This meant that they had a higher root density per unit soil volume next to the soil surface than the susceptible varieties. Therefore, genotypes Duma, R830, R831 and R748 most likely benefit from little moisture from light precipitation because their fibrous root system next to the soil surface

4.4.8 Root: Shoot Ratio

There were no significant differences in root shoot ratio in the six genotypes tested in season one. This indicates that there was an equal partitioning of assimilates to the roots and shoots in this season. Similar observations were made by Wein (1997) who indicated that a normal growing plant under very ideal conditions partitions its assimilates equally to the shoot and roots such that the root shoot ratio is almost uniform (Table 6).

In both seasons variety line R831 had the highest root: shoot ratio (0.49 in season one, 0.45 in season two and 0.52 in the two seasons) while line and variety Mbuni had the lowest. Ericsson (1995) showed that the allocation of assimilates to the roots in short genotypes in more than in tall genotypes Taiz and Zeigler (1991) further explain that when stress is in the roots, the plant partitions more assimilates to the roots thus resulting to more roots. This suggested the significant difference in season two was probably due to some form of slight aerial stress on the shoots leading to a change in the allocation of assimilates or due to the allocation of assimilates depending on plant height as was found by (Ericsson, 1995). Since the environment in the greenhouse was almost similar in both seasons, there was a higher possibility of the shoots not suffering some form of aerial stress in season two and not in season one. It therefore appeared that Ericsson's (1995) findings were more supported than Wein's (1997). This was because across the two seasons there was significant difference in the root shoot ratios. The root: shoot ratios indicated that lines R830, R831 and R748 had more roots than shoots. They also had the lowest plant heights. Genotype Duma on the other hand had a root: shoot ratio that did not differ significantly with that of susceptible Kenya Mbweha and Mbuni. This meant that the distribution of the photosynthates to the shoots and roots was probably the same for the three genotypes. This supports the observation that Duma might be having a high water use efficiency. This is because of its smaller size and greater ability to absorb water by having most of its roots concentrated next to the soil surface.

4.5.0 Pearson's correlation analy~~sis~~ for shoot characteristics, root characteristics and grain yield

There was a significant positive correlation between root depth and percentage of plants dead after three weeks of no water application (0.84) (Table 7). This positive correlation suggested that the taller plants might have had a lower water absorption and mineral uptake or higher transpiration rates. This was probably due to high plant heights and low leaf area indices leading to high wilting percentages, death rates and revival numbers.

There was a significant negative correlation between root depth and leaf area index (–0.73), growth rate (-0.96) and number of plants revived after resuming water application (-0.83) (Table 7). This negative correlation suggested that deep rooted genotypes had a lower rate of carbon dioxide fixation probably due to the lower leaf area indices. These plants might have been partitioning assimilates more to the roots than the shoots.

When root depth was correlated with grain yield there was a significant negative correlation with yields from Lanet and. This negative correlation indicated that deep rooted seedlings might have been poorly adapted to the marginal areas than shallow rooted seedlings. This might have been because shallow root systems can easily absorb more water from light precipitation.

The significant positive correlation between root total length and leaf area index (0.74), growth rates (0.84) and number of plants revived after desiccation (0.91) indicted that high root total lengths were associated with high leaf area indices and growth rates (Table 7). This might have been because of high water use efficiency or high cordon dioxide fixation efficiency in these seedlings. High

Table 7: Pearson's correlation coefficients for seedling shoot and root characteristics of six bread wheat genotypes grown in two seasons between September 1998 and April 1999

	Plant Height	leaf area index	Growth rate	% wilted plants	% dead plants	Number of Revived plants after desiccation
Root depth	0.45	-0.73*	-0.96*	0.02	0.84*	-0.83*
Total length	-0.28	0.74*	0.84*	-0.35	-0.71*	0.91*
R.A.S.area	-0.16	-0.76*	0.78*	-0.01	0.90*	0.93*
Root number	-0.23	0.01	0.05	-0.66*	-0.09	0.14
Root spread	-0.16	0.71*	0.83*	-0.39	-0.70*	0.89*
Widest root Spread	-0.04	0.50	0.70	-0.18	-0.18	0.49
Root Concentration	0.18	-0.24	-0.19	0.75*	0.22	-0.16
Root shoot Ratio	0.16	-0.50	0.29	-0.02	0.76*	0.61*

* significant difference at $p=0.05$ level of probability. R.A.S – relative absorptive surface area.

Table 8: Pearson correlation's table for seedling root characteristics of six bread wheat genotypes grown in two seasons between September 1998 and April 1999 in Njoro against yields from three sites

	Elementaita	Mogotio	Lanet
Root depth	-0.86*	-0.87*	-0.16
Total length	-0.73*	0.75*	0.19
R.A.S.A	0.87*	0.79*	0.07
Root number	-0.19	0.32	0.19
Root spread	-0.76*	0.79*	0.21
Widest root Spread	0.13	0.80*	0.60*
Root Concentration	0.40	-0.94*	0.65*
Root shoot Ratio	0.29	-0.27	0.71*

*denotes a significant difference at p=0.05 while.
R.A.S.A- relative absorptive surface area.

amounts of carbohydrates thus produced may have given them a higher chance to survive no water application leading to more plants revived. These results agreed with Bartels and Ingram's (1999) observations that a good root system increases plant ability to survive. However, the significant negative correlation between root total length and the percentage of dead plants after three weeks of no water application (-0.71) was probably due to the root distribution or pattern. Blum and Sullivan (1997) and Volkmar (1997) found similar results. Blum and Sullivan (1997) and Volkmar (1997) showed that high root total lengths enabled plants to absorb more water and thus increase their ability to revive after desiccation.

The significant positive correlation with grain yield from Mogotio as well as the significant negative correlation with grain yield from Elementaita suggested that seedlings with a high root total length had advantage over the others only in some areas (Table 8). This was probably due to differences in the soil conditions of these places.

Results showed that was a significant positive correlation between relative absorptive surface area and growth rate, the percentage of plants dead after three weeks, number of plants revived after desiccation and grain yield from Elementaita and Mogotio (Table 7 and 8). This observation suggested that low growth rate, high leaf area indices, low plant heights, low death rates after three weeks of no water application and high numbers of plants revived were characteristics of stress tolerant genotypes. It also suggested that although relative absorptive surface area might not differ between the susceptible and tolerant genotypes, as was the case in season two, it plays a major role in conferring drought resistance.

When root number was correlated with shoot characteristics, there was a positive non significant correlation between root number and leaf area index, number of plants revived after desiccation and grain yield from Mogotio and Lanet (Table 7 and 8). This observation indicated that the higher the number of roots the higher the yields. This was found to be true because it was observed that although variety Duma's relative absorptive surface area was not significantly different from that of Mbuni, it might have had a higher active absorptive surface area. This could have been the case for the genotypes R830, R831 and R748 because they all had a higher relative absorptive surface area than Duma and more roots than Mbuni.

Correlation between root spread at six centimetre depth and shoot characteristics had a significant positive correlation with leaf area index, growth rate, number of plants revived after desiccation and grain yields from Mogotio (Table 7 and 8). This suggested that a high crown root spread lead to good leaf formation that probably fixed more carbon dioxide leading to more plants revived. This might also have been the reason to the high yields in Mogotio. This observation supported the idea that shallow root systems were more efficient in moisture uptake in the dry environments (Boubaker and Yamada, 1995). The significant negative correlation between root spread at six centimetres depth and grain yield from Elementaita indicated that good crown root development might not be the only contributing factor to drought tolerance in all environments.

Correlation between widest root spread (nodal root spread) and shoot characteristics indicated that there were non significant positive correlation's with leaf area indices, growth rate, and number of plants revived after desiccation. While there was non significant negative correlation between widest root spread (nodal root spread) and plant height, the percentage of plants wilted and dead (Table

7). This result indicated that a good nodal root spread might have had the same effects as a good crown root spread with the crown root spread having a higher effect on shoot characteristics. However, when correlated with grain yield there was a significant positive correlation with yields from Mogotio and Lanet (Table 8). This result suggested that a good nodal root spread could be enhancing the effects of a good crown root spread in drought tolerance. This result agreed with Volkmar's (1997) finding that nodal and seminal roots also contribute to drought tolerance.

Root concentration depth had a significant positive correlation with the percentage of wilted plants. This suggested that plants with roots distributed in a large volume of soil generally had poor water uptake leading to significantly higher percentages of wilted plants. This might have been because of poorer water use efficiency in these plants. The significant positive and negative correlation between root concentration depth and grain yields from Lanet and Mogotio on the other hand suggested that another root or shoot characteristic might be enhancing the effects of shallow root systems in drought tolerance.

Plant height had no significant correlation with other shoot characteristics (Table 9). However, with leaf area index and percent wilted plants there was as positive correlation with plant height. This indicated that although plant height was influenced by other factors in the environment, generally a high leaf area index resulted in taller plants. On the other hand this high leaf area index might have resulted in more water loss through evapotranspiration leading to more wilted plants. This finding agreed with Kinyua's (1991) finding that short genotypes are more drought tolerant than taller ones.

Leaf area index had a significant negative correlation with growth rate. This

Table 9: Pearson correlation coefficients for seedling shoot characteristics of six bread wheat genotypes grown in two seasons between September 1998 and April 1999 in Njoro

	Plant Height	leaf area index	Growth rate	% wilted	% Dead
Leaf area index	0.054				
Growth rate	-0.11	-0.70*			
% wiltsd	0.05	0.18	-0.008		
% dead	-0.51	0.68*	0.72*	0.17	
Revival after desiccation	-0.16	-0.76*	0.82*	-0.16	-0.74*

*denotes a significant difference at p=0.05 while.

suggested that plants with a low leaf area index might have had a higher conversion efficiency than the plants with a higher leaf area index leading to higher growth rates. This high conversion efficiency might have might have been as a result of either more stomates per leaf or a higher enzyme activity at the stomates leading to a higher cordon dioxide fixation. The negative correlation between relative absorptive surface area (Table 9) and leaf area index indicated that the possibility of more stomates per leaf was high since high transpiration losses are due to numerous stomates. High transpiration losses might have lead to more water absorption was needed to maintain turgidity. Since seedlings with low relative absorptive surface area had the highest leaf area index it might have been possible that the water absorbed was probably not enough to satisfy the transpiration demands. This might have been the reason for the significant positive correlation between leaf area index and percentage dead plants. High relative absorptive areas might have been enabled the plants to compensate the transpiration losses leading to more plants revived and thus a significant negative correlation. Since seedlings with low leaf area index probably had high conversion efficiencies, the significant positive correlation between growth rate and number of plants revived indicated that high biomass accumulation favoured plant recovery. This might have been due to the high relative absorptive surface area and low leaf area index associated with high growth rates.

Number of plants revived had a significant negative correlation with the percentage of dead plants indicating that genotypes that had high numbers of dead plants had fewer plants revived. This showed that seedlings recovered were only those that were able to withstand withholding of watering.

4.6.0. Genotype Root Patterns

The genotypes Duma, R748, R830, and R831 in both trials had the highest total root length, root spread at six centimetres depth, widest spread and root: shoot ratios (Table 7). These genotypes also yielded highly in the marginal areas.

Variety Duma had high root depth (105 cm and 111 cm) in both trials. It also had a relatively average root total length (1206 cm and 1068.7 cm), a low relative absorptive surface area and a root number that did not differ significantly with that of Mbuni. In season one it's roots spread to a maximum of 18.00 cm in the crown region with the seminal roots achieving a maximum spread of 26.33 cm in trial two. Generally the roots were concentrated up to 59.83 cm deep although the longest root was 111.67 cm. Duma yielded 2244.0kg/ha in Lanet, 1760.42 kg/ha in Mogotio, 361.11 kg/ha in Elementaita. Duma was the most drought resistant although it was not resistant in all the environments. This might have been due to difference in soil types probably influenced the development of roots, the difference in rainfall distribution in the different environments or due to genotype / environment interaction (Appendix 4). It seems Duma's rooting pattern was efficient only in some locations and as such it cannot be used a general description for drought resistant genotypes.

Line R830 had a shallow root depth (75.33 cm and 104.67 cm) in both trials. It also had a relatively high total root length (1351.0 cm and 2301.0 cm), a high relative absorptive surface area and a root number that did not significantly differ with that of genotypes R831 and R748. In season one the roots spread to a maximum of 17.85 cm in the crown region with the seminal roots achieving a maximum spread of 27.67 cm. Generally the roots were concentrated up to 62.36

cm deep although the longest root was 115.00 cm (season two). Line R830 yielded 275.0kg/ha in Mogotio, 1944.44kg/ha in Lanet and 1263.89kg/ha in Elementaita.

Line R831 had high root depths (101.33cm and 110.667cm) in both trials. It also had a relatively high root total length (1256cm and 1705.7cm) and a low relative absorptive surface area. In trial one the roots spread to a maximum of 20.33cm in the crown region with the seminal roots achieving a maximum spread of 25.67cm in trial two. The roots were concentrated up to 77.25cm deep although the longest root was 118.75cm. Line R831 yielded 2034.72kg/ha in Mogotio, 1864.58kg/ha in Lanet and 493.06kg/ha in Elementaita. This genotype might have been drought resistant although it is not resistant in all the environments. This might have been due to a difference in soil types that influenced the development of the roots or the difference in rainfall distribution in the different environments. Line R831's rooting pattern was probably efficient only in some locations and could not be used as general description for drought resistant genotypes.

Line R748 had the lowest root depth (73.667cm and 82.33cm) of all the selections in both trials. It also had a relatively very high root total length (1623.7cm and 2522.7cm), a very high relative absorptive surface area and the same number of roots with the other resistant genotypes. In season one the roots spread to a maximum of 22.83cm in the crown region with the seminal roots achieving a maximum spread of 28.85cm in trial two. Generally the roots were concentrated up to 59.73cm deep although the longest root was 137.58cm. This line yielded 2444.44 in Mogotio, 2392.36kg/ha in Lanet, 315.97kg/ha in Elementaita. This genotype was drought resistant although it did not produce more than 2 tones per hectare in Elementaita as it did in the other environments. This might have been as a result of difference in soil types which might have influenced the development of the roots. The difference in the rainfall distribution in the different environments (Appendix 4) or due to genotype / environment interaction might have affected the yields.

Variety Kenya Mbweha had a fairly low root depth (91.00 cm and 96.33 cm) in both trials. It also had a relatively low total root length (1044.7 cm and 1297.3 cm), a low relative absorptive surface area and the same number of roots with most of the other genotypes. In season one its roots spread to a maximum of 13.66 cm in the crown region with the seminal roots achieving a maximum spread of 24.17 cm. Generally the roots were concentrated up to 81.65 cm deep although the longest root was 128.00 cm (season two). The variety gave low yields in all the seasons.

Variety Mbuni had the highest root depth (116.00 cm and 113.03 cm) in both trials. It also had the lowest total root length (916.3 cm and 774.3 cm) and a low relative absorptive surface area. In trial one its roots spread to a maximum of 11.83 cm in the crown region with the seminal roots achieving a maximum spread of 22.00 cm in trial two. Generally the roots were concentrated up to 95.33 cm deep although the longest root was 139.67 cm. The variety gave low yields in all the trials. This variety was susceptible to drought, a condition that might have been caused by its rooting pattern, which contrasts that of the resistant Duma, R830, R831 and R748.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Shoot and root characterisation

From the findings, there was a strong indication that screening for drought resistance is possible through shoot and root screening at seedling stage.

Among the shoot characteristics that could be used in shoot screening were wilting percentages after three weeks of no water application, the percentage of dead plants after three weeks of no water application and the number of revived plants after desiccation. These parameters ranked the genotypes in a similar way as genotype ranking based on grain yield from marginal areas. This was because the characteristics are quantifiable and a result of many physiological, metabolic and biochemical processes in the plant. Since drought resistance is also a result of many physiological, metabolic and biochemical processes in the plant these parameters were able to reflect the advantages of their combined effects in performance of these genotypes. This finding concurred with the observations of Winter *et al.* (1988) that survival tests are among the most suitable techniques for screening drought resistance in wheat.

Wilting percentages after three weeks of no water application, the percentage of dead plants after three weeks of no water application and the number of revived plants after desiccation therefore emerged as strong candidates for routine procedures in shoot characterisation trials for drought resistance.

Other shoot parameters such as plant height, leaf area index and growth rate could not be recommended for routine procedures in selection tests. This was because plant height as a shoot character is highly affected by the environment. On the other hand leaf area index could not separate susceptible genotypes from resistant ones. This is because different genotypes have different leaf area indices, which together with other mechanisms contribute to the drought resistance. Just as Kozlowski (1983) had shown, growth rate is an unreliable measurement because it gives very varied results depending on the environmental conditions and time. This was why growth rate results in some seasons did not show any significant difference. Therefore growth rate as a shoot parameter is unsuitable for drought resistance screening procedures.

All the root characteristics tested were significantly influenced by the genotypes. The ranking of genotype on the basis of these characteristics closely resembled the ranking by yielding ability under marginal climatic conditions. This might have been because of the fact that root characteristics are quantitatively inherited.

Root characteristics, especially root spread at six centimetre depth, widest root spread and root concentration depth gave more reliable information on the difference in the genotypes in relation to drought resistance. This made suitable parameters for routine procedures in selection for high yielding genotypes in the marginal areas of Kenya.

Generally root depth, total root length, number of roots, root spread at six centimetres depth, widest root spread, root concentration and length of the longest root provided the best information for use when describing the rooting pattern of bread wheat seedlings. By knowing the type of rooting pattern, selection could be done using the guideline described in section 5.2 and 5.3.

5.2 Shoot characteristics of drought resistant / susceptible wheat

Results indicated that drought resistant wheat seedlings for example R748, R830, R831 and Duma generally had high leaf area indices, narrow but numerous leaves as well as high growth rates. They also had low plant heights, low wilting percentages and dead plants after three weeks of withholding water. More plants were revived after three weeks of re-watering.

Drought susceptible genotypes like Mbuni and Kenya Mbweha generally had low leaf area indices, low growth rates, high numbers of wilted and dead plants after three weeks of no water application as well as very few revived plants after re-watering for three weeks.

5.3 Rooting patterns of drought resistant and susceptible wheat

Drought resistant genotypes generally had a slightly higher number of roots with crown roots spreading between twenty one to twenty six centimetres. The nodal and seminal roots spread to a maximum of between twenty five to twenty eight centimetres with most of them concentrated up to seventy centimetres deep. They also exhibited slightly higher root shoot ratios i.e. (Root: shoot ratio greater than 1:2).

Drought susceptible genotypes had the deepest roots and the longest roots. The roots were fewer in number compared to those of the resistant genotypes (mostly less than 20). Their nodal and crown roots spread to a maximum of 23 cm with most of them concentrated between the surface of the soil and 84 cm deep. These roots reached a maximum depth of less than 1m three weeks after germination and they generally had low relative absorptive surface areas

5.4 Simple technique for testing drought resistance in wheat seedlings

Method and box studies indicated that the planting methods affected the leaf area index, growth rate, wilting percentages, the percentage of dead plants after three weeks on no watering and the percentage of plants revived. In both seasons, the double line planting method gave the most reliable results because they were less varied. It provided the least stress due to competition for light, water nutrients and space. The double line method therefore emerged as the most reliable method of planting the genotypes. On the other hand box studies showed that box size (0.03x1x0.3) m subjected the least edaphic stress on the wheat seedlings.

The method used in this research for shoot screening was found to be suitable. The box size, soil ratio, the double row planting method, water amount, and data described in the materials and method was recommended for use in shoot characterisation procedures. For the root screening research, boxes of sizes 0.03mx1mx0.3m should be used. The procedure of nailing the plywood sheets, filling the boxes, planting, watering and data collection described in the materials and method should be used.

5.5 Recommendations

On the basis of this study, the following recommendations are made:

(a) Use of number of wilted plants after three weeks of no water application, number of dead plants at the same time and number of revived plants after watering is resumed should be adapted in shoot screening tests for drought resistance.

However, more research needs to be done on other shoot morphological and physiological characteristics to find other suitable parameters for shoot characterisation.

(b) In root screening tests total root length, root spread and widest spread is recommended for use because they highly correlate with yield. However, it is recommended that more research should be done involving more genotypes and the other root parameters not used in this research to try and establish clearly the critical points separating drought resistant and susceptible wheat.

(c) Correlation analysis for shoot and root characteristics should be done for the individual genotypes since this was not done in this research. This will help in the understanding of the relationship between these two plant characteristics.

(d) Path effect analysis should be done to establish the exact contribution of each of the shoot and root characteristics on genotype tolerance or susceptibility.

(e) Greenhouse conditions should be as close as possible to the following conditions: temperatures should range between 24-26^{0}C, relative humidity between 75-85% and the glass shaded to leave approximately 70% light. This will reduce the difference in the results over seasons and increase accuracy.

(f) This study did not consider the economic aspect, which is very important. As such it is recommended that economic analysis be done to establish if this method has any advantage over the preliminary field trials in screening programs for drought resistance.

(g) These results strongly indicate that field yield trials cannot be replaced with screening under greenhouse conditions. As such it is recommended that screening shoots and roots for drought resistant genotypes should only be used as a guide to eliminate the very susceptible genotypes after which field yield trials should be done.

(h) Since it is clear that drought resistance is genetically controlled, more research needs to be done to identify, characterise and isolate the genes for seedling drought resistance to enable more precise screening.

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APPENDIX

RESEARCH LAYOUT

Appendix 1 Layout of the Shoot screening trials (All in one box)

Replicate 1	Replicate 2	Replicate 3
6	1	5
1	3	1
4	6	6
3	2	4
5	4	3
2	5	2

Appendix 2: Layout of the Shoot screening trials (each variety per rows).

Replicate 1

6	4	5	3	1	2

Replicate 2

3	4	2	5	6	1

Replicate 3

4	6	5	1	3	2

Appendix 3: Layout of the shoot screening trials (varieties in double rows).

R1	R2	R3
4	3	5
2	6	6
3	1	3
1	5	4
6	2	1
5	4	2

KEY

R746------------1	Duma-------------------4
R830------------2	Kenya Mbweha-----5
R831------------3	Mbuni-----------------6

Appendix 4: Average rainfall and temperature in Mogotio, Lanet and Elementaita in 1998.

	Mogotio		Lanet		Elementaita	
Month	Temp (^{0}C)	Rain (mm)	Temp (^{0}C)	Rain (mm)	Temp(^{0}C)	Rain (mm)
January	24.2	41	18.5	16	17.5	16
February	25.3	23	19.5	24	17.5	9
March	25.7	62	19.5	60	17.8	33
April	25.3	70	19.1	127	17.3	70
May	24.8	83	18.5	107	16.9	63
June	24.1	52	17.8	80	16.3	43
July	23.7	86	17.2	109	15.9	40
August	23.5	37	17.2	67	16.1	66
September	24.4	36	17.7	54	16.3	29
October	24.5	40	18.2	30	16.7	21
November	24.8	47	17.7	60	16.8	42
December	24.2	40	18.9	30	16.6	39

APPENDIX 5: Seedling boxes for shoot and root studies.

Appendix 6: Mean sums of squares for analysis of variance for the effect of different box sizes on root characteristics of wheat seedlings (variety Duma) grown in two seasons between September 1998 and April 1999

Season.	Source.	df.	Total Length.	Spread 6cm deep.	Widest root spread.	Root shoot ratio.	Concentration of most roots.	Root Depth.
1	Rep	3	0.01	5.48	12.00	3.17	4.11	6.44
	Size	8	0.58*	34.70*	45.66*	6.64*	230.80*	64.69*
	Error	15	0.13	8.11	6.33	0.74	15.48	64.69
2	Rep	3	0.03	1.02	14.95	339.09	10.82	339.00
	Size	8	0.37*	73.23*	56.61*	2584.00*	259.90*	296.70*
	Error	15	0.14	8.58	11.53	296.70	91.29	296.70
1&2	Rep	3	0.03	1.02	14.95	339.09	10.820	339.00
	size	8	0.38*	73.23*	56.61*	2584.00*	259.90*	2584.00*
	Error	15	0.15	8.45	9.79	277.82	59.24	208.40

df refers to the degrees of freedom. *denotes a significant difference at $p=0.05$. Size refers to box size.

Appendix 7: Mean sums of squares for analysis of variance for root characteristics of six different bread wheat genotypes grown in two seasons between September 1998 and April 1999

Season	source	df	Root depth	Total length	Relative absorptive surface area	Root number	Root spread 6cm	Widest root spread	Root/shoot ratio	Root concentration
1	Variety	5	85.70*	162.00*	2.69*	13.96*	50.05*	26.35*	449.00*	0.13*
	Error	10	13.70	24.00	0.44	4.46	6.62	6.25	58.23	0.01
2	Variety	5	44.60*	310.00*	3.18	3.42*	4.38*	11.55*	35.20*	0.15*
	Error	10	12.35	135.00	5.78	1.00	1.41	1.65	11.03	0.04
1&2	Variety	5	175.90*	803743.0*	5.29*	53.77*	3.32*	4.52*	4.89*	0.51
	Error	10	55.27	228593.4	0.42	17.60	1.10	1.47	1.31	0.05

*Denotes a significant difference at alpha level 0.05.

Appendix 8: Mean sums of squares for analysis of variance for different seedling characteristics compared when six wheat genotypes were planted in one row, each genotype in a row, and each genotype in double rows

of Season	Source	df	Plant Height	leaf area Index	Growth rate	% normal plants	% live plants	Number revived plants
1	Rep	2	1.31	8.62	1.67	1.32	0.13	0.02
	Method	2	2.56*	1.86	21.40*	6.03*	2.79*	146.00*
	Error	34	0.54	0.64	0.23	0.57	0.73	2.47
2	Rep	2	0.64	6.70	6.29	0.16	0.22	2.84
	Method	2	16.70*	10.40*	1.12	2.03	0.55	12.30*
	Error	34	0.55	0.23	0.002	0.45	0.24	2.97
3	Rep	2	1.33	1.72	2.67	6.26*	0.19	1.79
	Method	2	8.49*	1.64	134.8*	5.49*	89.3*	177.00*
	Error	34	0.33	0.05	0.003	1.18	0.46	1.71
1,2&3	Rep	2	0.88	0.29	0.51	0.57	0.07	0.19
	Method	2	0.32*	2.70*	0.24*	5.28*	2.46	1.98*
	Error	34	0.86	0.13	0.003	1.09	17.3	1.70

*Indicate significant difference at p=0.05, df. Refers to degrees of freedom

Appendix 9: Mean sums of squares for analysis of variance for seedling characteristics of six wheat genotypes grown in three seasons between September 1998 and April 1999 in Njoro

season	Source	df	Plant height	leaf area index	Growth Rate	% normal plants	% live plants	Number of plants revived
1	Variety	5	1.290*	27.20*	0.020*	2.770*	1.790*	22.10*
	Error	12	0.610	0.004	0.005	0.230	0.160	4.06
2	variety	5	2.932*	21.93*	0.002*	0.622*	1.256*	61.256*
	error	12	0.670	0.009	0.003	0.189	1.256	34.622
3	variety	5	2.722*	21.93*	0.002*	0.622*	1.167*	10.06*
	error	12	0.820	0.007	0.002	0.189	0.233	2.256
1,2&3	variety	5	2.400*	3.460*	5.600*	7.340*	2.860*	5.660*
	error	12	0.670	0.635	0.004	0.290	0.730	1.680
	total	17						

*Denotes a significant difference at p=0.05. df. Refers to degrees of freedom. Data on variety and error mean sums of squares is presented